PIPE WELDING Procedures

SECOND EDITION

Hoobasar Rampaul

Industrial Press

PIPE WELDING PROCEDURES

Second Edition

by Hoobasar Rampaul

Industrial Press
New York, New York

Library of Congress Cataloging-in-Publication Data
Rampaul, Hoobasar.
Pipe welding procedures / by Hoobasar Rampaul.--2nd ed.
p. cm.
ISBN 0-8311-3141-1
1. Pipe--Weldinge. I. Title.

TS280 .R27 2002
621.8'672--dc21

2002033938

Industrial Press Inc.
200 Madison Avenue
New York, NY 10016-4078

Second Edition

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2 3 4 5 6 7 8 9 10

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Foreward from First Edition

Today, most pipe is joined by welding, but this was not always true, for until about 35 years ago pipe was joined by screw threads or by bolted flanged joints. Welding, now considered the best method for connecting pipe, is used even in the most demanding high-pressure and high-temperature service.

Much of the credit for this progress must be given to the welding industry; however, credit must also be given to the many welders who, through trial and conscientious effort, developed the welding procedures which consistently produce reliable weld joints. A great many welders contributed their efforts toward this end and it is unfortunate that their names have not been recorded.

One person who has contributed greatly to the improvement of general pipe welding procedures is Hoobasar Rampaul. He has worked as a pipe welder in refinery construction and maintenance, as a welding inspector, and as a teacher at the Hobart School of Welding Technology where I have been closely associated with him and have often witnessed his outstanding skill as a pipe welder. His success is due to his fine technical knowledge of welding as well as to his outstanding manipulative skill. By blending these he has been able to develop and qualify procedures that consistently result in pipe welds of the highest quality.

In order to make this skill available to many more welders I have encouraged Mr. Rampaul to write this book. It is a major contribution to the art and technology of pipe welding and I highly recommend it to all those craftsmen who have an interest in this field.

HOWARD B. CARY

Preface

Industries, such as power plants, oil refineries, chemical plants, food processing plants, and those that operate cross-country pipelines, have created a great demand for welders who are capable of producing high-quality pipe welds consistently.

This book is intended to help meet this need by assisting in the training of pipe welders in trade schools and to help those welders now working at the trade to enlarge their knowledge and improve their skills.

The chapters that treat the various welding procedures describe in detail the correct welding techniques that should be used as the weld progresses around the pipe joint. Possible mistakes are pointed out, and the reasons for using the recommended procedures are given. For these reasons, the welder who uses this book on the job, or while training, will find it to be a very useful reference aid.

In addition to the manipulative procedures, a welder should acquire as much technical and theoretical information related to welding as possible. This knowledge is most helpful in learning the craft of pipe welding and in progressing upward on the job. Therefore, there are informative chapters on welding metallurgy, on recognizing and correcting welding defects, on distortion in pipe joints, on fitting-up pipe joints, and on welding complicated pipe joints.

The author has gained much valuable experience as a pipe welder in various industries, not only in the United States but in the Caribbean; and he has been associated with the Hobart Brothers Company as an instructor in pipe welding at the Hobart School of Welding Technology. He would like to thank Mr. Howard B. Cary, Vice President, Hobart Brothers Company, for providing the inspiration to write this book and for his encouragement in its preparation.

The author would also like to take this opportunity to acknowledge, among many others, the help given in the preparation of this book by James Hannahs, Wade Troyer, Rudy Mohler, Denny Deweese, Nan Kidder, Helen Wilt, Marilyn Tarcea, Judy Parrish, and Lana Shelkon. He would also like to express appreciation to the American Welding Society and the following firms for their assistance in providing illustrations: The Hobart Brothers Company, the Tube Turns Division of the Chemetron Corporation, and the H & M Pipe Beveling Company.

Finally, the author would like to gratefully acknowledge the help and advice given by Karl Hans Moltrecht, Technical and Vocational Editor, Industrial Press Inc., especially for his contribution in the preparation of Chapters 11 and 12.

Acknowledgment by the Publisher

Industrial Press wishes to express its sincere appreciation to Robert O'Con for his invaluable assistance in the preparation of the second edition of this book.

CHAPTER 1

Introduction

Only high quality pipe welds are acceptable in modern industry; for the failure of a pipe weld not only can disrupt the operation of a plant, it can be the cause of a serious accident with the possible loss of life and property. For this reason, a pipe welder must be a thoroughly qualified person in his craft.

The objective of this book is to describe the techniques that will result in a successful pipe weld, which must be sound throughout as well as look good. The pipe welder will be provided with the related information necessary for him to do his job correctly. To be a successful pipe welder and achieve high quality pipe welds, such as shown in Fig. 1-1, requires practice in welding pipe. It cannot be

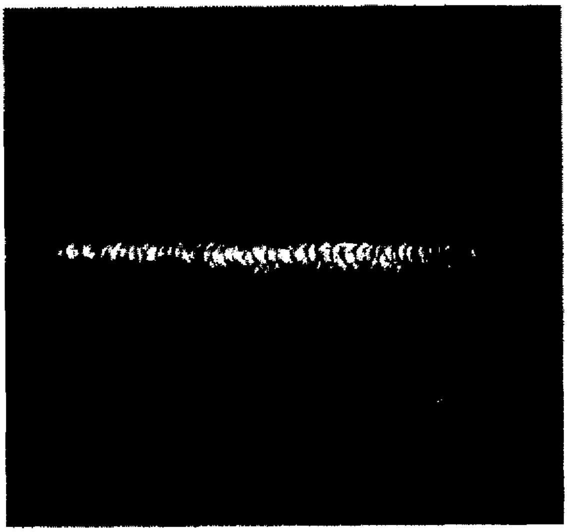


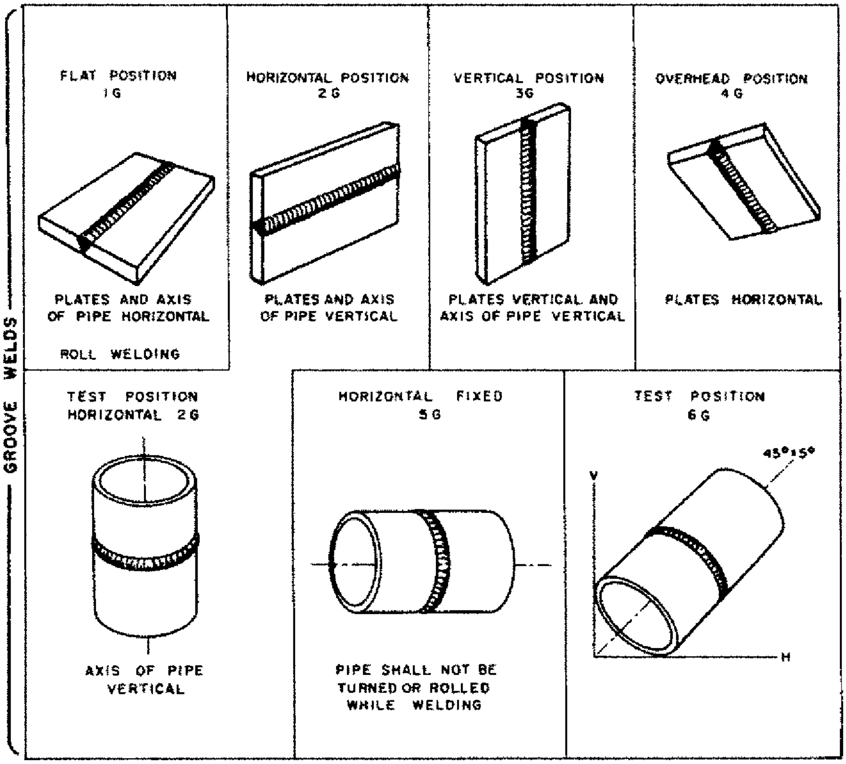
Fig. 1-1. Example of a high quality pipe weld.

learned by reading a book alone; however, if incorrect techniques are repeated, practice alone will never lead to successful pipe welding. Those who will take the time and effort to read this book will learn the correct techniques which, if practiced, will result in obtaining the skills required to be a successful pipe welder.

Before starting to learn pipe welding, a person should be proficient in welding in the four basic positions: 1. flat; 2. horizontal; 3.

vertical; and 4. overhead. All of these positions are used to weld pipe. Since the pipe has a round shape, there is usually a gradual transition from one position to another.

The welding positions are defined by standard symbols which are shown in Fig. 1-2. It is important for the welder to learn to identify



Courtesy of the Hobart Brothers Co.

Fig. 1-2. Standard symbols designating the welding positions.

these positions by their symbols (1G, 2G, etc.). These symbols will be used in this book to identify the various welding positions.

When making the weld, the welder is confronted with two primary tasks. First he must prepare to make the weld, and second he must concentrate his entire attention on the welding operation.

In preparing to make the weld, the welder is concerned with the following matters:

1. The type of metal to be welded
2. The selection of the correct welding electrode
3. The preparation and cleaning of the edge, or weld joint
4. The fit-up of the pipes to obtain the correct alignment.

After all of the preparations have been made, the welder must give his complete attention to making the weld. He must strike the arc and manipulate the electrode correctly in order to deposit a sound bead. He must watch the molten puddle of metal and, when welding a root bead, he must watch the keyhole (see Chapter 5, Fig. 5-4) constantly. Ever alert to notice small changes that may affect the quality of the weld, he must be prepared to make instantaneous adjustments in his welding technique when required. In other words, when the weld is in progress, the welder should see and think of nothing outside the area of the weld.

Basic Pipe Welding Procedures

When the pipe is in the 5G position, with its axis horizontal as in Fig. 1-3, positions on the pipe can readily be identified by their likeness to the numbers on the face of a clock. Thus, the top of the pipe is in the 12 o'clock position and the bottom is the 6 o'clock position.

Two different welding procedures are used when the pipe is in the horizontal position: downhill and uphill pipe welding. The choice of the method is not affected by the diameter of the pipe; it depends primarily on the wall thickness and the alloy content of the pipe, as explained in the following section.

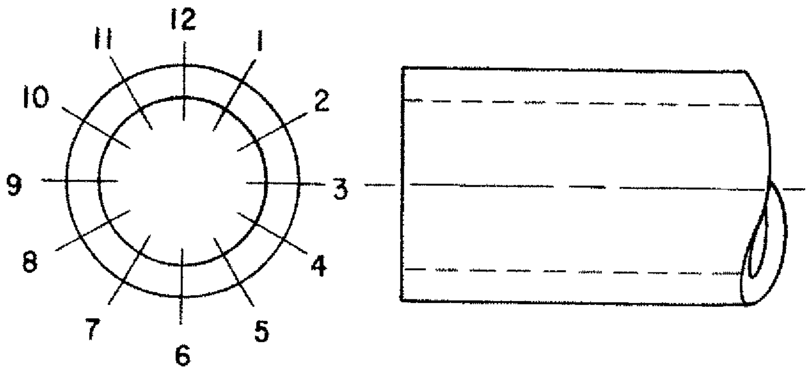


Fig. 1-3. The identification of the welding positions around the pipe joint by the numbers on the face of a clock.

Downhill Pipe Welding. Regardless of the method used, the pipes must first be tack welded together. For downhill welding (Fig. 1-4), the weld is started in the 12 o'clock position and the bead is welded progressively downward around the pipe until the 6 o'clock position is reached. Starting again at the 12 o'clock position, the bead is welded around the other side of the pipe to close with the first bead at the 6 o'clock position.

Downhill pipe welding is used primarily to weld thin-wall mild steel pipe having a wall thickness of ⅛ to $^5/_{16}$ inch. The relatively thin wall of the pipe retains the heat longer than thick metal would. This causes the metal in the area of the weld to cool slowly if the speed of welding and the heat input are the same. Slow cooling is

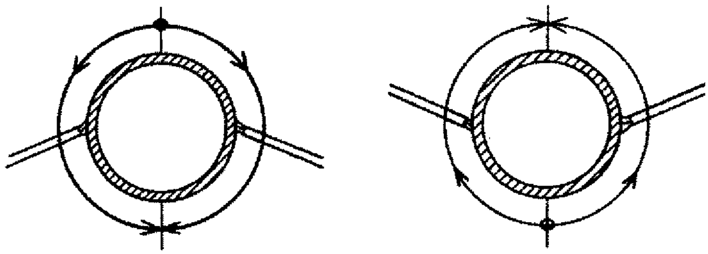


Fig. 1-4. (Left) General procedure for downhill pipe welding. Fig. 1-5. (Right) General procedure for uphill pipe welding.

desirable because a softer and more ductile grain structure is then obtained in the metal in the area of the weld.

When welding mild steel pipe, the slower cooling rate of the thin-walled pipe does make it possible to deposit the weld at a faster rate without harmful effects to the welded joint. For this reason, downhill welding is preferred when welding thin-wall mild steel pipe. The ductility of the metal in the weld and in the surrounding area can be further improved by depositing several beads around the weld. Each succeeding bead heats the previous bead, which cools relatively slowly.

The fabrication of cross-country transmission pipelines and other low pressure storage vessels are examples where the downhill method of arc welding (SMAW) is used. Since such fabrications will be of materials less than 3/8 of an inch thick, the downhill technique allows faster welding speeds with less tendency to burn through the root of the joint. In contrast, thicker materials and many of the alloy steel materials require the uphill welding method.

Downhill welding requires the use of fast-freezing, lightly coated electrodes such as 6010, 6011, 6012, 7010, and 7014 that produce minimum slag. As the electrode is moved down along the joint the molten puddle and it's slag covering will tend to smother the arc causing porosity and slag inclusions in the weld. The use of the proper electrodes, proper rod angle, and adequate travel speed, keeping ahead of the molten slag will insure sound welds. In some instances the use of straight polarity (electrode negative) along with the downhill method will eliminate burn though when poorly fitted joints are encountered.

The use of the heavier coated electrodes such as 7024 and the iron powder low hydrogen types are not suitable in downhill welding as the problems of slag entrapment, porosity, and cold lapping become insurmountable. Such electrodes will also require higher operating currents thus increasing the chance of burn though.

Early in the twentieth century the oxy-acetylene welding (OAW) process was used to join the low and medium carbon steel pipe material used at the time. Later, in the 1930's, when electric arc welding (SMAW) came into general use in pipe fabrication, the higher welding temperatures generated by the arc caused cracking problems, particularly in the root or first stringer pass.

Since that time pipe manufacturers have refined and improved the metallurgy of their products to take advantage of the newer welding processes and electrodes that were becoming available.

In recent years as the demand for larger diameter pipe with thicker

Fast moving welding crew.

walls for transporting grade oil over very long distances and natural gas at higher pressures, the pipe industry has improved the mechanical properties of the pipe by additions of manganese and silicon, along with more rigidly controlled amounts of carbon. Also small amounts of columbium and vanadium have been used, usually in the range of 0.20-0.26 percent. Such materials are known as "low alloy" piping because attempting to increase strength by excessive alloying causes additional problems in welding such as cracking and embrittlement of the heat effect zone (HAZ).

Increasing the carbon, manganese, and silicon content to achieve these higher level mechanical properties may seem reasonable. However, it will not be in the interest of joining pipe edges by welding without risking faulty welds. Even small-quantity increases in carbon can have great effects, increasing both the tensile strength and hardness. Likewise, manganese will increase both toughness and ductility, but will suffer from not having the necessary value to resist cracking.

Today's pipelines, and all of the Lx60 and Lx65 grade pipe materials, are being made by alloying techniques, other than simply increasing carbon and manganese levels, to the limits appropriate for carbon steel. In most instances, columbium or vanadium are added to a steel containing 0.20-to-0.26 percent carbon and 1.0-to-1.35 percent manganese,and. a "hot roll" practice within the critical range is responsible for grain refinement and adequate mechanical properties.

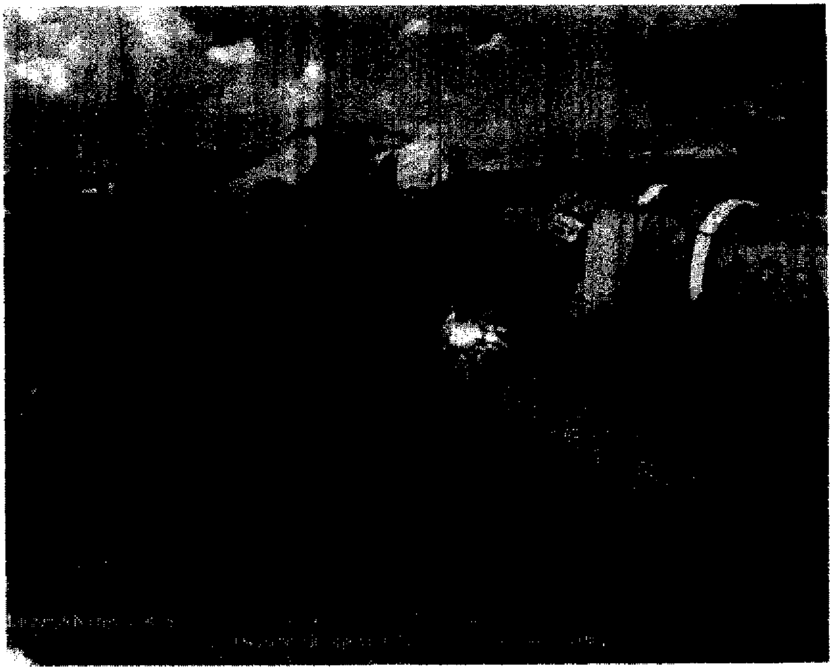
Pipelines welders are on the go all day. They are provided with welder helpers who are responsible for grinding and wire brushing each layer of weld deposit. They are also responsible for adjusting the welding current as instructed by the welders, keeping the welder supplied with electrodes, and handing the welders an electrode each time the one in use is consumed. The welder's helpers play a very supportive role because of their knowledge and experience in grinding and brushing welds complements the welder's effort in making perfect welds.

The welder helper's responsibility goes even further. After welds have been brushed and grinding is completed, the welder helper is often the first to discover defects such as surface porosity, poor fusion, poor tie-in, and inadequate filter metal on the weld groove before capping. The helper then informs the welder, who will provide instruction about what additional steps are needed to correct such defects. Because of the many variables on pipeline construction, especially with welding procedures and standards, welder helpers should be given training, or brought up to date, before pipeline construction commences.

The majority of pipelines constructed today use low alloy grade materials, although it is very possible higher strength alloy pipe material will be introduced in the future. Meanwhile, because of their role with preheating, interpass temperature, screening welds from wind and rain, and observing surface defects, welder helpers should be formally trained. Note: Chapter 8 continues the discussion of pipeline welding.

Uphill Pipe Welding. After the pipe has been tack welded, the weld is started at the lowest spot on the pipe or the 6 o'clock position (Fig. 1-5), and the bead is deposited upward around the pipe until the 12 o'clock position is reached. The second half of the pipe is then welded by again starting at the 6 o'clock position and welding upward around the other side to the 12 o'clock position, where the joint is closed.

This method is preferred for welding heavy-wall pipe and pipe made of alloy steel. The thicker pipe wall acts as a "heat sink" by withdrawing the heat more rapidly from the weld area than does a thin-wall pipe. The faster cooling rate causes the metal in the weld area to become more brittle in mild steel pipe. In alloy steel pipe the tendency toward brittleness is greatly increased.



Cross country pipeline laying.

To overcome this tendency the cooling rate in the weld area must be reduced. This can be accomplished by decreasing the welding speed and by depositing a heavier bead. Both of these objectives — slower welding speed and a heavier bead — are achieved by welding the pipe in the uphill direction.

Horizontal Pipe Welding. When the pipe is in the 2G position, with its axis vertical, the weld joint connecting the two pipes is in a horizontal plane, and a horizontal position (2G) weld must be made around the pipe. Horizontal pipe welding will be treated in detail in a later chapter.

There are, of course, cases where the weld must be made in still other positions, such as the 6G, or inclined, position. Welding in these positions is usually done by using one of the methods just described. Sometimes a combination of procedures is required and the welder must exercise good judgment in selecting the best one.

PIPE WELDING STANDARDS AND CODES

Welded joints in pipes play a vital part in industry. They are used in oil refineries (see Fig. 1-6), chemical plants, power generating stations, and food processing plants. Welded joints in pipes also play a vital role in the transportation of liquids and gases, as exemplified

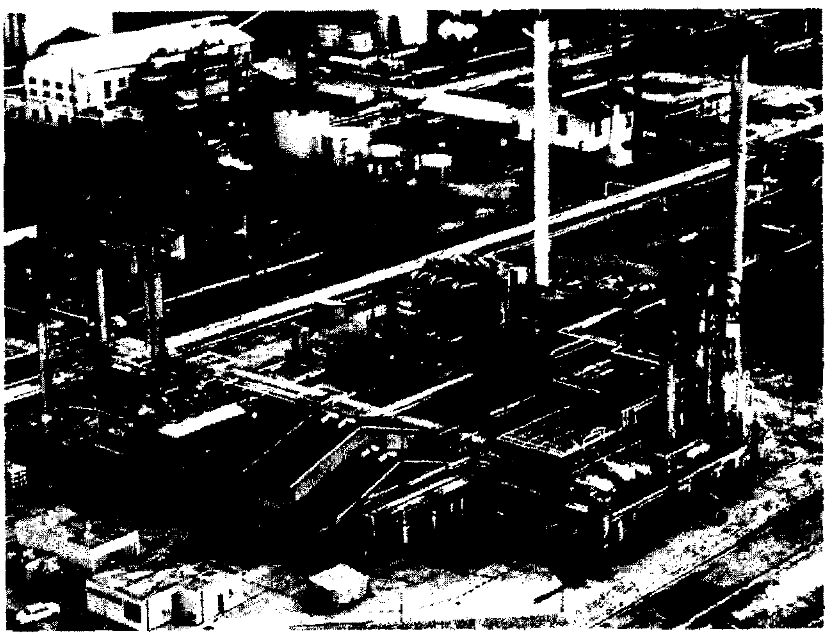


Fig. 1-6. Typical plant requiring many pipe-weld joints.

by cross-country pipelines. In the construction industry pipe welded members are used to support heavy loads.

Since public health and safety are involved in almost all of these cases, codes and standards have been established to protect the public interest. The following organizations are primarily responsible for these codes:

American National Standards Institute (ANSI)
The American Welding Society, Inc. (AWS)
American Society of Mechanical Engineers (ASME)
American Petroleum Institute (API)

It is not possible to list here all of the standards and codes that apply to the design and construction of pipe welded joints. The welder should, however, be aware of those affecting the job on which he is working.

CHAPTER 2

Essentials of Shielded Metal-Arc Welding Technology

The objective of this chapter is to provide a review of shielded metal-arc welding technology. By learning the principles treated here, the welder will have a better understanding of how and why to make adjustments to the machine and in his welding technique.

Basic Concept of Electric Arc Welding. In shielded metal-arc welding, an electrical circuit is established between the workpiece and the welding machine. The current in this circuit may be either alternating current (AC) or direct current (DC), although DC welding is preferred for welding pipe.

When using DC current, the polarity may be straight or reversed. Straight polarity means that the electrode is negative and the work is positive. The current in this case flows from the electrode to the work. For reversed polarity the above conditions are reversed; the work is negative, the electrode is positive, and the current flows from the work to the electrode.

Current flow is measured in amperes, and the term "amperage" is sometimes used to refer to current flow. Voltage refers to electrical pressure, which is measured in volts and which can be likened to hydraulic pressure. Voltage is the force that causes the current to flow. It is important to realize that a force, as well as a voltage, cannot exist unless there is a resistance to overcome. Feel the force built up in your arm when you press against a wall and then try to do this by "pressing" into the open space around you.

Open circuit voltage is a term encountered in electric arc welding. It is the voltage existing when there is no contact between the electrode and the work and when there is no arc. No current can flow in this case because the resistance is too great for the voltage or electrical pressure to overcome. However, the electric generator is trying to overcome this resistance by generating the maximum voltage of which it is capable.

When the electrode touches the workpiece, the resistance to the current flow is lowered and the current will flow in the circuit. Because there is less resistance, the electrical pressure required to "push" the current is less; i.e., the voltage is much lower than the open circuit voltage. In this case so much current will flow that if the electrode is stuck to the workpiece, it will overheat.

However, if the electrode is backed away slightly from the workpiece to form the arc, less current will flow because there is increased resistance to the flow of current caused by the gap. Since there is more resistance to the flow of current, more voltage will be generated to overcome this resistance.

When the arc is long and the gap is larger, more voltage is generated and less current will flow than when the arc is short, say normal, for welding. The increased current flow encountered when a normal arc length exists causes a greater temperature rise in the workpiece and deeper penetration, as compared to a long arc length.

When current flows, it encounters a resistance to this flow in the workpiece which causes its temperature to rise. An even greater resistance is encountered in "jumping" the gap, which creates much heat within the arc. The effect is to cause the metal in the workpiece and at the end of the electrode to melt.

The metal at the end of the electrode forms a droplet or globule which is transferred across the arc to the workpiece. If a molten pool of liquid metal exists on the workpiece, this globule or filler metal will mix with the metal in the molten pool, or base metal, forming an alloy, consisting of filler metal and base metal.

When the arc moves on, the puddle of molten metal is maintained by melting additional base metal ahead of the arc and adding filler metal from the electrode. However, some of the metal behind the arc solidifies to form the bead.

Metal Transfer. Of particular importance is that the pipe welder should understand how the metal is transferred from the electrode to the workpiece.

The droplet or globule is transferred from the electrode to the base metal by the propellant force of the arc and by an attractive force exerted on the globule by the base metal. In passing from the electrode to the puddle, the force of gravity also acts on the globule. When welding in the flat position the transfer of the globule is assisted by gravity. However, in the overhead position it opposes this transfer.

With the normal arc length used in overhead welding, the combined effect of the propellant force and the attractive force is large enough to overcome the pull of gravity and the filler metal will be deposited on the workpiece. When a long arc is maintained in overhead welding, the globule has a longer path to travel and more time is available for the pull of gravity to act, causing the globule to slow down. In this case, the globule will sometimes not reach the base metal and if it does, it will be moving at a slower speed. If, as is usually the case when the arc is long, the workpiece is not hot enough, the slow moving globule will not attach itself to the workpiece and will drop to the ground. Therefore, when a long arc is used in overhead welding, no filler metal is transferred to the workpiece. This is important when striking an arc to start a bead in the overhead position.

Electrode Coating. Almost all modern electrodes are coated. The function of the coating is to form a gaseous shield over the molten metal to protect it from the effect of the atmosphere (see Fig. 2-1).

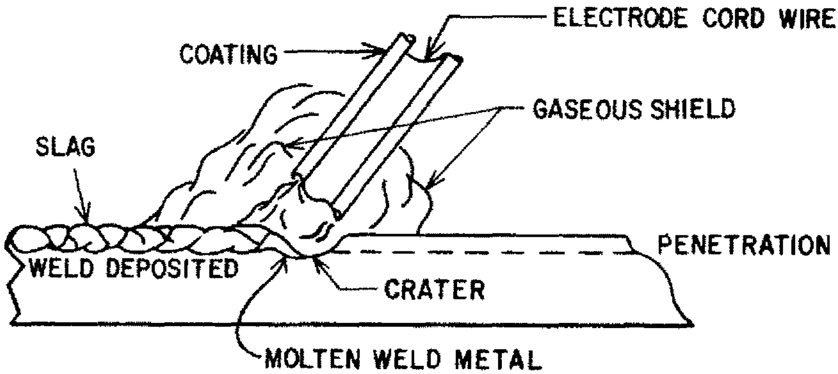


Fig. 2-1. Shielded metal-arc welding.

Certain ingredients in the coating enter the molten puddle to deoxidize the metal. The compounds thus formed are lighter than the molten metal and rise to the top of the puddle to form a slag coating when the metal solidifies. This coating, while it is still hot, protects the solidified metal from the atmosphere.

In some electrodes there are additional ingredients, certain of which are included to stabilize the arc. Others may be added in the form of powdered metals to provide alloying elements or additional iron for the puddle.

In welding, care must be exercised to manipulate the puddle of liquid metal so as not to trap the slag within the metal as it solidifies. It must be allowed to rise to the surface of the weld bead. Also, for the same reason, the slag coating or crust must be completely removed before a second bead is welded over the first bead. Entrapped slag can have serious harmful effects on the quality of the weld.

Arc Length. Arc length is the gap or distance between the electrode tip and the surface of the puddle. The correct arc length is primarily dependent upon the type of electrode used and upon the environmental conditions in which the welding is done.

When a heavily coated and highly alloyed electrode is used, a short arc length must be maintained because the higher alloyed filler and base metal are very sensitive to porosity. Holding the short arc protects the puddle from the atmosphere, which is the cause of porosity.

Since the cooling rate is faster with lightly coated electrodes, the arc length should not be choked. By maintaining a longer arc (approximately 3/32 to 1/8 inch) the voltage will increase slightly, causing the puddle to spread out or enlarge. This, in turn, will allow the filler metal to flow across the entire puddle, as shown in Fig. 2-2A.

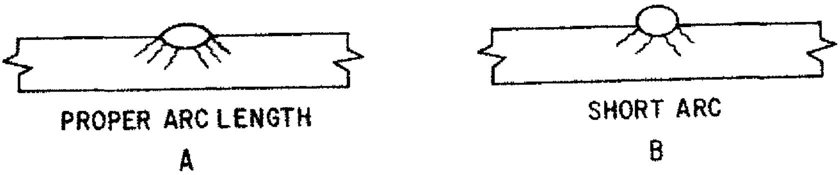


Fig. 2-2. The effect of the arc length. A. Correct arc length; B. Short arc length.

If the arc is too short (approximately 1/16 inch), the size of the puddle is reduced considerably and the filler metal has a limited area in which to be deposited. This causes the filler metal to rise, which can result in incomplete fusion along the edge of the bead, as shown in Fig. 2-2B.

The arc length also depends upon the environmental conditions, whether in a closed shop or in the open atmosphere, as in the case of an oil line or a refinery. Generally, a shorter arc is required when welding outdoors; and for heavily coated and highly alloyed electrodes a short arc is used in all situations.

CHAPTER 3

Heat Input and Distribution

The intense heat of the arc increases the temperature of the metal beneath the arc, which therefore reaches the melting point very quickly. As soon as a temperature difference exists, the heat energy starts to flow out of the weld area and heats the surrounding metal. In welding, the welder must use skill to control the input and distribution of heat.

Heat Input

The heat input is controlled primarily by the current setting. To some extent the heat input can also be controlled by the arc length. When welding, the heat *input* into the puddle is often controlled by the welding speed and by the weave or whip, as discussed further on in this book. However, more correctly, this is a matter of heat *distribution.*

Unfortunately, it is not possible to provide exact recommendations for the current settings to be used in each case for the following reasons:

1. The adjusting devices on all welding machines are not the same. One machine set at 90 amps may liberate the same amount of heat as another machine set at 130 amps.
2. The age and condition of the machine will affect the heat obtained at a given current setting.
3. Electrodes made to the same classification but manufactured by different companies may require different current settings to liberate the same amount of heat.
4. The mass or thickness of the pipe must be considered because a larger mass will absorb more heat away from the welded area.
5. The length of the cable in the circuit will affect the heat in the arc. For a given machine setting, increasing the length of the cable will result in less heat at the point of welding.
6. Environmental conditions affect the current setting to be used. For example, a current setting made outdoors on a windy and very cold day may be different from the setting made indoors in a shop.

Since there are so many reasons why current settings vary, it is common practice for welders to evaluate current settings by depositing a weld or a bead on a piece of scrap metal. Conducting this evaluation beforehand is a very important step in making a perfect weld.

For pipe welding, this evaluation should be conducted on plates in the vertical (3G) position. Weld the test plate uphill or downhill, depending upon the direction to be used to weld the pipe. The plate should be free from dirt and rust. Rust, when in contact with the molten pool of metal, will cause undercuts at the edges of the weld. In conducting the evaluation, the welder should try out different arc lengths. He must be cautioned to remember that after a few deposits are made on a small plate, the plate will become very hot and will, in many instances, give misleading results. Before this occurs, a different plate should be used to make the evaluation.

As a result of the evaluation, the welder should be able to determine the current setting that will give the best results for the conditions at hand.

The effect of the arc length, welding current, and the welding speed can best be understood by studying Fig. 3-1.

Heat Distribution

The distribution of the heat and the rate at which it is withdrawn from the weld zone are dependent on the following factors:

1. Conductivity of the work material
2. The mass of the metal surrounding the weld zone
3. The paths available for heat conduction
4. The use of the weave, or whipping, technique.

When compared to most other materials, all of the metals are good conductors of heat. However, all metals are not equal in their ability to conduct heat. For example, aluminum is a better conductor of heat than stainless steel, as shown in Fig. 3-2. The metal in the area of the weld will cool more rapidly in the case of aluminum than in stainless steel. Moreover, the heat will disperse throughout an aluminum plate more rapidly.

A large mass of metal adjacent to the weld zone will tend to withdraw heat from the weld zone more rapidly than a small mass. For example, heavy plates and thick-wall pipes will tend to cool the weld more rapidly than thin plates or thin-wall pipes. As another example, the corner fillet in Fig. 3-3 can withdraw heat more rapidly

Fig. 3-1. Weld quality inspection.

than the ordinary fillet. The bevel butt joint has the least ability to withdraw the heat.

Another factor to consider in estimating the rate at which heat will be withdrawn is the number of paths available along which the heat can flow. In Fig. 3-4 the plates have the same thickness, but the heat will be withdrawn more rapidly from the lap joint than from the edge joint because the lap joint provides two paths or directions of heat flow as compared to one direction for the edge joint. The paths along which heat can flow for a few typical weld joints are shown in Fig. 3-5.

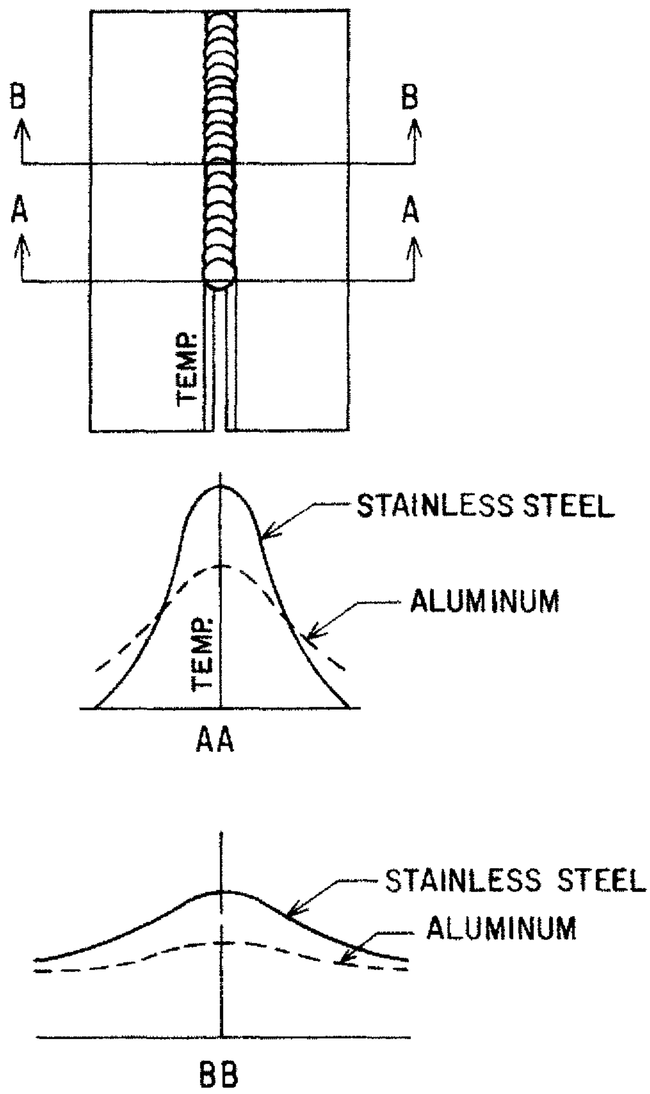


Fig. 3-2. The temperature distribution for an aluminum plate and a steel plate at two sections (*AA* and *BB*) of a plate while welding. At *AA* the melting point of stainless steel is shown by the higher temperature of the molten metal in the puddle. At *BB* the temperature of the entire welded plate has increased in both cases but the temperature of the aluminum plate is more equal throughout.

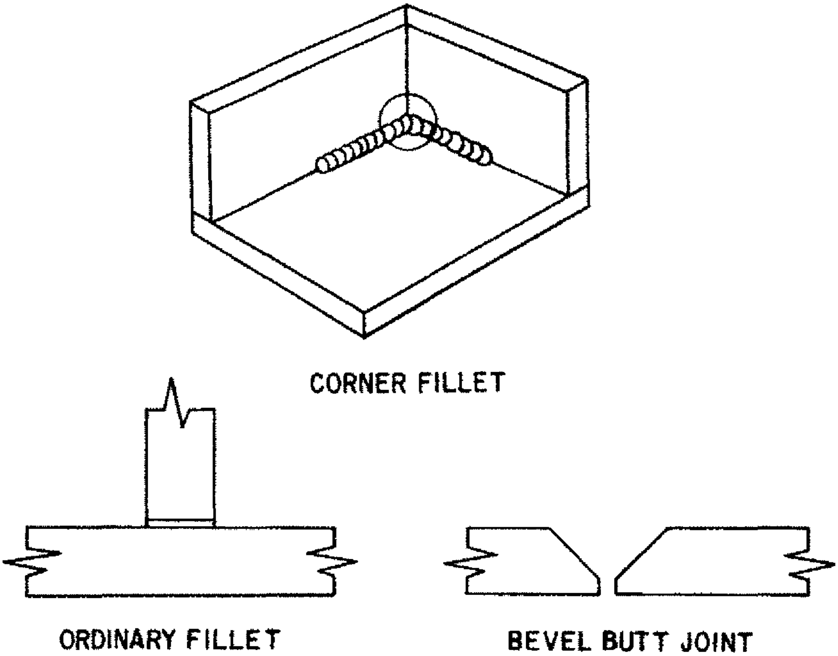


Fig. 3-3. The corner fillet will cause the heat to disperse from the weld more rapidly than the ordinary fillet. The ordinary fillet will disperse heat more rapidly than the butt joint.

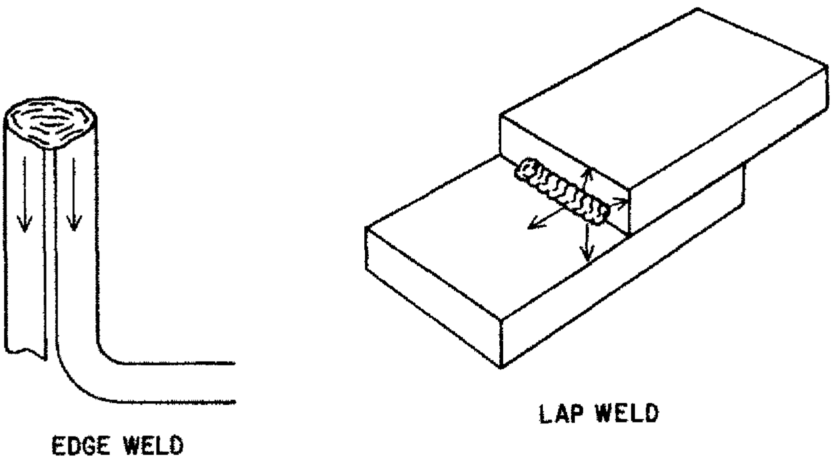


Fig. 3-4. The edge weld has fewer paths than the lap weld, along which the heat can flow from the welded joint.

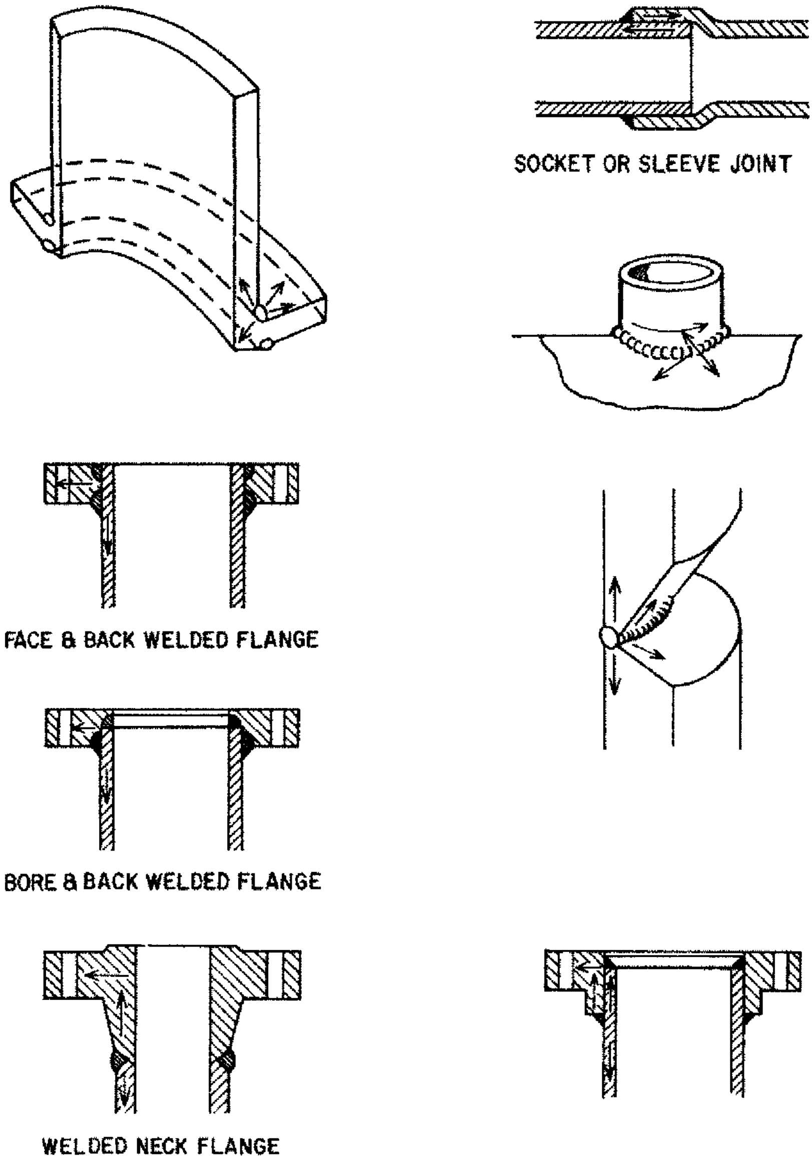


Fig. 3-5. Paths of heat flow found in some typical pipe weld joints.

The distribution of heat in the weld zone is affected by the welding technique. While welding, the electrode and the arc are sometimes deliberately moved in and out of the puddle of molten metal, in a uniform pattern, to reduce the temperature of the molten metal and to preheat the metal ahead of the weld. This technique is called "whipping." When the puddle of molten metal is moved back and forth in a uniform manner across the weld joint, the heat in the area close to the weld is spread out; this technique is called "weaving." It is used to spread the heat and to obtain a wider weld bead without maintaining an excessively large puddle of molten metal. Whipping and weaving will be treated in greater detail in later chapters.

In summary, the welder must analyze the weld joint and estimate the directions in which the heat will disperse. He can then adjust the current setting on the machine to provide an adequate amount of heat to maintain the molten puddle of metal and to obtain the desired welding speed. If the weld joint causes the heat to be withdrawn rapidly, the current setting is increased and possibly, the welding speed will have to be slowed down. On the other hand, if heat will not disperse readily from the weld joint, a lower current setting is used and it may be necessary to use the whipping technique.

CHAPTER 4

Preparation of the Pipe Joint

The preparation of the pipe joint is an essential part of pipe welding, as the quality of the weld is affected by the care used in preparing the joint. Indeed, in many instances the failure of the pipe joint can be attributed to faulty joint preparation. The pipe welder must understand and then practice those skills required to prepare the joint properly for welding. This is the first step in making a successful pipe weld.

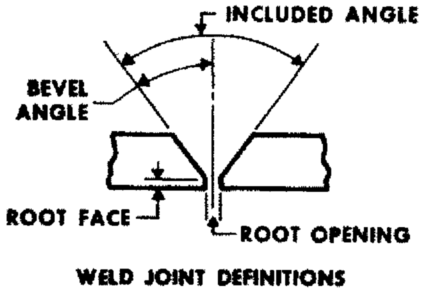
The preparation of the joint consists of four separate steps:

1. Prepare the edges
2. Clean the joint surfaces
3. Fit-up the pipes
4. Tack weld the pipes together.

Each step will be treated separately in this chapter. However, first there will be a brief discussion on how to practice pipe welding. Short lengths of pipe, or pipe nipples, should be used to practice weld to economize on the cost of the pipe. However, if the pipes are too short, the cooling rate of the weld may be affected to the extent that the weld will not correctly simulate conditions for welding longer pipe lengths. For this reason, a length of 7 inches is recommended for each of the two pipes to be welded. Experience has shown that this length does not affect the cooling rate of the weld significantly.

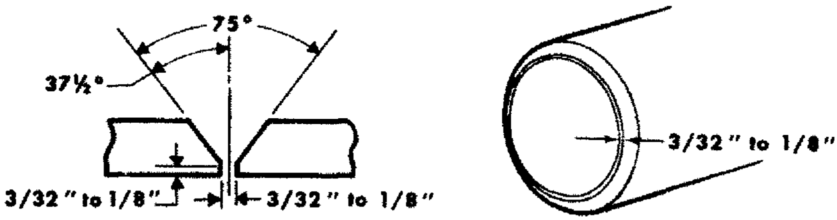
As mentioned in Chapter 1, two different basic procedures are used to weld pipe. For thin-wall pipe, the downhill method is used; and for thick-wall pipe, the uphill method is used. Except for details involving the size of the joint and welding the tack weld, the procedures for preparing the joint are the same, whether the pipe is thin-wall or thick-wall.

Preparing the Pipe Edges. Single-vee butt joints are usually used to weld sections of pipe together. The elements or parts of the joint have been given standard names, which are shown in Fig. 4-1. These names are used so frequently in pipe welding that they should be committed to memory.



Courtesy of the Hobart Brothers Co.
Fig. 4-1. Weld joint definitions.

Figure 4-2 shows the standard joint specifications for thick-wall pipes that are to be welded together by the shielded metal-arc welding method. The included angle of this pipe joint is 75 degrees. In order to obtain this angle when the pipes are brought together for welding, the bevel angle on the end of each pipe should be equal to one-half of the included angle, or 37½ degrees in this case.

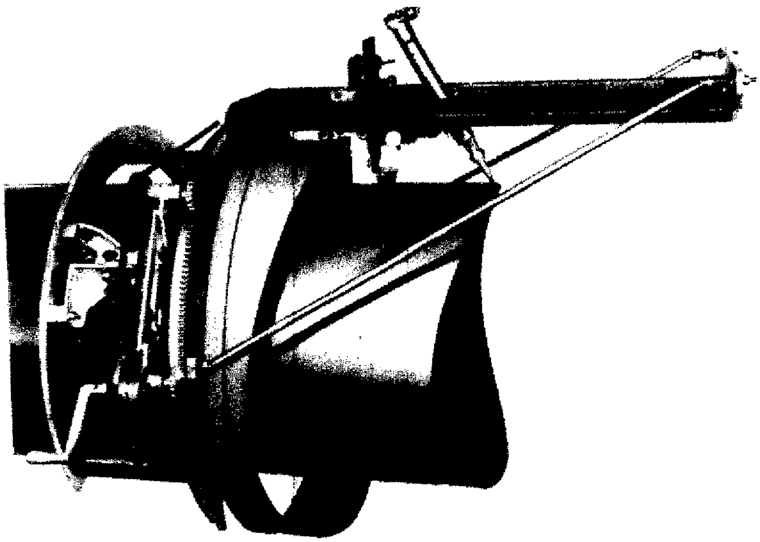


Courtesy of the Hobart Brothers Co.
Fig. 4-2. Standard joint specifications for thick-wall pipes.

Care should be exercised in making the bevel to leave the correct width of the root face. In Fig. 4-2, the width of the root face for heavy-wall pipe is shown to be $\frac{3}{32}$ to $\frac{1}{8}$ inch.

Usually the pipes and the pipe fittings are beveled by machining in a shop before they are sent out on the job and no further preparations are required before they are fit-up, other than cleaning. Sometimes, however, the pipes are not beveled and this operation must be performed on the job. In this case the bevel is cut with an oxyacetylene cutting torch and finished by grinding with a hand grinder.

Often the bevel is cut manually, using an ordinary hand oxyacetylene cutting torch. This requires care and skill. When available, a pipe-beveling machine is used, such as shown in Fig. 4-3. This machine is fastened to the end of the pipe and then is carefully adjusted to cut the bevel. Next, the oxyacetylene cutting torch is fed



Courtesy of the H & M Pipe Beveling Machine Co., Inc.
Fig. 4-3. Pipe-cutting machine.

around the pipe to cut the bevel. Depending on the design of the machine, the feed may be accomplished by a hand crank or by a self-contained power feed.

The surface produced by the oxyacetylene cutting torch will have a tightly adhering oxide film. If not removed, this film is very detrimental to the quality of the weld. For this reason, the beveled surface should be entirely free of the film before any welding is done over it. The oxyacetylene cutting torch also produces a rather rough surface that is difficult to weld over.

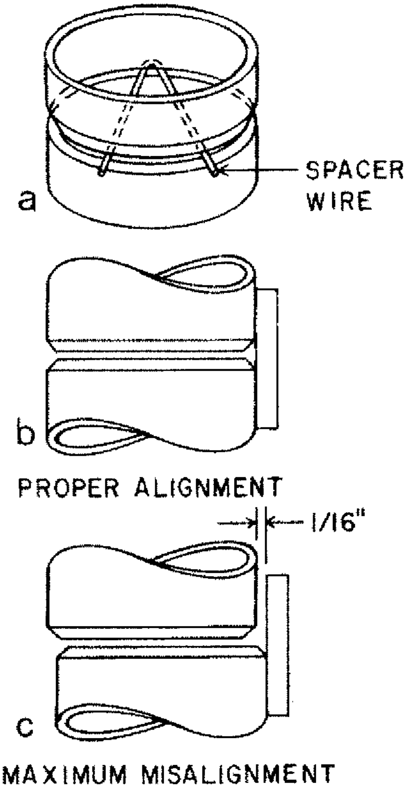
Grinding the bevel following the oxyacetylene cutting operation is done to remove the oxide film and to obtain a smooth, flat contoured surface over which to weld. On very thin-wall pipe (1/8 in.) the entire bevel is sometimes ground with a hand grinder.

Cleaning the Joint Surfaces. Contaminants such as grease, oil, scale, or rust will have a harmful effect on the quality of the weld. As already explained, all traces of the oxide film produced by the oxyacetylene torch must be removed. The welder must also make certain that any other contaminants are removed before starting to weld. This can usually be accomplished by the vigorous application of a wire brush.

Fitting-up the Pipe. The two pipes to be welded together must be accurately aligned prior to welding. The inside surfaces of the pipes must blend together smoothly, as should the outside surfaces. In many instances the pipes must be aligned so that the finished piping system will be in the correct location. Considerable skill is required to fit-up two pipes in preparation for welding. This is an essential part of the pipe welder's craft.

Because an understanding of how to fit-up pipe is so important, Chapter 14 is entirely devoted to this subject. The present chapter will treat only the method of fitting-up two short pipe nipples in preparation for practice welding and the reader is referred to Chapter 14 for further details on this subject.

Short pipe nipples are not only used for practice welding, but also for jobs in the shop and in the field. The pipe nipples recommended for practice welding are 7 inches long. They are made from 8-inch Schedule 60 mild steel pipe, for which the actual outside diameter is 8.625 inches and the wall thickness is .406 inch.



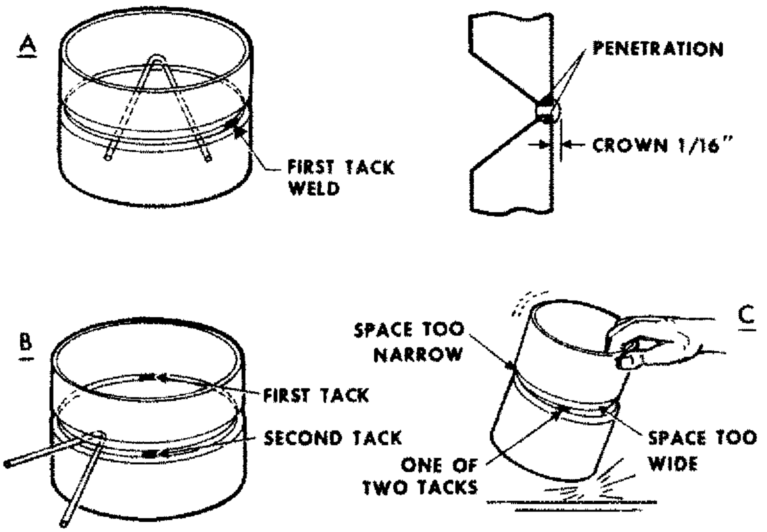
Courtesy of the Hobart Brothers Co.

Fig. 4-4. Method of spacing two pipe nipples in preparation for tack welding (a); Correct alignment of pipe nipples in preparation for welding (b); and maximum allowable misalignment (c).

To fit-up the pipe nipples, first determine the required width of the root opening. Next, find a piece of wire having a diameter equal to the width of the root opening and bend it into a vee-shape, as shown in Fig. 4-4 (a). Place one of the nipples on end on the welding table (b) and place the other nipple on top of it with the wire between them to act as a spacer. With the spacer wire in place, align the two pipes with a straight edge (c). The maximum misalignment allowed (d) is $1/16$ inch, which is specified by the ASME Code. When properly aligned, the two pipe nipples are ready to be tack welded together.

Tack Welding. After the pipes are aligned, four tack welds, evenly spaced around the pipe, are made in the root of the weld using a $1/8$-inch E6010 electrode in this case. Each tack weld should be about $3/4$ inch long. Since the tack welds will remain as part of the root bead, they must be sound throughout. They must be strong, and they should penetrate to the root of the weld from start to finish.

With the pipe nipples properly aligned, one tack weld is made in the root of the joint, as shown in Fig. 4-5A. The spacer wire is then moved so that only the bent end is between the nipples, as shown in Fig. 4-5B. Then the second tack weld is made on the side opposite from the first tack weld.



Courtesy of the Hobart Brothers Co.

Fig. 4-5. A. First tack weld with wire spacers in place; B. Second tack weld made with wire spacer partially withdrawn; C. Method of tapping on table to equalize root opening.

Remove the spacer wire entirely from the joint and inspect the root opening. If the opening on one side is only slightly wider than the other, weld the wide side next. The shrinkage of the tack weld will equalize the spacing. If the space is too wide to correct by welding, bump the pipes on the table as shown in Fig. 4-5C until the openings are equalized. Then weld the third and fourth tack weld 90 degrees from the first two tack welds.

In most cases the ends of the tack welds should be ground to a feather edge to facilitate the tie-in with the root bead. This is not, however, always done. Sometimes a grinder is not available on the job and the welder must be able to make a tie-in on tack welds and other welds that have not been ground to a feather edge. If he can do this, he will have no difficulty in making a good tie-in on weld beads that have been ground. For this reason, when learning to weld, it is recommended that ends of the tack welds not be ground.

The correct procedure for welding the tack welds will be described in the following paragraphs. It will be assumed that the correct welding rod has been selected and that the welding machine setting is also correct.

It is important to start any weld correctly, whether tack welding or welding a longer bead. When the arc is struck, it should not be shortened immediately. Time should be allowed to stabilize the arc and to allow the gaseous shield to form.

If an unstable arc is brought close to the root face, the electrode may stick or small globules of filler metal will be deposited on the beveled edge which can restrict the manipulation of the arc. The gaseous shield protects the molten metal from oxidation. In the absence of the gaseous shield, the molten metal in the puddle will combine with oxygen in the air to form oxides and thus will not readily flow into the root opening. When this occurs, the first deposit is usually a large lump of metal that is seldom properly fused, and in

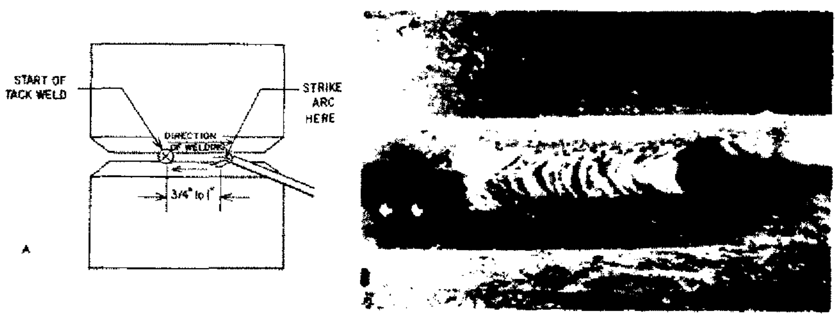


Fig. 4-6. A. Method of striking the arc ahead of the tack weld; B. The keyhole.

almost all cases the penetration into the root opening is insufficient. The result is a defective deposit that must be removed from the weld.

For the tack weld, the correct procedure is to strike the arc ahead of the weld, or that part of the groove in which the weld bead is to be deposited, as seen in Fig. 4-6A. Maintain a long arc and move the electrode along the groove to the position where the weld bead is to start. This serves to preheat this surface as well as to provide time for the arc to stabilize and for the gaseous shield to form. During this time the globules of metal transferred from the electrode will be deposited as spatter outside of the weld. On larger pipes, where it is often necessary to deposit a tack weld in the overhead position, no filler metal will be transferred when a long arc is maintained in this position.

The electrode should be held at the correct electrode angle, as shown in Fig. 4-7, A and B. It is held over the starting point until the edges of the groove begin to melt and then is shortened to obtain the correct arc length for welding. When the keyhole (Fig. 4-6B) has

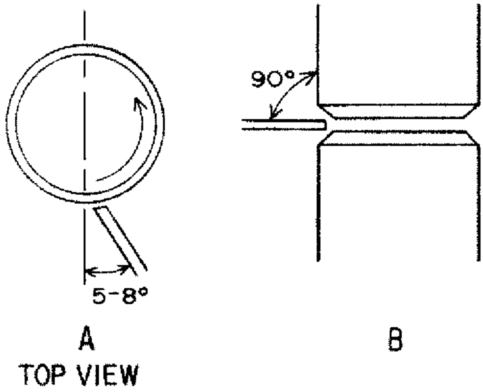


Fig. 4-7. Correct electrode angle for welding the tack weld.

formed, the weld bead is made, using a slight whipping technique. This is described further on in this Chapter for welding in the 2G position and in Chapter 5 for welding in the 5G position.

The Keyhole

The keyhole is an essential part in welding a root bead. It should be about 1⅓ times the diameter across the electrode coating in size. The keyhole helps to insure that the deposited bead will penetrate to the root as evidenced by the small crown at the back of the bead. This crown, Fig. 4-8, should rise about $\frac{1}{16}$ inch above the inside surface of the pipe. While welding, the welder should watch the

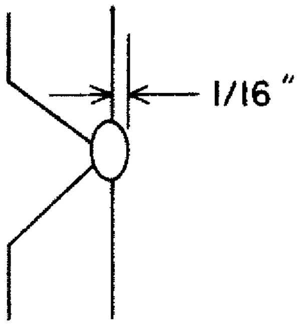


Fig. 4-8. The root bead. (Note the crown at the base.)

keyhole constantly. If it becomes enlarged, overpenetration will result. This can be corrected by reducing the welding current or, in some cases, by increasing the welding speed. If the keyhole is too small, the penetration of the root bead will be insufficient. While slowing the speed of welding will help in some cases, usually it is necessary to increase the welding current to correct this condition.

The Whipping Technique

When the pipe nipples are tack welded in the 2G position, the weld is horizontal and it is necessary to use a slight whipping motion to control the molten metal in the puddle. The whipping motion, shown in Fig. 4-9, is a quick movement of the arc away from the puddle, in the direction of welding, after which it is returned to the puddle. The arc must be kept within the groove made by the weld joint and it should not be carried outside of this area. The length of this movement should be short, about 1½ electrode diameters, in order to maintain a gaseous shield over the molten metal at all times. After each whip the electrode should pause over the top edge of the keyhole, where the molten metal joins the solidified bead, to deposit filler metal and to keep the puddle fluid. The whipping motion should be made by moving the wrist, not the entire forearm. The purpose of whipping is to decrease the fluidity of the molten metal puddle, allowing it to become somewhat mushy but not to solidify completely.

Stopping the Weld

The procedure that is used for laying down the root bead is continued until the bead is about ¾ inch long. At this point the weld

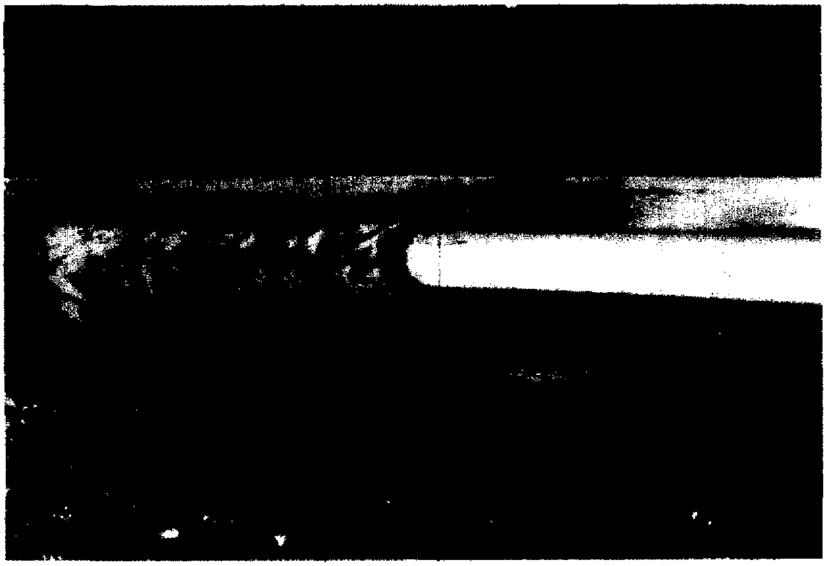
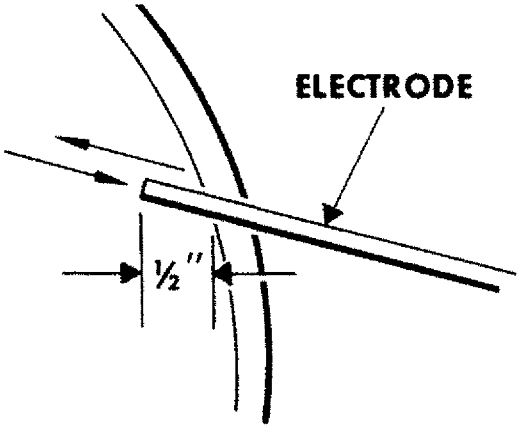


Fig. 4-9. Welder's view when welding the tack weld in the horizontal position. A slight whip should be used, as shown, to prevent the molten metal in the puddle from dripping.



Courtesy of the Hobart Brothers Co.

Fig. 4-10. Quenching the arc by a stab through the keyhole when welding a root bead.

is stopped. The procedure for stopping the weld is to push the electrode through the keyhole by a quick movement, as shown in Fig. 4-10. After the arc is extinguished, it is quickly withdrawn. This method of stopping a root bead helps to obtain full root penetration when restarting the weld at this point and when making a tie-in.

The tack welds should be cleaned and inspected before welding the remainder of the root bead. All of the slag coating must be removed with a chipping hammer, and the surface of the bead should be brushed vigorously with a wire brush. Any defects should be removed by grinding or with a hammer and a chisel. The defective areas should be rewelded, although this may be done after the remainder of the root bead has been welded. A perfect tack weld is shown in Fig. 4-11.

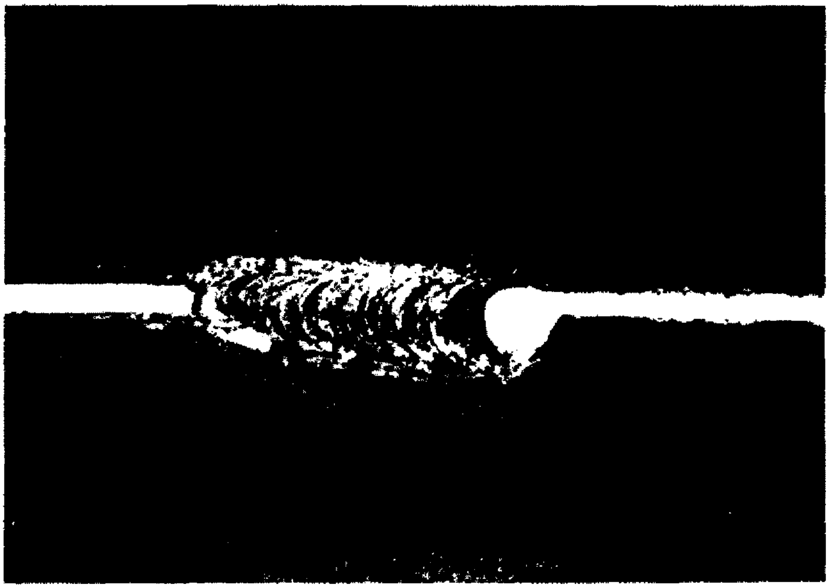


Fig. 4-11. View of a perfect tack weld.

Uphill Welding the Root Bead on Heavy-Wall Pipe (5G Position)

The Root Bead

The root bead is the foundation of a successful pipe weld and must be made as perfectly as possible. An illustration of a perfect root bead is shown in Fig. 5-1.

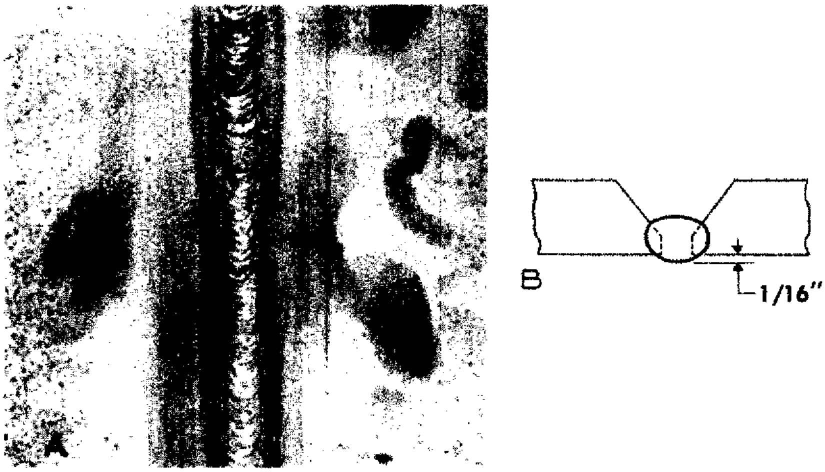
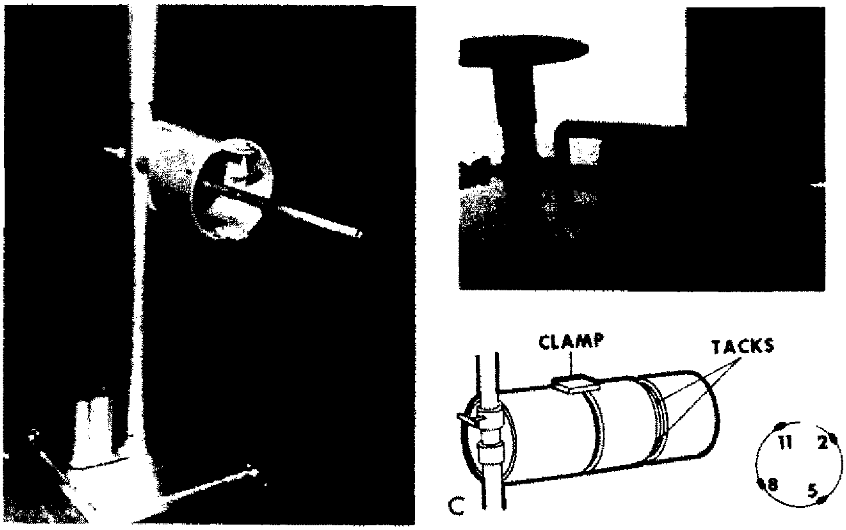


Fig. 5-1. A. Top view of a perfect root bead; B. View of section through the root bead.

Perhaps the most difficult position in which to weld pipe is in the horizontal, or 5G, position. Once this is mastered, welding pipe in other positions is less difficult to learn. For this reason, it is best to start by learning how to weld in the 5G position.

For practice welding in the 5G position, a convenient method of holding the pipes is to clamp them in a fixture or pipe stand as shown in Fig. 5-2A. Two previously tack welded pipe nipples are shown clamped in position on the pipe stand in Fig. 5-2B. When clamping the pipe nipples in the fixture, they should be positioned so that the tack welds are in the positions shown in Fig. 5-2C.



Courtesy of the Hobart Brothers Co.

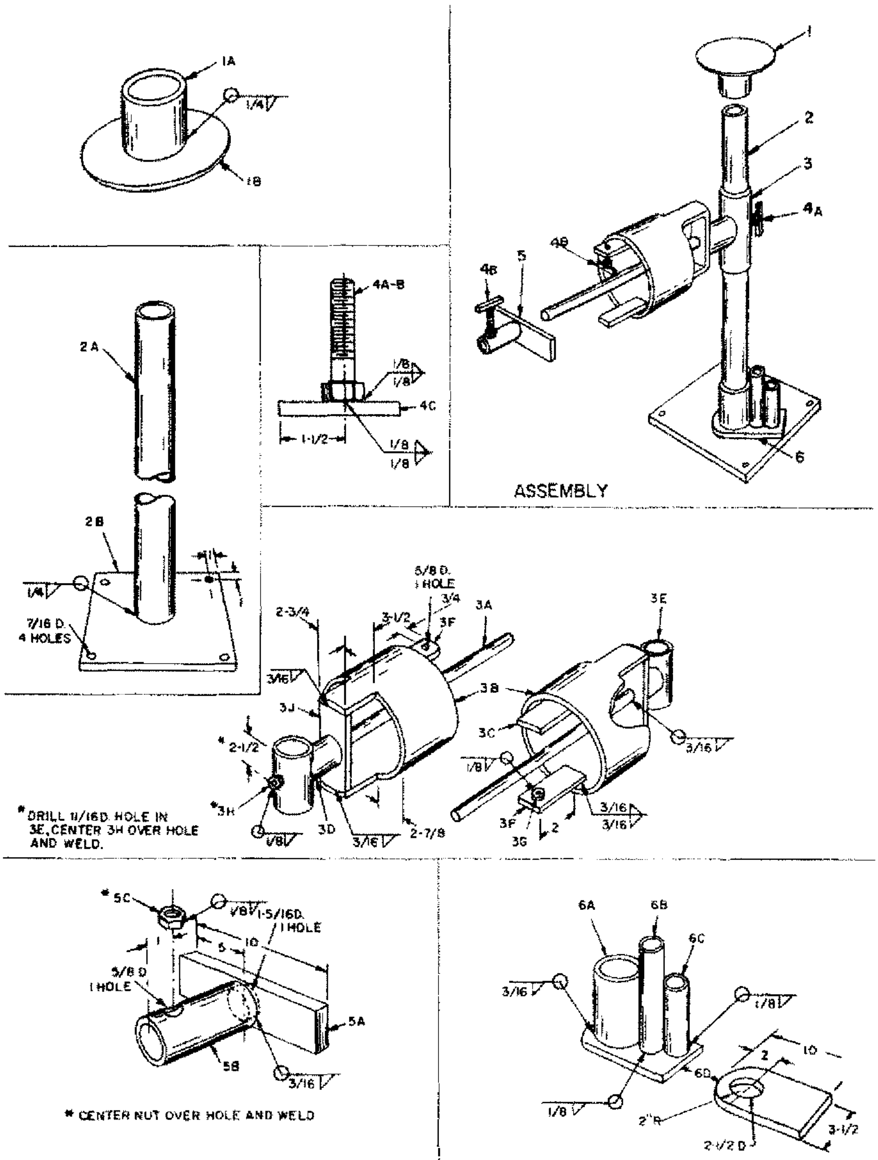
Fig. 5-2. Pipe welding stand. A. Unloaded stand; B. Pipe clamped in place; C. Position of tack welds.

Figure 5-3 gives a view of the details of the pipe stand. While all of the details are shown, not all of the dimensions are given because they depend on the size of the pipe to be welded and must be specified accordingly. From this illustration it should be possible to design a pipe stand on which the practice welds can be made.

General Procedure for Uphill Root Bead Welding

The procedures given in this chapter are recommended for welding the root bead on all heavy-wall pipe. In the following discussion 8-inch Schedule 60 mild steel pipe will be used as the example of welding in the 5G position. The actual outside diameter is 8.625 inches and the wall thickness is .406 inch. For welding this pipe a ⅛-inch E6010 electrode should be used. The pipe should be clamped on the fixture with the tack welds in the 2, 5, 8, and 11 o'clock positions, as shown in Fig. 5-2C. Since the pipes to be welded are heavy-wall pipes, the uphill welding method will be used. The general procedure is to start at the 6:30 o'clock position and to weld up to the 12 o'clock position around one side of the pipe, and again, from the 6:30 o'clock to the 12 o'clock positions around the other side of the pipe, to close the weld.

Three basic welding positions are used to weld the root bead when the pipe is in the horizontal, or 5G, position. The weld is started by welding in the overhead (4G) position; then gradually there is a



Courtesy of the Hobart Brothers Co.

Fig. 5-3. Details of the pipe stand.

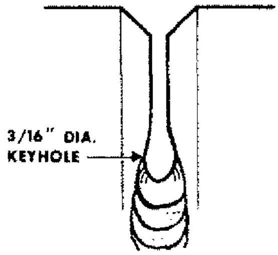
change to the vertical (3G) position, welding in the uphill direction. From this position there is another gradual transition to the flat (1G) position.

When welding around the pipe from the bottom to the top, the transitions from one position to another are gradual. This requires the welder to be alert in order to maintain the correct electrode angle at all times and to change his welding technique as necessary.

Welding in each of the positions will be described separately. However, the welder must develop the skill to recognize which welding method to use and when a change must be made.

The Keyhole

Before going further, it is necessary to say a word about the keyhole. As seen in Fig. 5-4, the keyhole is a teardrop or pear-



Courtesy of the Hobart Brothers Co.

Fig. 5-4. The keyhole.

shaped enlargement of the root opening ahead of the bead. When welding a root bead, the keyhole is necessary in order to obtain the required weld penetration.

The keyhole is the basic guide to the welder as he welds the root bead. When starting to weld, the welder should make certain that the keyhole has formed. The correct amount of penetration is obtained when the keyhole is about $1\frac{1}{3}$ times the diameter across the electrode coating, or slightly less. While welding the root bead, the welder must pay careful attention to the keyhole and watch for changes in its size. If it becomes enlarged, excessive penetration, burn-through, or internal undercut will result. If it is too small, the penetration of the root bead will be insufficient to produce a satisfactory weld. These defects are shown later in Fig. 5-14.

Starting the Root Bead

Since the weld is started at the lowest position on the pipe, it is usually necessary for the welder to be in a kneeling or crouching position. Whether kneeling or crouching, he should be situated comfortably in order to avoid any unsteadiness in manipulating the welding electrode. Getting into a comfortable position, then, is the first step in welding a root bead (see Fig. 5-5).

With the machine setting and all of the electrical connections made, the welder starts by striking an arc between the 6 and 6:30

Fig. 5-5. Starting to weld the pipe joint.

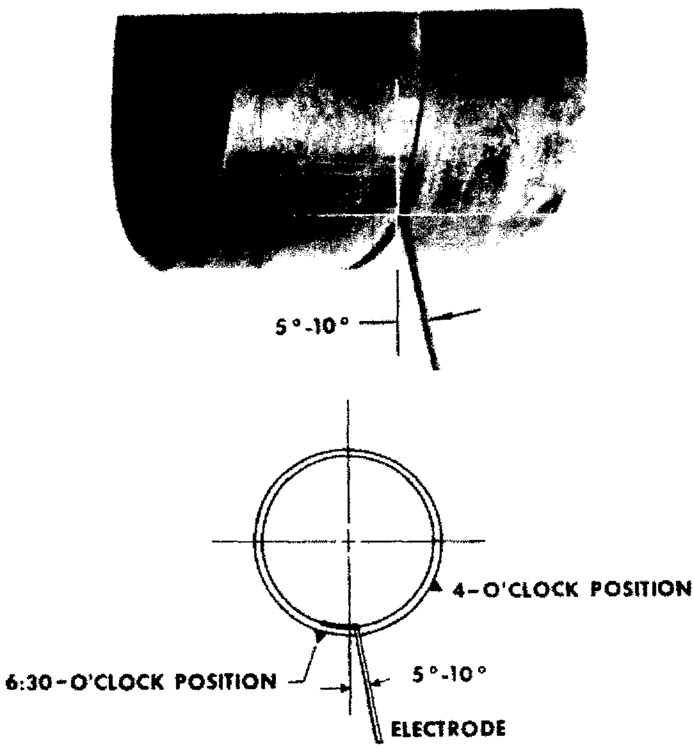


Fig. 5-6. Correct electrode angle for welding in the 6:30 position.

position on the pipe joint. The arc should be struck in the joint and never on a tack weld. A long arc length should be maintained for a short period after the arc has been struck. During this time he should weave the electrode backward and forward to preheat the bevel ahead of the weld.

In addition to preheating the bevel, maintaining the long arc length stabilizes the arc and allows the gaseous shield to form. No filler metal is transformed from the electrode to the workpiece when the long arc is maintained in the overhead position.

After the arc has been stabilized and the gaseous shield has formed, the electrode is brought back to the 6:30 position, which is the actual starting position for the root bead. With the electrode held at the correct angle (see Fig. 5-6), it is carefully moved toward the root bead until the correct arc length is established. If necessary, the electrode is held momentarily in this position, long enough to form the keyhole and the puddle of molten metal. Then the electrode is advanced at a slow, steady pace to form the weld bead.

Uphill Welding the Root Bead

With the keyhole and the puddle established and with the electrode held at the correct angle, the electrode is advanced around the bottom of the pipe. There is no back-and-forth motion across the pipe joint, only a linear, or straight, movement along the joint in the direction of welding. The movement of the electrode should be slow and uniform. Maintaining the correct arc length, the end of the

Fig. 5-7. Welder's view when welding the root bead at the bottom of the pipe.

electrode should be kept near the top of the keyhole, which is the part of the keyhole adjacent to the deposited weld bead. The position of the electrode is shown in Fig. 5-7. If the current setting is correct, it should not be necessary to resort to whipping in order to control the puddle and the size of the keyhole.

While welding, the welder should pay careful attention to the puddle and to the keyhole. As the electrode moves along at a steady pace it melts the edges of the bevel in front of the arc and the molten metal flows toward the back of the arc. There it enters the puddle and flows into the root opening. As the electrode moves on, the molten metal in the puddle that is left behind solidifies to form the weld bead. Since the bead will be deposited in a circular pattern around the pipe, the tilt of the electrode must be changed gradually to maintain the correct electrode angle.

If the keyhole size becomes too small, the electrode angle should be decreased slightly by pointing the electrode more directly toward the keyhole. Also, the welding speed may be decreased slightly. Should the keyhole become enlarged, the remedy is to increase the electrode angle slightly. If this is not effective, welding should be stopped and the current setting reduced before proceeding again.

Whipping is sometimes used in overhead welding to reduce the keyhole size and to control the puddle. However, this practice is not recommended and should not be used unnecessarily in the overhead position. When excessive whipping appears to be necessary, it is best to reduce the current setting.

Stop and Restart. When welding the root bead, the electrode is consumed and will need replacement. This necessarily involves breaking the arc. Welding is also stopped after a tie-in has been made with another weld, such as a tack weld; however, the procedure for making a tie-in will be treated later on in this chapter.

To stop the weld, the arc is broken by making a quick stab through the keyhole with the electrode and then by withdrawing it quickly to clear the work. By this procedure a full size keyhole is left so that complete penetration can be obtained when the weld is started again.

Before restarting the weld, the slag coating of the weld bead should be chipped off with a chipping hammer and the bead should be wire brushed for a distance of 1 inch, or more, from the keyhole. All traces of the slag coating should be removed to eliminate the danger of any of it being trapped in the molten metal when restarting.

To restart the weld, the arc should be struck on the part of the bead that has been cleaned. Maintaining a slightly longer than normal arc, the electrode should be brought forward to the edge of the keyhole and held there momentarily to allow the arc to stabilize and the gaseous shield to form. It is also held at this length in this position to allow time for the liquid puddle to form at the edge of the keyhole. When sufficient liquid metal appears at the edges of the keyhole, but not before, the arc can be shortened to its normal length and the electrode manipulation can be started to resume the weld.

Vertical Uphill Welding of the Root Bead

The nature of the welding process changes gradually from overhead welding to vertical uphill welding as the bead progresses from the 5 o'clock to the 4 o'clock position. As the weld moves toward the vertical position, it becomes apparent that the liquid metal will tend to flow downward at a faster rate than when welding in the overhead position.

When the continuous application of heat resulting from the slow steady movement of the electrode starts to cause an overflow of the molten metal, the remedy is to resort to the whipping procedure. The whipping procedure must always be used when welding in the vertical uphill portion of the pipe. It is continued until the weld is stopped at the 12 o'clock position.

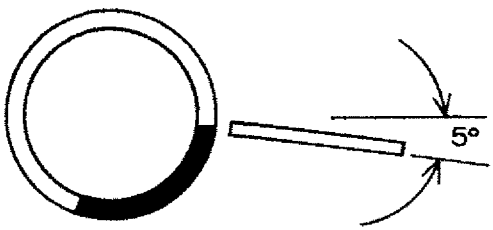
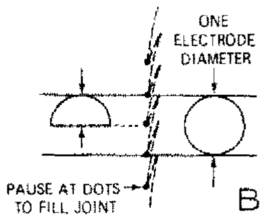


Fig. 5-8. Correct electrode angle for vertical uphill welding of the root bead of a pipe joint.

The electrode must be held at the correct angle, as shown in Fig. 5-8, and the electrode must follow the path shown in Fig. 5-9A. It is moved upward about one electrode diameter, Fig. 5-9B, and then returned to the face of the keyhole, which should be about one and one-half the electrode diameter.

The electrode should then pause at the face of the keyhole, which is the lower part of the keyhole adjacent to the deposited weld bead. In this area the intense heat of the arc can be absorbed by the metal, and the filler metal from the electrode is deposited here in order to build up the bead progressively. The electrode should not pause



Courtesy of the Hobart Brothers Co.

Fig. 5-9. A. Welder's view when whipping, showing the path of the electrode. B. The length of the stroke when whipping should be approximately one electrode diameter but should not exceed 1½ electrode diameters.

directly over the keyhole because the initial heat in this area will cause the intense heat of the arc to melt the edges around the keyhole. This will result in excessive penetration and possible burn-through.

Whipping should be done by a precise wrist movement and not by moving the entire forearm. This procedure can be described as a repeated "whip and pause."

The objective of whipping is to allow the molten pool of metal to cool sufficiently to lose some of its fluidity. When the molten metal in the puddle is somewhat mushy, a further deposit of filler metal from the electrode will not cause it to overflow.

The length of the stroke when whipping should not be excessive. If it is excessive, the hot liquid metal in the puddle will be exposed to the atmosphere as a result of the removal of the gaseous shield. Rapid oxidation will result, which leads to porosity in the weld. Excessive whipping can also cause slag entrapment in the weld.

Some welders have a tendency to use a current setting that is too high. Then, to prevent overflowing, they resort to whipping, even in the overhead position which soon becomes excessive. In such cases, better results are obtained if the welding current is reduced and whipping is kept to a minimum. The length of stroke when whipping should not exceed one and one-half electrode diameters and preferably be less, in order to minimize the effect of uncovering the gaseous shield from the weld and to prevent slag entrapment.

Flat Welding the Root Bead

Conditions approaching flat welding occur as the weld progresses to the vicinity of the 1 o'clock position. When this occurs, the molten pool of metal becomes even more difficult to control and the whipping procedure must be continued until the weld is stopped in the 12 o'clock position.

When welding a single-vee groove, open butt joint in the flat (1G) position, the molten metal will tend to drip through the opening causing the bottom of the weld to build up and form a high crown. This is excessive penetration. In more severe cases, burn-through will result, especially if the current setting is too high. In some shops, back-up plates are positioned at the bottom of the joint to prevent this from happening. However, this is not necessary when the weld is made by a skilled welder, using the whipping procedure and the correct current setting.

From what has been said above, it is evident that the welder must watch the puddle and the keyhole for signs of excessive penetration. He must continue the whipping procedure to control the pool of molten metal. If signs of excessive penetration occur, he may increase the electrode angle somewhat as shown in Fig. 5-10B. The

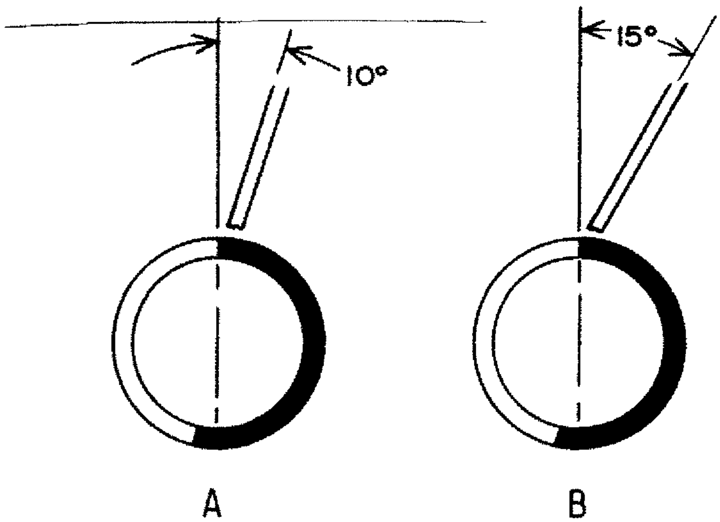


Fig. 5-10. Correct electrode angle for flat welding at the top of the pipe.

normal electrode angle for welding in this position is shown in Fig. 5-10A. If this does not help, the weld should be stopped and the current setting reduced. Excessive whipping should not be used to correct this situation.

If the current setting is correct and the correct whipping procedure is used, a perfect root bead can be welded in the flat position on top of the pipe joint. When the weld bead has reached the 12 o'clock position, the weld should be stopped by stabbing the electrode quickly through the keyhole and withdrawing it when the arc is quenched. After the weld has cooled sufficiently, the slag coating is removed in preparation for welding the second half of the pipe joint.

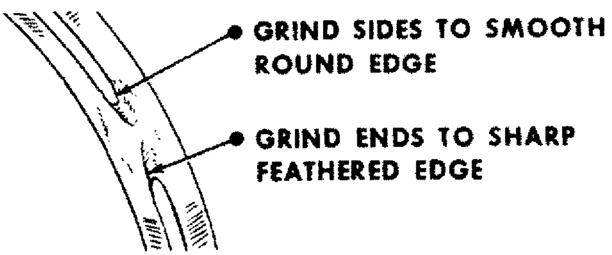
Welding the Second Half of the Pipe Joint. The procedures used for welding the second half of the pipe joint are identical to those used in welding the first half.

To start the second half of the pipe joint, a restart must be made in the 6:30 position against the starting point of the first root bead. It is advisable to restart with a new electrode so that a continuous bead can be deposited, if possible, until a tie-in is made to the tack weld in the vicinity of the 8 o'clock position. Then, after making a restart at the other end of the tack, the weld is made around the pipe, stopping when necessary to replace the electrode and to make the tie-in with the remaining tack weld, until the final tie-in is made at the 12 o'clock position to close the weld. The procedure for making a good tie-in, which must be mastered, is given in the next section.

The Tie-In Procedure

The process of joining a bead, in this case the root bead, is called a tie-in. The previous weld may be a tack weld or it may be the first half of the root bead. In either case, the two welds must be brought together smoothly and without discontinuities.

Making a tie-in requires extra care in welding. It is easier to make a good tie-in if the edges of the existing weld are ground to a feather edge, as shown in Fig. 5-11. This is done with a hand grinder, using a thin grinding wheel. When the ends of the existing bead are ground to a thin edge, the metal in the bead will heat up more rapidly than



Courtesy of the Hobart Brothers Co.

Fig. 5-11. Edges of a tack weld ground to a feather edge in preparation for making a tie-in.

in the case of an unground edge, where there is a relatively large bulk of metal.

Sometimes facilities are not available for grinding the edges of the existing bead, and the tie-in must be made to an underground edge, which is a more difficult job. Since this situation does occur, the beginner should first practice making the tie-in to an unground edge. Having mastered this technique, he will have no difficulty in making a tie-in to a feathered edge.

Sometimes the tie-in must be made on approaching the keyhole, while at other times it must be made by approaching the opposite, heavy end, of the bead. These conditions are shown in Fig. 5-12. Two different welding techniques must be used in these cases.

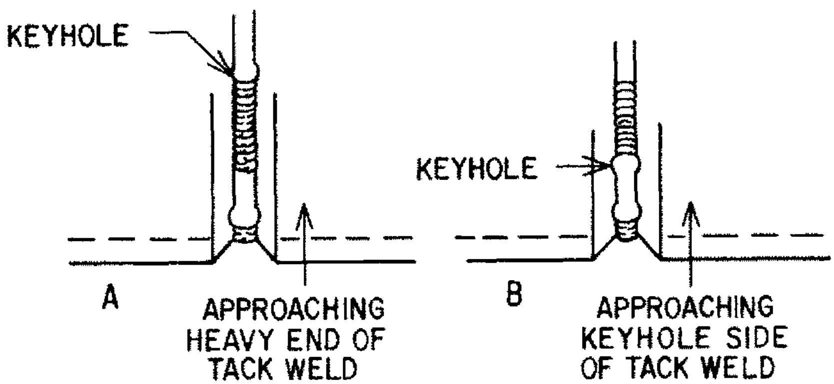


Fig. 5-12. A. Tie-in being made to heavy end of bead; B. Tie-in being made to keyhole end of bead.

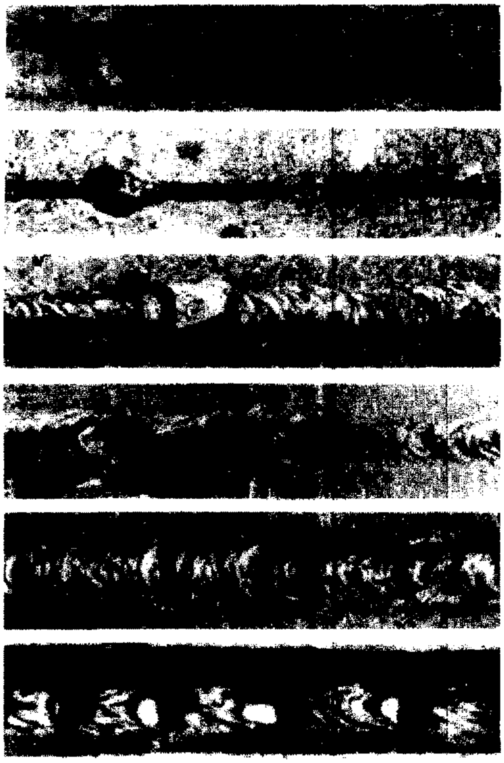
When the root bead approaches the keyhole, maintain the same speed of welding used to deposit the bead. Weld toward the previous weld at this speed and then gradually close the keyhole. As the keyhole is beginning to close up, watch the liquid puddle. When the liquid puddle appears to have joined the previous weld in a smooth pattern, withdraw the electrode by simultaneously reversing the electrode beyond the point of the tie-in and lengthening the arc somewhat; then break the arc with a sudden movement.

Sometimes the keyhole will become enlarged as the arc approaches the point of the tie-in. In this event, the whipping technique is used to cool the metal and to avoid excessive penetration at the tie-in. If necessary, there should be no hesitancy in using the whipping technique; however, the welder must be sure that there is penetration to the bottom of the root face at the tie-in. A perfect tie-in is shown in Fig. 5-13.

WELD QUALITY INSPECTION

A GOOD WELD

COMMON WELDING MISTAKES



POOR APPEARANCE

1. Welding current too high
2. Faulty joint preparation
3. Lack of arc control

INSUFFICIENT PENETRATION

1. Welding current too low
2. Travel speed too fast
3. Root opening too narrow

EXCESSIVE PENETRATION

1. Root opening too wide
2. Welding current too high
3. Travel speed too slow

BAD TIE-IN

1. Current too low
2. Wrong electrode angle
3. Wrong starting technique

SUCK-IN

1. Welding current too high
2. Travel speed too slow
3. Root opening too wide

BURN-THROUGH

1. Welding current very high
2. Travel speed too slow
3. Root opening too wide

Courtesy of the Hobart Brothers Co.

Fig. 5-14. Weld quality inspection showing good weld and common welding defects.

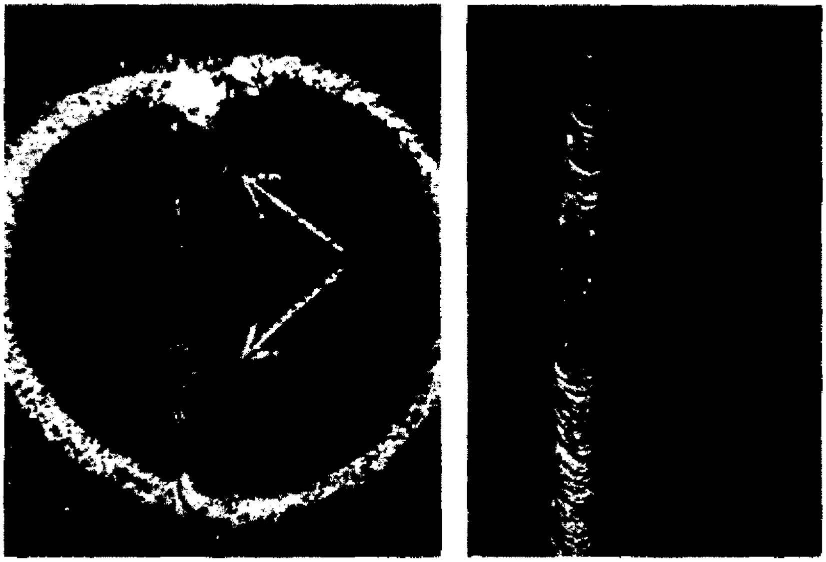


Fig. 5-13. (Left) A perfect tie-in to the keyhole end: A. Tie-in; B. Restart. (Right) A perfect tie-in to the heavy end.

When the tie-in is made at the heavy edge of the weld, the speed of welding should be decreased somewhat, a short distance (approximately ⅜ inch) away from the edge of the previous weld. This is done to allow time for the thick edge to heat up. If the arc is too short and the welding speed is too fast when approaching the tie-in, insufficient penetration will result. The welding speed should be slow and the arc length normal, until the puddle joins the thick edge of the previous weld. When the puddle is tied-in smoothly with the previous weld, the electrode is moved slightly in the reverse direction while at the same time lengthening the arc slightly; the arc is then broken with a quick movement.

Inspect the Weld

After the entire root bead has been completed, it should be thoroughly inspected for visible welding defects. Figure 5-14 illustrates such defects, which are discussed in detail in Chapter 11. Any major defect should be removed before the second bead is deposited. A portable grinder equipped with a thin edge composition grinding wheel can be used to remove the defect.

If it is necessary to remove a large section or a deeply penetrating section of the root bead to correct a defect, this part of the bead must be rewelded before the second bead is deposited. However, if the correct welding technique described in these pages has been used with skill and care, very few or no defects should appear on the weld. The welding techniques described so far have been proved to result in a successful pipe weld by countless applications in the field.

Poor Fit-up, Wide Root Opening. With careful workmanship it should be possible to obtain a good fit-up at all times in preparation for welding pipes together. A good fit-up is not uncommon in pipe welding. However, poor fit-up cannot be ignored because, on occasion, welding must be done under these circumstances. Frequent causes of poor fit-up are manual flame cutting of the bevel by inexperienced operators, or mistakes in measurements.

One condition encountered as the result of poor edge preparation is a wide root opening. Wide root openings are difficult to weld and in such cases a decision must be made whether to attempt the weld or to replace the entire length of pipe. Replacing the entire pipe can be very expensive and sometimes cannot be afforded. Usually this decision depends on the type of job. For example, a poor fit-up job would be unacceptable in a chemical or an atomic plant.

If the root opening is too wide, the first step is to join the pipes together with tack welds. If the tack welds must be made with the pipes in the horizontal, or 5G, position, they should be welded in the 12, 3, 6, and 9 o'clock positions around the pipe. If the root openings are normal, the tack welds are made in the 2, 5, 8, and 11 o'clock positions. When tack welds are made in the 6 o'clock position, the root bead is started against a tack weld, contrary to the usual procedure.

In starting the tack weld it is first necessary to build a bridge of weld metal across the wide gap at the root. This is done by welding a number of small nuggets of weld metal on the root faces until finally

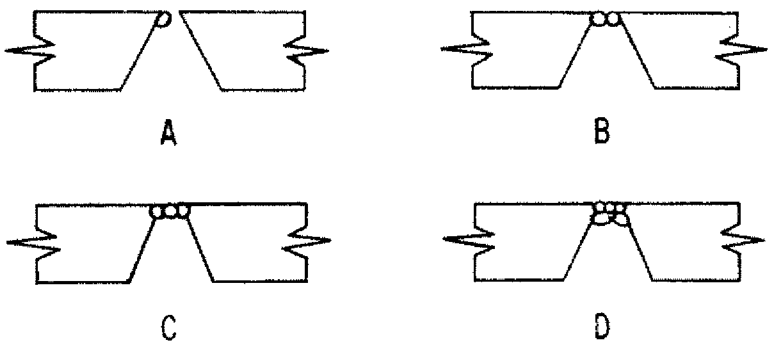


Fig. 5-15. Bridging a wide root opening by depositing a series of nuggets.

one of the nuggets joins the two faces together. This procedure is shown in Fig. 5-15.

The welding current should be reduced slightly to weld the nuggets. After the arc is struck it is held just long enough to become stabilized and then it is shortened. A small nugget of weld metal is deposited on the root face after which the arc is quenched. It need not be fused perfectly, the principal objective being to deposit a small lump of metal. The same procedure is then used to deposit a small nugget of metal on the opposite root face. After cleaning each nugget, the same procedure is used to deposit one nugget on top of another until the bridge is built.

The purpose of the bridge is to form a metallic path across the wide root opening that can be used to maintain the arc when starting to weld the bead. These nuggets are imperfectly fused. Because the gaseous shield may not have formed completely, they are likely to be porous and lumpy. For this reason they must be removed after a strong bead of perfectly welded metal has been deposited. Often this is done by grinding after the first half of the weld has been made around the pipe joint. The entire bridge and about ½ inch of additional metal along the bead should be removed with a grinding wheel or with a hammer and a chisel.

After the bridge has been built across the root opening, the remainder of the tack weld can be deposited. A slightly reduced current setting should be used in this case. As usual, the bridge should be cleaned before striking the arc. The arc is struck in the joint ahead of the bridge and a long arc is held until the arc is stabilized and the gaseous shield has formed. It is then brought over the bridge and shortened. The arc length should be slightly shorter than normal. It is moved slowly across the bridge once or twice until some liquid metal appears; the weld bead can then be deposited.

The weld bead is deposited by using a U-weave, as shown in Fig. 5-16. It is necessary to use this weave in order to bridge the wide root opening. Because the root opening is already wide, a full keyhole may not form; however, the edges of the root face must be melted at the edges of the weld zone.

One danger encountered in welding across a wide root opening is excessive penetration resulting from overheating. For this reason the arc length should be somewhat shorter than normal and the current setting should be somewhat lower than normal.

In making the U-weave, Fig. 5-16, the electrode should be manipulated to bring the arc all the way out of the molten puddle. The arc should be moved along the face of the bevel and kept away from the edges of the bevel. The molten pool of metal should be allowed to

Courtesy of the Hobart Brothers Co.
Fig. 5-16. Welder's view of the correct procedure for making a U-weave.

solidify completely before the arc is returned to the weld zone. This requires the use of a long U-weave. Then, where the arc is returned to the weld zone, remelting of the solidified metal takes place to form a somewhat smaller and less fluid pool of liquid metal. When the filler metal from the electrode is deposited in this puddle, the molten metal will not overflow the root opening.

If a slight amount of overheating does occur, the electrode angle should be increased. If this does not prevent overheating, it may be necessary to discontinue the arc at short intervals to allow the weld to cool before welding is again resumed. This is indeed a slow process which calls for patience and smooth electrode movement. When the tack weld is about ¾ inch long, the arc is quenched in the usual manner.

When welding a wide root opening, the root bead is started at the 6 o'clock position, against the end of the tack weld. The arc is struck on the tack weld and a long arc is maintained over the end of the tack weld in order to preheat this area. As soon as some molten metal appears at the edges of the tack, the arc is shortened and welding is commenced.

The root bead is welded as described above, using a short arc and a long U-weave. Care must be exercised to avoid overheating and excessive penetration. The U-weave is used to weld entirely around the joint. Before welding the second half of the pipe joint, the bridge used to start the weld and about ½ inch of the tack weld must be removed.

Poor Fit-up; Narrow Root Opening. The pipe welder will encounter situations where the root opening is smaller than the recommended size; sometimes the root may be closed entirely. This situation may be corrected by recutting the edge of the pipe with an oxyacetylene cutting torch or by grinding the edge with a hand grinder.

Often, however, the joint is simply welded together without making any alteration to the root opening. To do this, the same techniques for welding a normal size root opening are used with only slight modifications.

When the root opening is too small or nonexistent, the welding current flow must be increased, usually by as much as 10 to 20 amps. The heavier current flow increases the penetration of the weld. Also, it is usually best to decrease the arc length when welding. Sometimes a near "drag" arc length can be used.

The welder must give close attention to the amount of penetration obtained while welding the narrow root opening. If the penetration is too deep or overpenetration occurs, a slight whipping motion may avoid this condition. Increasing the speed of welding may also be helpful. If these measures do not succeed in correcting the overpenetration, the current setting must be reduced. Underpenetration can be corrected by increasing the welding current and by using a somewhat slower welding speed.

When confronted with a narrow root opening, it is always good practice to make some test welds on pieces of scrap metal first. The plates should be beveled and set apart a distance equal to the narrow root opening. In this way the current setting and the welding procedure can be adjusted before welding the pipe; and defective welds, which must later be removed, can be avoided on the pipe.

Poor Fit-up; Wide and Narrow Root Openings. Sometimes a combination of narrow and wide root openings is encountered in a pipe joint. This can be the result of the ends of the pipe being cut incorrectly or of the pipes being misaligned — that is, oriented at a slight angle to each other.

Welding a combination narrow and wide root opening requires the application of both of the methods previously described. The method used obviously depends upon the root opening encountered.

It is usually necessary to adjust the welding current setting several times when welding around the pipe.

First of all, of course, the four tack welds should be welded in place. To prevent restraint cracking, the first tack welds should be made in the region of the narrow root openings. For the same reason and because it is less difficult to obtain a start, it is desirable to weld the narrow root opening first, when welding the root bead. This is not always possible, however, because the basic method of welding the pipe from the bottom toward the top should not be abandoned. For this reason it may be necessary to start the root bead in a region having a wide root opening.

Poor Fit-up; Root Face Too Wide. When the root face is too wide, it may be possible to correct this condition by recutting the end of the pipe. Normally, however, the pipes are welded together in the usual manner, using a higher current setting to obtain complete penetration.

Poor Fit-up; Root Face Too Thin. In this case the edge, at the root, will melt very rapidly while the rest of the weld is relatively cold. The method of overcoming this difficulty is to reduce the current flow and to use a U-weave for depositing the bead. By reducing the current setting less heat is generated by the arc and the possibility of burning through the thin edges is diminished. The U-weave preheats the bevel ahead of the edge, thereby insuring that the weld deposit will fuse properly with the parent metal. As before, when using the U-weave, it may be necessary to allow the puddle to become mushy before the arc is returned each time.

Welding the Root Bead with Low-Hydrogen Electrodes. Root beads are seldom welded with low-hydrogen electrodes because very highly skilled welders are required to make welds that are free from defects. High-pressure pipe joints are usually welded by welding the root bead with a deeply penetrating type electrode, such as E6010, or by the Gas Tungsten Arc-Weld process (GTAW, described in Chapter 6), and the remainder of the joint with a low-hydrogen electrode. However, with skill and care it is possible to weld root beads with low-hydrogen electrodes. The following instructions describe how this may be done.

As shown in Fig. 5-17, the diameter across the coating of the ⅛-inch E7018 low-hydrogen electrode is larger than that of the ⅛-inch E6010 electrode. The heavier coating of the E7018 electrode does not allow the arc to be taken close enough to the root face, thereby making it difficult to establish the correct arc length. Welding with an arc that is too long can cause suck-in (see Fig.

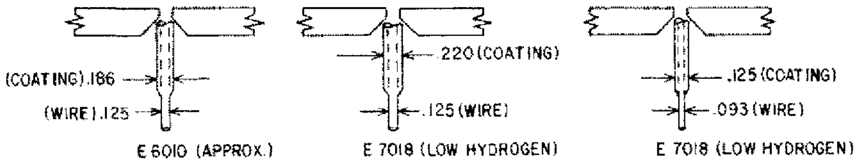


Fig. 5-17. A. Diameters across the coatings of .125 in. E6010 and E7018 low-hydrogen electrodes; B. Diameter across the coating of a .093 in. E7018 low-hydrogen electrode.

5-14). Furthermore, the heavier coating interferes with the manipulation of the electrode when making a weave. For this reason a smaller size (.093 inch) hydrogen electrode should be used to weld the root bead. It has a diameter across the coating that is approximately equal to that of the ⅛-inch E6010 electrode.

When welding with low-hydrogen electrodes, pinholes can be caused by incorrect arc striking, chipped flux coating, moisture in the weld joints, or wet electrodes. To avoid pinholes while striking the arc, strike just ahead of the starting point and shorten the arc as quickly as possible to the proper length. Then back-up the arc to the starting point and proceed to weld as soon as the molten pool of metal has formed. Chipped spots on the electrode coating will cause the arc to be erratic at that point, resulting in pinholes and a hard zone in the weld. For this reason electrode containers should be handled with care and damaged electrodes discarded. Wet joints should be heated with an oxyacetylene torch to drive off all moisture.

The electrode flux coating is sensitive to moisture and must be kept dry. Open containers should be stored in a "dry box" or controlled-humidity storage oven, where the electrodes are kept at a temperature of 300 to 400F. Electrodes that have been exposed to moisture can be reconditioned by drying for one hour at a temperature of 600 to 800F, the exact temperature depending on the make of the electrode.

A higher current setting is almost always used for welding with low-hydrogen electrodes and, therefore, more heat is liberated. The arc characteristic is also different. The low-hydrogen electrode produces an arc that is relatively smooth but lacks the penetrating power of the more lightly coated electrodes.

The heavy electrode coating will form a heavy blanket of slag over the liquid puddle of molten metal, which causes the cooling rate to be slower and the metal to remain liquid for a longer period. The viscosity of the molten slag and weld metal is lower; i.e., it will flow more readily than a liquid having a higher viscosity. The combined effect of the slower cooling rate and the lower viscosity of the liquid will cause the molten puddle to drip readily. For this reason, difficulty is experienced when welding in the overhead and vertical positions with low-hydrogen electrodes.

The general procedure for welding the root bead with low-hydrogen electrodes is the same as before. Tack welds are made around the pipe, after which both sides of the joint are welded from the bottom to the top of the pipe. The welding technique, however, is different.

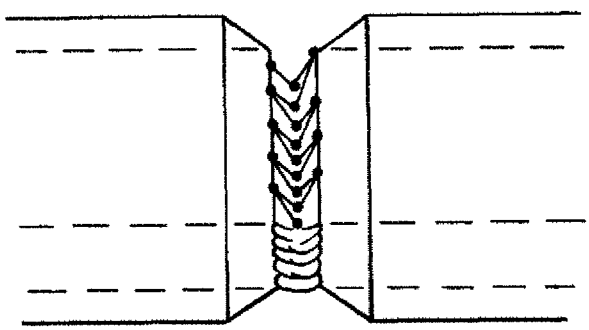
A very short arc should be used at all times when welding with low-hydrogen electrodes. The electrode must be kept very close to the root face in order to obtain adequate penetration. When the arc is struck, it should be shortened immediately, as explained before. The whipping procedure should never be used when welding with low-hydrogen electrodes.

A V-shaped weave, Fig. 5-18, must be used for welding the root bead entirely around the pipe when using the low-hydrogen electrode. The objective of this weave is to allow the molten slag and metal in the puddle to cool and to lose some of its fluidity (or to increase its viscosity) in order to prevent dripping. Using this weave also preheats the metal ahead of the weld.

The weave should be made by smooth and precise movements of the wrist. The arc should be brought out of the puddle and up along the bevel with a quick movement. Allowing just enough time for the puddle to lose some of its fluidity by slowing down the return movement, the arc is returned to the puddle and held there for a short pause. This movement is then repeated up and along the other bevel.

The liquid metal must never be allowed to solidify during the weave. Some of the slag may also solidify and, if this occurs along

Fig. 5-18. Welding the root bead with a low-hydrogen electrode using a V-weave.



the edges of the weld, it may be difficult to dissolve the heavy slag entirely — resulting in a lack of fusion. If the puddle is always kept liquid, the slag will seldom be trapped because it has a lower melting point than the weld metal. Since the arc is smooth and lacks deep penetrating power, the movements must be smooth and precise to avoid solidification of the puddle.

Summary of Root Bead Welding

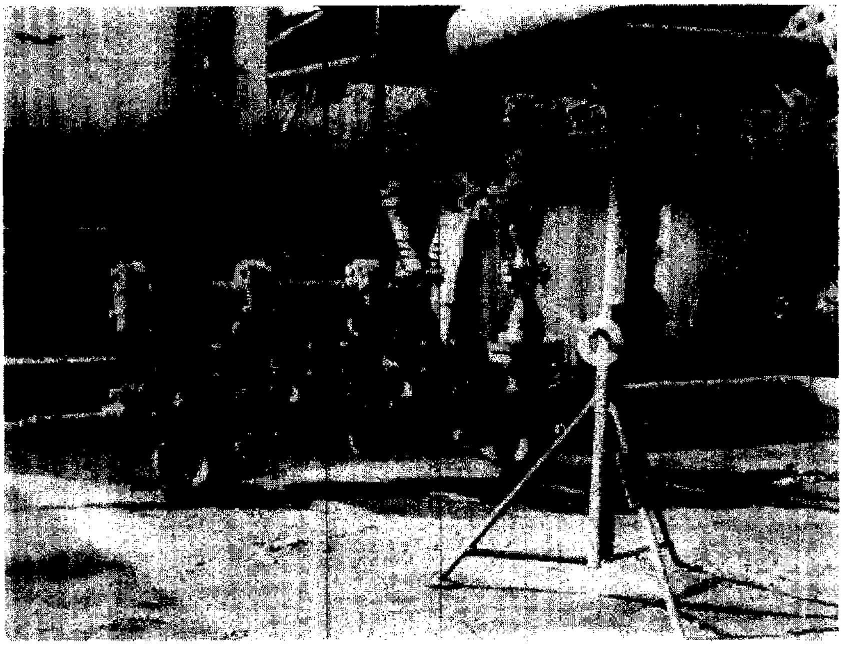
A perfect root bead should be free from undercuts, porosity, incomplete fusion, insufficient penetration, and excessive penetration (see Fig. 5-14). All of these defects can be avoided by learning and practicing the correct welding procedures.

It should be kept in mind that these defects are the responsibility of the welder. Porosity cannot be blamed on the equipment, but rather on not cleaning the weld sufficiently when grease, oil, and rust are present prior to welding. Other causes of porosity are defective electrode coatings such as chipped coatings, flaking of the coating, and coatings containing an excessive amount of moisture. All of these electrode defects can be detected by the welder before he strikes the arc.

Proper root opening and edge penetration help to attain complete penetration. The composition of the weld metal is also affected by the edge preparation. When the spacing and the edge preparation are correct, the welder will be able to manipulate the electrode comfortably so that there will be a better intermixing of the base metal and the filler metal.

Restraint cracking occurs when small welds are made on thick metal sections, such as heavy-wall pipe. This subject is discussed at length in Chapter 13. Suffice to say here that the size of the root bead must be large enough to withstand the shrinkage stresses without cracking. This calls for careful attention to the condition of the joint before welding.

The presence of hydrogen in the weld or in the base metal heat-affected zone becomes dangerous if the microstructure in both of these areas becomes martensite, with hardness exceeding 30 Rockwell. The danger increases as the carbon content increases. The base metal heat-affected zone needs particularly close attention to prevent cold cracking. Hydrogen alone cannot be blamed for under bead cracking; other contributing variables in the immediate vicinity of the weld area must be considered as well. The following welding procedures can also con-



Manifold - Welds been x-ray-(Perfect) and hydrostaticly tested OK for receuvubg station. (crude oil)

tribute to cold cracking: 1) reaction stress from restraint of the base member; 2) residual stress from the unequal stress caused by contraction of the base metal and weld metal; 3) the development of short range stress due to the transformation; and 4) structure stress resulting from the austenite-to-martensite transformation. This transformation is influenced by the alloying elements, especially the carbon content in respect to higher stress levels; it is likely to increase further from the melting of the base metal and inducement of filler metal into the weld. The use of premium electrodes carrying the prefix LC (Low Carbon) is strongly recommended.

Multiaxial stress develops in those alloys with limited toughness and ductility. There are limited options for accommodating this high stress. If hydrogen is present in such a weld, then very little energy will be needed to promote cracking. Hydrogen in a weld of hardenable steel is a powerful promoter of cracking.

Carbon steel generally contains less than 0.30 percent carbon. When joined alloy steel containing 0.10 percent carbon will usually call for countermeasures against the influence of hydrogen. Even the addition of manganese to a level of about 1.25 percent in a carbon steel that contains 0.30 percent carbon might need precautions against hydrogen when welding heavy sections.

It is not difficult to decide when countermeasures are needed against hydrogen if consideration is given to the principle of anticipated microstructure, as discussed earlier. The reasoning for such apprehension is clear. Such steel in heavy sections with tend to form martensite in the heat-effective zone, unless welding was conducted with controlled heat input to secure a relatively slow cooling rate.

Welding procedure are not just for information, but must be implemented. The specifics cannot be ignored during welding of an alloy material, nor can the welder fail to follow these written instruction. For example, if preheating and the interpass temperature are ignored, the metal experiences a cooling rate that would likely lead to a martensite structure with poor ductility and toughness. Steel has a tendency to develop a higher level of hardness with an increasing cooling rate. Therefore, it can be difficult to determine if a service failure is due to defective welding or simply weld induced brittleness.

It is important to control cracking in medium or higher carbon steel, and in steel which incorporates any alloying element to achieve qualities such as strength and hardness, corrosion resistance, impact resistance and toughness, and toughness at sub-zero temperature. Sometimes adding a single alloying element will work; in other cases multiple elements are more effective. For instance, it is uncommon to find iron without carbon as a strengthening additive. Carbon is more powerful and effective than any other element when added in small quantities. Its effectiveness increases as it is increased for tensile strength and hardness.

Carbon, as an alloying element, is soluble in high-temperature iron to an appreciable extent, but is soluble in the low-temperature form only to a limited extent. With the addition of alloy to a point where its high temperature crystalline form exists and the alloying element enters the lattices to form a solid solution. Upon cooling the alloy to the point where the crystalline transformation occurs, the alloying element suddenly experiences the full effects of limited solution (solid), and precipitation takes place. This results in embrittlement and reduced ductility in the HAZ.

The cooling rate must be regulated to produce a fine dispersion of precipitation throughout the metal so that it has high ductility and a fine grain structure. Otherwise, the structural condition will result in a marked decrease in ductility. Transformation hardening is the principal mechanism used to increase the hardness and tensile strength of carbon and alloy steel. Tensile strength moves to higher levels when the carbon and manganese content increase. In the alloy steels, moderate addition of carbon also increase these mechanical properties, but reduces ductility and toughness.

Depending upon the welding process employed, the conditions under which steel hardens to its martensite structure varies. Also, residual stress, reaction stress, and hydrogen can cause delayed cracking during extended service, particularly in large heavy weldments. Alloying steel along with steel making practices in recent years has led to improvements in terms of toughness. This is especially true when welding high strength, low alloy material and medium-high alloys. A minute fissure or void in such a weld can or will be accepted, depending on the, the joint design, and the severity and variation of load carrying capacity.

In recent years, toughness has received much more attention within the microstructure and the heat affected zone, along with the fusion line. Molten alloy exhibits much more of the stronger carbide forming elements; it has a slower dissolving rate from its higher temperatures, and higher preheating, requirements, approximately to 450° F. Caution may be necessary to control grain growth by carefully preheating and the use of temp sticks to indicate when the appropriate preheat has been reached. The success in welding carbon and alloy steel is determined by the familiarity with the microstructural characteristics of each particular type of steel, and avoiding the development of an unsuitable structure (low toughness) in or adjacent to the weld joint. In merging the chemical composition of carbon steel with low and high alloy, the addition of an alloying element from a filler metal can improve a particular quality or may unexpectedly appear as a hindrance to improving toughness. Other important factors include the microstructural changes involving the transformation of austenite, ferrite, and martensite. Grain size, cooling rate, residual elements, and multiple alloy may also bring about synergistic effects, though little is yet known about such synergy. Preheating and postheating can also help attain the required level of toughness while avoiding cracking and other metallurgical difficulties.

Emphasis must be given to the type of the base metal (chemical composition) to be welded, steel making practices, wall thickness, joint design, and, in most cases, the work function of such a welded component. In addition, the welding engineer and metallurgist need to determine the effects of microstructures of a weld based on a hydrogen free weld, or how to maintain a hydrogen-free condition. Preheating, interpass temperature, and post weld heat treatment are very important. Even considering which electrode to use for a weld is important to the welding engineer in terms of dilution, pick-up, and recovery. The welding engineer must consider all these facts and write an operation sheet which adequately reflects the above concerns. A qualified welder can prevent defects such as porosity, slag inclusion, incomplete fusion, excessive penetration, incomplete penetration, undercutting, root bead cracking during welding, and distortion caused by shrinkage. Of all of these, cracking seem to be the most unwanted defect. Defects in the heat affected zone can be caused by the lack of adherence to proper procedure in terms of preheating and interpass temperatures.

CHAPTER 6

Welding the Root Bead by the Gas Tungsten Arc Welding Process (GTAW)

In the literature of welding the Gas Tungsten Arc Welding process is usually shortened to GTAW. It is also sometimes called TIG (Tungsten Inert Gas) welding.

When root beads of exceptional quality must be made, the GTAW process is very frequently used. Entire welds are seldom made by this process except in situations where unusually stringent requirements must be met, such as in the case of space vehicles.

Usually, only the root bead is welded by the GTAW process. However, sometimes the second pass is also made by this process because GTAW welded root beads tend to be somewhat thin. Stainless steel and high-alloy steel pipes, as well as mild steel pipes, are welded by the GTAW process, especially for high-pressure pipe joints that require high-quality welds.

The outstanding features of the GTAW process are:

1. Welds of exceptional quality can be made in almost all metals used by industry
2. Practically no post-weld cleaning is required
3. The arc and the pool of molten metal are readily visible by the welder
4. No filler metal is transported across the arc stream; thus there is no spatter
5. Welding is possible in all positions
6. There is no slag which might be trapped in the weld.

When weld deposits made by the Shielded Metal-Arc (Consumable Electrode process) and the GTAW processes are compared, the GTAW deposit is cleaner because there is no slag deposit, incidentally eliminating any chance of weld defects caused by slag inclusions. Moreover, the outside surface of the weld (Fig. 6-1 left), and, on root beads, the inside surface as well, are very smooth as shown in Fig. 6-1 (right). This eliminates the necessity for deslagging, grinding, or chipping after the root bead has been completed. The

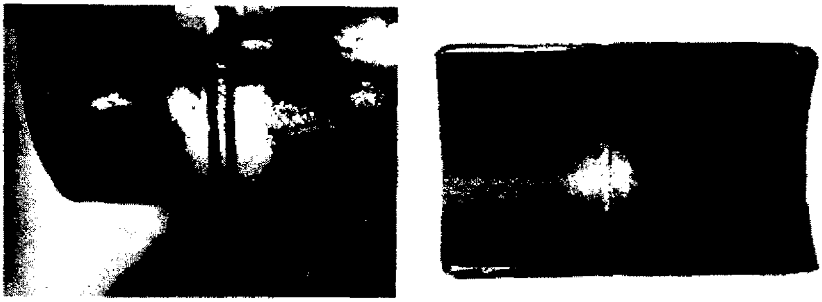


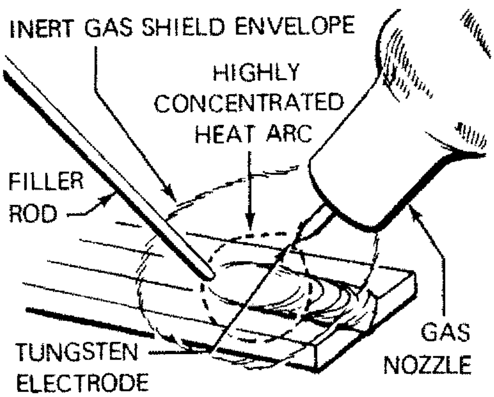
Fig. 6-1. (Left) Outside of a root bead welded by the GTAW process; (Right) Inside surface of the same root bead.

inside smoothness of the weld significantly reduces turbulence in any flowing substance inside of the piping system. In many cases this is a very important factor, such as in nuclear power plant piping systems.

A root bead made by the GTAW process is metallurgically sound throughout. By choosing the correct rod to deposit the filler metal, it is possible to obtain a weld having the same chemical, metallurgical, and physical properties as the base metal in the pipe. Defects such as oxidation are eliminated because the blanket of inert gas covers the weld and whipping is not used to deposit the bead.

The GTAW Process

Gas tungsten arc welding is a process whereby the base metal and the filler metal are melted by the intense heat of an arc that is maintained between the work and a non-melting tungsten electrode. An inert gas, or mixture of inert gases, is used to shield the hot metal



Courtesy of the Hobart Brothers Co.

Fig. 6-2. Elements of the Gas Tungsten Arc Welding process (GTAW).

from the effects of the atmosphere. Filler metal, supplied by a rod, is used to supplement the base metal except when welding very thin sheets of metal, for which no filler metal is used.

This process is shown in Fig. 6-2. The tungsten electrode is held within a welding torch, which also supplies the inert gas that is expelled from the end of the gas nozzle at a rate of 15 to 30 cubic feet per hour to form a shield over the hot metal. Right-handed welders hold the GTAW welding torch in the right hand while the rod that supplies the filler metal is held in the left hand. For left-handed welders these positions are usually reversed. In either case, both hands are used for GTAW welding.

Equipment

The major components of the GTAW process are:

1. The welding machine
2. The shielding gas and the gas controls
3. The GTAW welding torch
4. The tungsten electrode.

Welding Machine. The welding machines used for the GTAW process are specially designed for this purpose. Those welding machines designed for consumable arc welding, either AC or DC, can also be used if they are equipped with a special high-frequency attachment; however, the best welds are obtained by using machines designed specifically for the GTAW process.

GTAW machines are available in the form of AC/DC rectifiers or as DC generators driven by an electric motor or an engine. Either straight or reversed polarity can be used with direct current. High-frequency current is used only for starting the welding arc when using DC current; it is always used with AC current. The welding current is turned on by a foot or a hand control.

The current characteristic used depends upon the type of metal to be welded. Specific recommendations are given in Table 6-1.

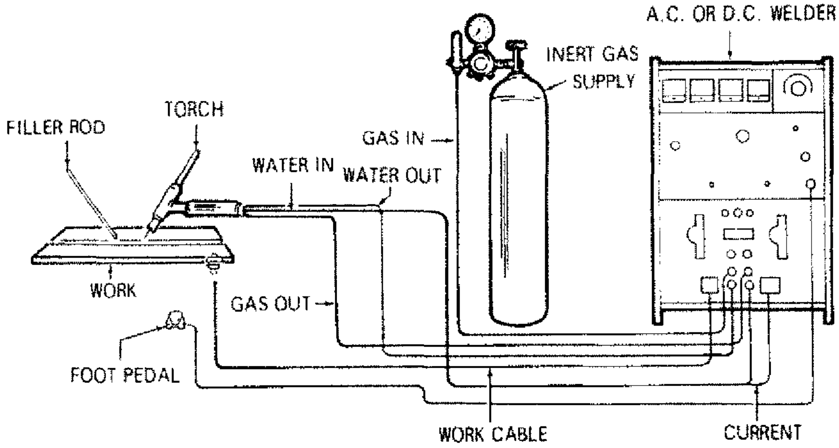
The Shielding Gas. To prevent oxygen and nitrogen in the air from contaminating the weld, either argon or helium, or a mixture of both, is used as a shielding gas. Argon is more widely used since it is easier to obtain and because it is a heavier gas, thus providing better protection, or shielding, at a lower flow rate. A gas flow of 15 to 30 cubic feet per hour (CFH) is normally used.

The gas is stored in a cylinder, Fig. 6-3, and control of its flow is similar to that used to control the flow of oxygen by a gas gage.

Table 6-1. Gas Tungsten Arc Welding (GTAW) Selection Chart

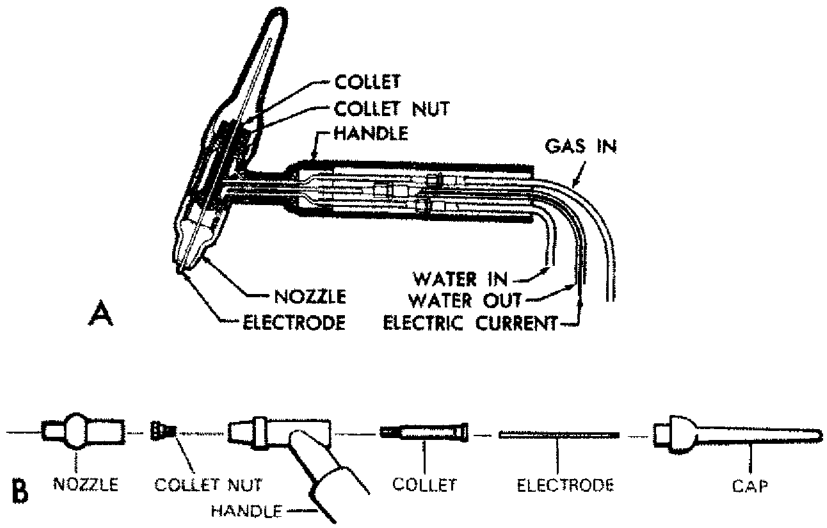
Material	Welding Procedure	Welding Current††	Shielding Gas	Tungsten Electrode
ALUMINUM (sheets, plates, castings)	Sheets, plates, castings	A.C.H.F. medium penetration	Argon or argon and helium — argon and helium for deeper penetration and faster travel	Pure or Zirconium Zirconium — X-ray quality welds
	Thick material only	D.C.S.P. deep penetration	Argon or argon and helium — argon and helium preferred	Thoriated —*
	Thin material only	D.C.R.P. shallow penetration	Argon	Zirconium or Thoriated —**
CARBON STEEL (sheets and plates)	Sheets and plates	D.C.S.P. deep penetration	Argon or argon and helium — argon and helium for extra deep penetration on heavy plate	Thoriated —*
	Thin sheets only (Do not tightly jig)	A.C.H.F. medium penetration	Argon	Pure or Zirconium Zirconium — longer lasting
COPPER† (sheets and plates)	Sheets and plates	D.C.S.P. deep penetration	Argon or argon and helium — argon and helium preferred for heavy material	Thoriated —*
	Very thin material only	A.C.H.F. medium penetration	Argon	Pure or Zirconium Zirconium — longer lasting
COPPER ALLOYS	Material thicker than 0.050	D.C.S.P. deep penetration	Argon or argon and helium — argon and helium preferred for heavy material except beryllium copper	Thoriated —*
	Material thinner than 0.050 Beryllium copper all thicknesses	A.C.H.F. medium penetration	Argon	Pure or Zirconium Zirconium — longer lasting
MAGNESIUM (sheets, plates, castings)	Sheets, plates, castings	A.C.H.F. medium penetration	Argon	Pure or Zirconium Zirconium — X-ray quality welds
	Thin sheets only	D.C.R.P. shallow penetration	Argon	Zirconium or Thoriated —**
NICKEL MONEL INCONEL	All thicknesses	D.C.S.P. deep penetration	Argon	Thoriated —*
STAINLESS STEEL (sheets, plates, castings)	Sheets, plates, castings	D.C.S.P. deep penetration	Argon or argon and helium — argon and helium for extra deep penetration on thick material	Thoriated —*
	Thin sheets only	A.C.H.F. medium penetration	Argon	Pure or Zirconium Zirconium — longer lasting
TITANIUM	All thicknesses	D.C.S.P. deep penetration	Argon	Thoriated —*

*Grind end to point or near point. **Use with balled end. Slowly increase welding current until ball forms. †Use brazing flux on 1/4" or thicker.
††A.C.H.F. — Alternating current — high frequency; D.C.R.P. — Direct current — reversed polarity; D.C.S.P. — Direct current — straight polarity.



Courtesy of the Hobart Brothers Co.

Fig. 6-3. Major equipment components for GTAW welding.



Courtesy of the Hobart Brothers Co.

Fig. 6-4. A. The GTAW welding torch. B. Components of the GTAW welding torch.

Beyond this gage, the gas to the torch and the weld is controlled either by a switch mounted on the torch or by a foot pedal. When the gas leaves the tank it is fed through an electrical control valve that is actuated by the switch which allows the gas to flow only when the welding current is turned on. The gas can be made to flow continuously by means of manual control but this can be very costly.

GTAW Torch. The GTAW torch, Fig. 6-4A, holds the tungsten electrode and directs the welding current to the arc. Torches can be water-cooled or air-cooled, depending on the welding current amperage. For root bead welding, which is normally deposited using a current range of 75 to 200 amps, water-cooling is not required.

The parts of a torch are shown in Fig. 6-4B. A nozzle surrounds the electrode, which is held in place by a collet chuck. Different collets, ranging in size from .020 to .250 inch, are available to accommodate the same range of electrode diameters. To insert an electrode, the cap is removed and the correct-size collet is inserted in the torch. Insert the electrode in the torch and push it about ½ inch beyond the end of the nozzle, using the wrench furnished for this purpose to adjust the collet. Attach the cap to the torch and tighten it lightly. Then adjust the electrode so that it extends beyond the nozzle the correct distance, which is usually about 1½ to 2 times the electrode diameter, and finger tighten the cap. The torch is then ready to be used.

Two different types of nozzles are available. One type is made of ceramic, which is not transparent. Another is of glass, which offers better visibility of the pool of molten metal when welding.

Electrodes. The electrodes used with the GTAW process are made from tungsten alloys. They have a very high melting point (6900F) and are practically non-consumable. When properly positioned, the electrode is located over the puddle and the intense heat of the arc keeps the puddle liquid. The electrode, which must be kept clean at all times, must never touch the molten metal to avoid the possibility of contaminating its tip with metal from the puddle. Should it become contaminated, the electrode must be removed from the torch and the contaminant removed either by grinding or by breaking off the end of the electrode to remove the contaminated portion.

There are three types of electrodes:

1. Pure tungsten
2. 1 or 2 percent thoriated tungsten
3. Zirconiated tungsten.

Recommendations for the applications of the types of electrodes are provided in Table 6-1. Thoriated tungsten electrodes are used for most pipe welding applications, including mild steel pipe.

The shape of the electrode tip has a marked influence on the contour, penetration, and width of the face of the weld deposit. It is especially important to shape the electrode tip correctly, similar to a sharpened pencil, when it is to be used to weld a root bead on a pipe joint.

The working end, or tip, of the electrode is shaped by grinding it with a very fine grinding wheel that should be used only for this purpose. A fine-grained wheel should be used in order to obtain a very smooth surface finish on the tip of the electrode, which is helpful in maintaining a more stabilized arc. For this purpose, a 60 grain, O to M grade silicon carbide grinding wheel should be used, such as a C-60-M-V wheel. If the electrode becomes contaminated with metal, it should be reground immediately.

Exact specifications for the shape of the electrode tip are given in Fig. 6-5. The included angle of the point should be about 22 to 23 degrees, or the length should be ground back to a distance equal to about 2½ electrode diameters. It is important to blunt the tip slightly by grinding it flat at the end for a distance slightly less than 1/64 inch from the point.

Shielding the Weld Metal. In all welding processes, the very hot metal in the region of the puddle is protected by some kind of shielding. A gas formed by heating the coating of the electrode protects the top of the weld in the shielded metal-arc process. In addition, the molten metal is protected by a coating of liquid slag that rises to the surface. On open butt joints, this coating protects the top of the weld and some of the slag flows through the liquid metal to the bottom of the joint where it also protects the exposed surface.

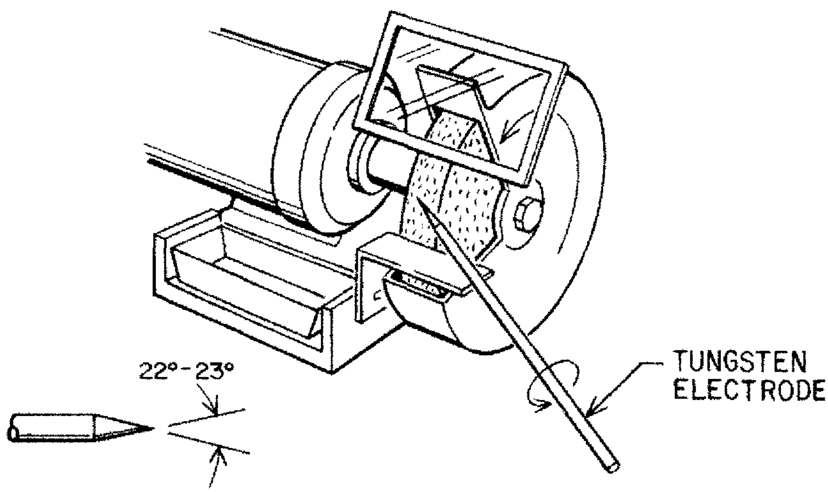


Fig. 6-5. Grinding the thoriated tungsten electrode tip for root bead welding. Point angle specification is shown as 22° to 23°.

Actually, there is some uncertainty about the amount of protection provided to the exposed surface at the bottom of the joint. However, when welding mild steel pipe with the Consumable Electrode Method, this presents no real problem.

Mild steel pipe can also be welded by the GTAW process without special precautions. A sufficient quantity of the inert gas reaches the bottom of the joint to provide adequate protection and the top of the weld is covered with a heavy blanket of inert gas. Highly alloyed steel pipe, however, when welded with the GTAW process, will require extra protection at the bottom of the joint. This is done by filling the inside of the pipes, in the region of the pipe joint, with an inert gas.

Several methods are used for containing the inert gas in the pipes; two of these are shown in Fig. 6-6. Two "pistons" having rubber seals are inserted on each side of the pipe joint (see Fig. 6-6A). The pipe joint itself is taped shut to prevent the inert gas, which is blown into the pipe at a very low pressure, from escaping. A small portion of the joint is left open to allow the air to escape. When welding, the sealing tape around the pipe is removed in sections just ahead of the weld, and additional inert gas is blown inside of the pipe to make up for the gas lost through this opening. This method can be used when welding short lengths of pipe; however, it is somewhat awkward to use on longer pipe lengths and on larger-diameter pipes.

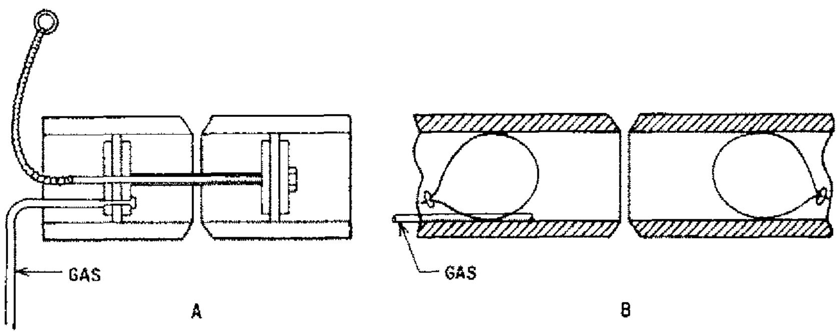


Fig. 6-6. Methods of containing the inert gas shield inside a pipe. A. Two pistons used for short, smaller-diameter pipes. B. Plastic gas bags used in conjunction with longer pipe lengths.

In field conditions, where the pipe diameters and lengths are frequently large, the joint can be sealed by inflating two plastic balloons in the pipe, as shown in Fig. 6-6B. They must be positioned far enough from the weld joint so that the heat from the weld will not burst them. The location of the balloons must also be marked on the outside of the pipe, for when the root bead is finished, just sufficient heat is applied by an oxyacetylene torch at these markings to burst the balloons. The joint itself is sealed with tape, as before, and the inert gas is blown into the pipe through a rubber hose or a length of small-diameter pipe or tubing. Another method of sealing the inside of the pipe is to tape a wall of polystyrene to the inside of the pipe. The advantage of these two sealing methods is that the materials used to make the seal can be blown out by compressed air or a stream of water after the pipe joint is finished.

Preparation of the Weld Joint. The procedure for preparing the weld joint is the same as for preparing the joint when welding by the Shielded Metal-Arc process. The principal difference is in the dimensions of the joint. The width of the root face is reduced to 1/16 inch and the root opening is narrowed to 1/16 to 3/32 inch, as shown in Fig. 6-7.

The pipe joint should be carefully fitted together to obtain an accurate alignment and the correct width of root opening. If alloy steel pipes are being welded, an inert gas should be blown into the inside of the pipe as described in the previous section. Highly alloyed

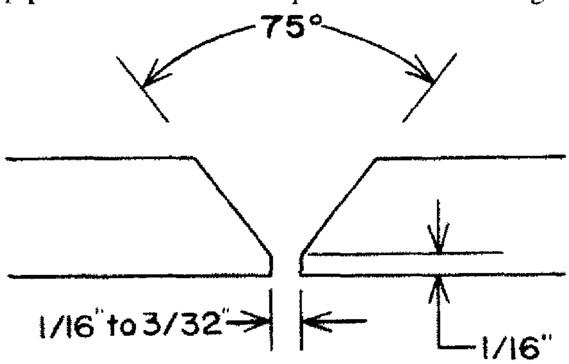


Fig. 6-7. Weld joint specification for GTAW welding of the root bead.

steel pipes should be preheated at the pipe joint from 200 to 300F prior to welding the tack welds and the remainder of the root bead.

When all of the preparations have been made, four evenly spaced tack welds are made around the pipe joints. Since these welds will become a part of the root bead, they must be made with the same care and craftsmanship as the remainder of the root bead.

Procedure for Welding the Root Bead. Even before the tack welds are made, the GTAW welding torch must be adjusted and the welding machine must be set to provide the correct current amperage and gas flow.

To weld 8 in., Schedule 60, mild steel pipe nipples, a $^3/_{32}$-inch diameter thoriated tungsten electrode and a $^1/_8$-inch diameter mild steel filler rod are used. The electrode should be ground to a point with a fine grinding wheel. In order to hold the electrode, a $^3/_{32}$-inch collet is placed in the welding torch, after which the electrode can be inserted.

For welding a root bead, the electrode must be positioned in the torch so that it will extend the correct distance beyond the end of the nozzle. This is done by placing the torch in an upright position with the nozzle resting on the bevel of the weld joint, as shown in Fig. 6-8. While this is being done, the welding current should, of course, be shut off. The electrode is then adjusted so that it is positioned

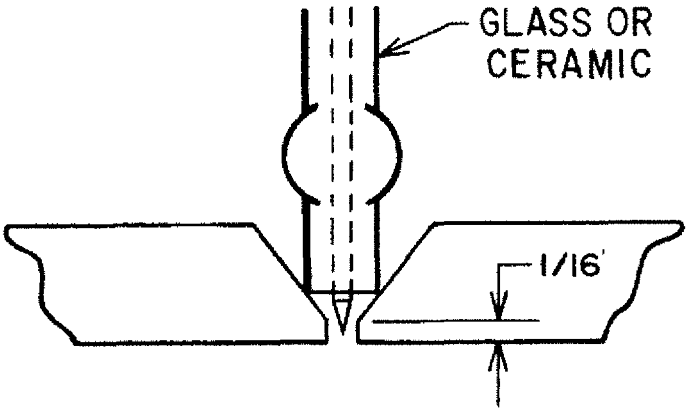


Fig. 6-8. Position of GTAW torch and tungsten electrode when adjusting the electrode for root bead welding.

with the end almost flush with the bottom of the joint or the inside surfaces of the pipe.

Reference to Table 6-1 shows that the welding current characteristic should be direct current, straight polarity (DCSP), when welding mild carbon steel pipe. Table 6-2 provides the range of the welding current amperage to be used. Because of the many variables encountered, it is not possible to give a more precise recommendation. In this case, using a $^3/_{32}$-inch electrode and a direct current, straight polarity current characteristic, the welding current flow should be 150 to 225 amps. The gas supply should be adjusted to provide a flow rate of about 20 cubic feet per hour.

When the pipe is in the 5G position, the tack welds should be made in the 8:30, 4:30, 1:30, and 11:30 positions. The regular root bead is started in the 6 o'clock position and the weld is made by uphill welding around one side of the pipe to the 12 o'clock position.

Then the other half of the pipe is welded, starting again at the 6 o'clock position and welding uphill.

There is no difference in the welding procedure used, whether welding in the 5G or the 2G positions. For this reason, the procedure that is recommended in the following paragraphs can be used in either position. In both cases (5G or 2G positions), the root bead should not be started against a tack weld. It is somewhat difficult to start a weld in the 6 o'clock position because of the stance that the welder must take; however, the procedure that is used to start the weld will be the same, regardless of the position of the weld.

The arc should not be struck in a manner similar to the procedure used for Shielded Metal-Arc Welding with consumable electrodes as this procedure would seriously damage the tungsten electrode.

To start the weld, the current and the inert gas supply to the welding torch must be shut off. The GTAW welding torch is held in the right hand (if left-handed, in the left hand) and the filler rod is

Table 6-2. Current Range Chart for GTAW Welding

Electrode Diameter (Inches)	Current (amperes)			
	A.C.H.F. Alternating Current with High Frequency		D.C.S.P. Direct Current, Straight Polarity (electrode neg.)	D.C.R.P. Direct Current, Reverse Polarity (electrode pos.)
	Pure Tungsten*	†Thoriated or Zirconium**	†Thoriated	†Thoriated or Zirconium**
.020	. . .	. . .	5 to 35	. . .
.040	10 to 40	15 to 60	30 to 100	. . .
1/16	30 to 70	60 to 100	70 to 150	10 to 20
3/32	70 to 100	100 to 160	150 to 225	15 to 30
1/8	100 to 150	140 to 220	200 to 275	25 to 40
5/32	150 to 225	200 to 275	250 to 350	40 to 55
3/16	200 to 300	250 to 400	300 to 500	55 to 90
1/4	275 to 400	300 to 500	400 to 650	80 to 125

*Pure tungsten — green tip
**Zirconium — brown tip
†Thoriated tungsten — 2% red tip, 1% yellow tip

held in the other hand. The torch is brought into position for welding by carefully placing the nozzle against the two beveled surfaces of the weld joint, which acts like a V-block to locate the electrode in the weld groove. In order to position the electrode in the center of the joint opening, the side angle of the electrode and the welding torch must be at zero degrees; i.e., the electrode must be perpendicular to the pipes in this direction.

However, the electrode angle must be steep, as shown in Fig. 6-9A and B. As shown, the welding torch to start with, should be positioned to hold the electrode at an angle of approximately 55

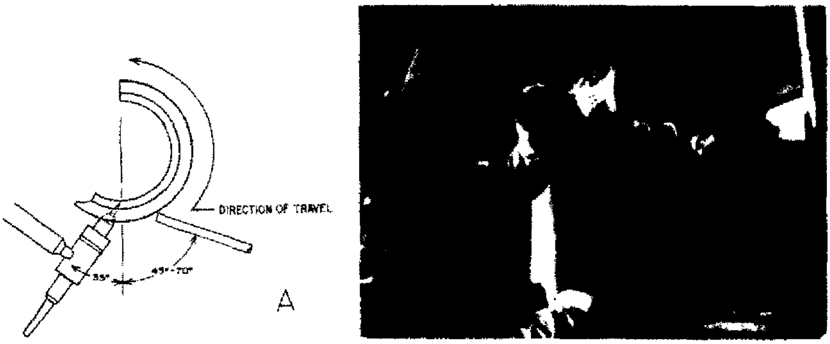


Fig. 6-9. A. Electrode angle and filler rod angle in preparation for root bead welding. The welding current is off when the electrode is in this position. B. Welder ready to start a bead.

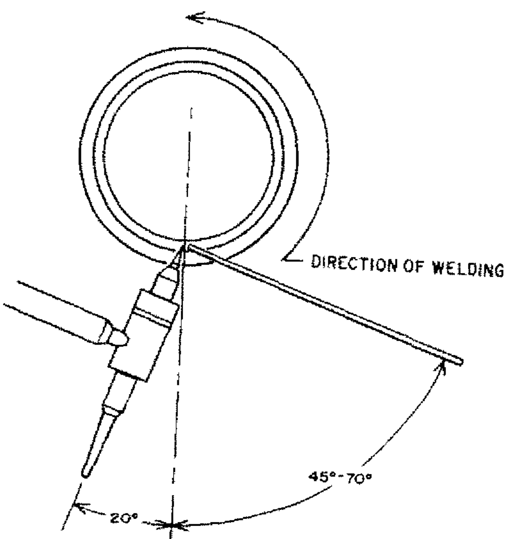


Fig. 6-10. Correct angles of the tungsten electrode and the electrode when welding.

degrees. At the same time, the filler rod should be positioned close to the weld in preparation for insertion in the weld after the arc is established and the molten pool of metal has formed. It should not be positioned in the arc area when the arc is first established; however, the welder should position the filler rod so that he can dip it into the molten puddle without any disturbing body movements that might affect the smooth manipulation of the electrode. When welding, the filler rod should be held at an angle that is between 45 and 70 degrees, as shown in Fig. 6-9A and Fig. 6-10.

With the welding torch and the filler rod held in the starting positions, the welder must then close his face mask and switch on the welding current using the foot switch or the switch on the welding torch. Slowly and carefully he will straighten the welding torch thereby reducing the electrode angle and bringing the tip of the electrode into the groove. In doing this the welding torch is pivoted around the end of the nozzle, which is held in position on the bevels of the weld joint.

While the welding torch is pivoted, the arc will be formed and become established. As shown in Fig. 6-10, the welding torch is pivoted until the electrode angle has reached 20 degrees, the correct angle for welding. The filler rod is held at an angle of 45 to 70 degrees. As the welding current is started, it also causes the flow of the inert gas to start to form a protective shield over the weld area.

After the arc has been established, the welding torch is held in place until a puddle of molten metal has appeared between the two edges of the pipe. After the puddle is established, the filler rod is dipped into the molten metal. The welder then begins to oscillate the welding torch from side to side, as shown in Fig. 6-11, allowing the arc to travel slightly beyond the edges of the pipe.

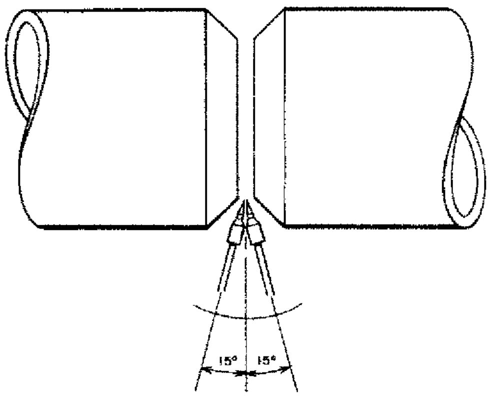


Fig. 6-11. Electrode oscillating procedure for welding the root bead with a GTAW torch.

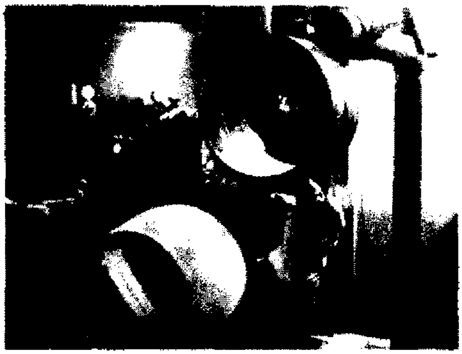
 

Fig. 6-12. Welding a root bead. (Left) Welder in welding position; (Right) Welder's view.

Welding a root bead is shown in Fig. 6-12. When the puddle has been built up to the required size by the addition of filler metal, the welding torch is then moved on by slowly and steadily gliding it over the bevel while at the same time the torch is oscillated from side to side. Filler is added continuously to the molten puddle from the end of the rod which is held in the puddle.

While welding, the welder must watch the puddle at all times to see that it is built up to a uniform height and forms a smooth bead with only traces of a ripple. As with most welding processes when welding pipe in the 5G position, there is some tendency for the puddle to drip, causing excessive penetration. When this occurs, corrective action should be taken by slightly increasing the speed of travel and the speed of the oscillating movement. If possible, more filler metal than usual should be added to the puddle which tends to chill the puddle and to reduce its size.

The welder must be careful at all times to prevent the electrode from making contact with the sides of the joint and the molten puddle. This would not only contaminate the end of the electrode but cause the arc to become unsteady. Should this occur, the weld should be stopped and the tip of the electrode reground before restarting the weld.

One problem that is occasionally encountered is that the nozzle will tend to stick or grab as it is lightly dragged over the bevel during welding. The end of the nozzle gets very hot, a factor which promotes its sticking to the heated bevel. As shown in Fig. 6-13A, the edge of the nozzle is square, and sticking can be avoided by grinding a radius on the edge of the nozzle as shown in Fig. 6-13B.

Stop and Restart. The weld should never be stopped unnecessarily. However, there are occasions when it must be stopped, such as when welding a tack weld or when the 12 o'clock position is reached. The weld must also be stopped and restarted when making a tie-in with a tack weld which will be discussed in the next section.

To stop the weld, the welding current is simply switched off. If the filler rod is to be replaced or if the weld bead is finished, the filler rod should be withdrawn beforehand. However, if the bead is to be continued, the filler rod is left in the puddle to solidify against the end of the bead.

The procedure for restarting the weld against a layer of weld metal is similar to the starting procedure previously described. With the welding current off, the welding torch is positioned on the bevel

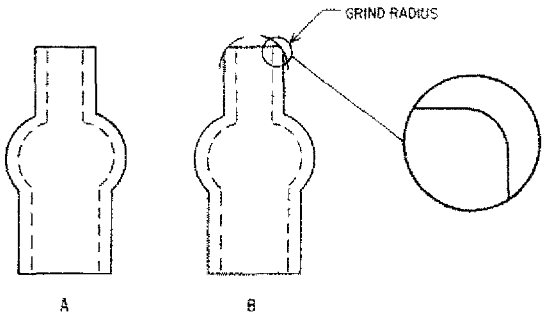


Fig. 6-13. A. Standard nozzle with square edge; B. Nozzle edge rounded to facilitate dragging the GTAW torch when welding a root bead.

Fig. 6-14. A perfect tie-in on a root bead, deposited by the GTAW welding process.

adjacent to the weld bead. This time, when positioning the welding torch, it should be held at the angle used for welding; i.e., the electrode angle should be about 20 degrees. The position of the electrode is carefully adjusted so that it does not quite touch the weld bead. The welding torch is then rotated about the nozzle until the electrode angle is about 55 degrees, as was shown in Fig. 6-9. After the filler rod is in position, the welding current is switched on and the welding torch is slowly rotated to the 20-degree position in preparation for welding, with care being taken not to allow the electrode to touch either the bead or the sides of the joint. When the arc has been stabilized and a sufficient quantity of molten metal has appeared, the filler rod is placed in the puddle and the electrode is oscillated, as before, and the weld is continued.

Making a Tie-in. When the weld approaches another bead, the normal GTAW welding procedure is continued until the weld is approximately $1/16$ inch from the bead. At this point the filler rod is withdrawn, but the welding torch is slowly moved on; it is tilted as necessary to prevent the electrode from coming in contact with the weld metal. The welder must watch the filling up of the gap between the beads. When a smooth blend between the beads has been obtained the current is switched off. A perfect tie-in, such as that shown in Fig. 6-14, will result if this procedure is followed with care and attention.

Second Pass. When a second pass with the GTAW torch must be made, the procedure is the same as that used in welding the root bead. However, it is necessary to readjust the position of the electrode in the GTAW welding torch. The length that the electrode protrudes from the end of the nozzle must be shortened so that it will not come in contact with the root bead or the molten pool of metal. The end of the electrode is ground to a blunted point, as before.

While welding, the electrode and the filler rod are held at the same angles as before. The welding torch is advanced by slowly and uniformly gliding and oscillating the welding torch with the end of the nozzle resting in the V-shaped groove of the weld joint. By welding slowly and carefully, the second layer will be deposited uniformly and with only a trace of a ripple.

Root Bead—Pulse Current—Gas Tungsten Arc Welding

Gas tungsten arc welding has been used to great advantage in all kinds of pipe welding applications. Besides affording the welder excellent visibility due to the lack of smoke and spatter, there is no porosity due to slag entrapment, and the deposits are essentially hydrogen free. The GTAW process is particularly useful, due to more precise heat control, in welding thin wall pipe and in many cases heavy wall pipe may have it's first root pass done with GTAW while subsequent fill and cap passes are completed with conventional stick welding. In such cases where root penetration must be as smooth as possible, a consumable insert is placed between the mating pipe edges and fused into the bottom of the root opening.

However as pipe welding is most often done in various "out of position" situations, the GTAW process needed even more precise heat control to avoid weld pool sagging and burn through. The 1960's saw the introduction of "pulsed current " welding control in which both high and low values of current could be preset on the power supply. During the "high" portion of the pulse cycle, actual fusion would take place. Then as the torch moves away, the current automatically switches to a lower value allowing the puddle to partially solidify before the next high current pulse begins. The length of time for each pulse is also adjustable making possible optimum welding conditions over a wide variety of pipe welding applications.

The pulse current mode is shown in Fig 6-15.

Pulse control offers a number of advantages over the inconsistencies that are experienced during the time the root bead is deposited. These advantages of using pulse current-gas tungsten arc welding include:

(a) control over puddle size and fluidity
(b) ability to increase and maintain adequate penetration
(c) ability to maintain uniformity of weld deposit
(d) ability to preset the pulse mode to any condition, as needed by the welder.
(e) ability to position the torch in its rightful position before the high pulse is activated

Comparing shielded metal arc welding with pulse arc welding for depositing the root bead on thinwall pipe, the latter shows absolute

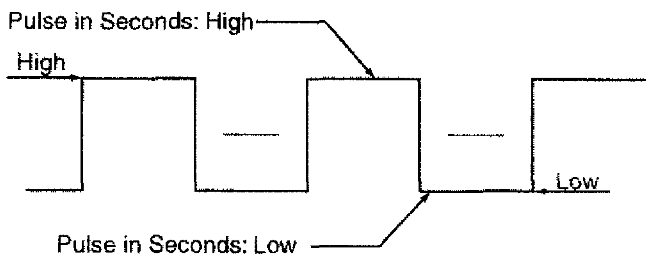


Figure 6-15

control of the puddle size, prevention of excessive penetration, complete protection from oxidation, and a clean inner surface of the root bead. Therefore, pulse arc welding is often preferable for welding pipe of both medium alloy and high alloy steel. Pulse arc welding is a useful innovation for thinwall pipe, including when thinwall pipe needs two passes to be completed.

Before using pulse arc welding for heavywall pipe, the welder must be fully acquainted with the appropriate variables. Heavywall pipe offers an excellent heatsink. The size of the tungsten electrode must be considered. If a slight oscillation will be used while depositing the root bead, it is important to know where the tungsten tip will be located and when the current mode changes to low. The tip should be placed so that welding occurs under a blanket of inert gas; the hot weld will then be protected from oxidation. The position of the tungsten tip should be one sixteenth of an inch on the weld, where there is a chance of only a slight fissure or tiny void. It is from that position that the welder should begin when the high pulse is enacted.

The filler metal should be placed between the root opening where the tip of the rod is in contact with the apex of the groove. The rod must not be allowed too close to the starting point. When the high pulse is initiated, the rod should be inserted, making contact where the rod touches the root bead.

Because the thickness of the pipe makes an excellent heatsink, the high pulse mode duration should be four times that of the low mode. When the low mode is inactive, the tungsten-tip should be raised one sixteenth of an inch. It should then be advanced forward when the high mode is enacted, with a slight oscillation to remove cumulative grains that may have form during the cooling pattern, and to assure that the tie-in to the root is properly fused. The slight backstep becomes necessary because the heat-sink, which is so effective, can cause a shrinkage crack. This depends on the frequency of changes between the modes. The high mode should be enacted while the cooling weld is still in a semi-solid state.

The power source design for pulse current welding calls for adjusting both the high mode current and low current pulse based on time duration. Adjusting both depends on wall thickness, preheating, fix or roll position, and the rootface thickness.

The internal surface of the pipe edges to be welded should be clean of oxide (rust) and other impurities.

Table 6

Prequalified Base Metal—Filler Metal Combinations for Matching Strength[8] (see 3.3)

Group	Steel Specification Requirements						Filler Metal Requirements				
			Minimum Yield Point/Strength		Tensile Range			Minimum Yield Point/Strength		Tensile Strength Range	
	Steel Specification[1,2]		ksi	MPa	ksi	MPa	Electrode Specification[3,6]	ksi	MPa	ksi	MPa
	ASTM A36[4]		36	250	58–80	400–550					
	ASTM A53	Grade B	35	240	60 min	415 min					
	ASTM A106	Grade B	35	240	60 min	415 min	SMAW				
	ASTM A131	Grades A, B, CS, D, DS, E	34	235	58–71	400–490	AWS A5.1 or A5.5[7]				
	ASTM A139	Grade B	35	241	60 min	414 min	E60XX	50	345	62 min	425
	ASTM A381	Grade Y35	35	240	60 min	415 min	E70XX	60	415	72 min	495
	ASTM A500	Grade A	33	228	45 min	310 min	E70XX-X	57	390	70 min	480
		Grade B	42	290	58 min	400 min					
	ASTM A501		36	250	58 min	400 min	SAW				
	ASTM A516	Grade 55	30	205	55–75	380–515	AWS A5.17 or A5.23[7]				
		Grade 60	32	220	60–80	415–550	F6XX-EXXX	48	330	60–80	415–550
	ASTM A524	Grade I	35	240	60–85	415–586	F7XX-EXXX or	58	400	70–95	485–660
		Grade II	30	205	55–80	380–550	F7XX-EXX-XX				
I	ASTM A529		42	290	60–85	415–585					
	ASTM A570	Grade 30	30	205	49 min	340 min	GMAW				
		Grade 33	33	230	52 min	360 min	AWS A5.18				
		Grade 36	36	250	53 min	365 min	ER70S-X	60	415	72 min	495
		Grade 40	40	275	55 min	380 min					
		Grade 45	45	310	60 min	415 min					
		Grade 50	50	345	65 min	450 min					
	ASTM A573	Grade 65	35	240	65–77	450–530	FCAW				
		Grade 58	32	220	58–71	400–490	AWS A5.20				
	ASTM A709	Grade 36[4]	36	250	58–80	400–550	E6XT-X	50	345	62 min	425
	API 5L	Grade B	35	240	60	415	E7XT-X	60	415	72 min	495
		Grade X42	42	290	60	415	(Except -2, -3, -10, -GS)				
	ABS	Grades A, B, D, CS, DS			58–71	400–490	AWS A5.29[7]				
		Grade E[5]			58–71	400–490	E7XTX-XX	58	400	70–90	490–620

(continued)

Table 6 continued

Group	Steel Specification[1, 2]		Steel: Minimum Yield Point/Strength ksi	Steel: Minimum Yield Point/Strength MPa	Steel: Tensile Range ksi	Steel: Tensile Range MPa	Electrode Specification[3, 6]	Filler: Minimum Yield Point/Strength ksi	Filler: Minimum Yield Point/Strength MPa	Filler: Tensile Strength Range ksi	Filler: Tensile Strength Range MPa
	ASTM A131	Grades AH32, DH32, EH32	46	315	68–85	470–585	SMAW				
		Grades AH36, DH36, EH36	51	350	71–90	490–620	AWS A5.1 or A5.5[7]				
	ASTM A441		40–50	275–345	60–70	415–485	E7015, E7016	60	415	72 min	495
	ASTM A516	Grade 65	35	240	65–85	450–585	E7018, E7028				
		Grade 70	38	260	70–90	485–620	E7015-X, E7016-X	57	390	70 min	480
	ASTM A537	Class 1	45–50	310–345	65–90	450–620	E7018-X				
	ASTM A572	Grade 42	42	290	60 min	415 min					
	ASTM A572	Grade 50	50	345	65 min	450 min					
	ASTM A588[5]	(4 in. and under)	50	345	70 min	485 min	SAW				
	ASTM A595	Grade A	55	380	65 min	450 min	AWS A5.17 or A5.23[7]				
		Grades B and C	60	415	70 min	480 min	F7XX-EXXX or F7XX-EXX-XX	58	400	70–95	485–660
	ASTM A606[5]		45–50	310–340	65 min	450 min					
	ASTM A607	Grade 45	45	310	60 min	410 min	GMAW				
		Grade 50	50	345	65 min	450 min	AWS A5.18				
II		Grade 55	55	380	70 min	480 min	ER70S-X	60	415	72 min	495
	ASTM A618	Grades Ib, II, III	46–50	315–345	65 min	450 min					
	ASTM A633	Grade A	42	290	63–83	430–570					
		Grades C, D	50	345	70–90	485–620	FCAW				
		(2-1/2 in. and under)					AWS A5.20				
	ASTM A709	Grade 50	50	345	65 min	450 min	E7XT-X	60	415	72 min	495
		Grade 50W	50	345	70 min	485 min	(Except -2, -3, -10, -GS)				
	ASTM A710	Grade A, Class 2 > 2 in.	55	380	65 min	450 min	AWS A5.29[7]				
	ASTM A808	(2-1/2 in. and under)	42	290	60 min	415 min	E7XTX-X	58	400	70–90	490–620
	API 2H[6]	Grade 42	42	290	62–80	430–550					
		Grade 50	50	345	70 min	485 min					
	API 5L	Grade X52	52	360	66–72	455–495					
	ABS	Grades AH32, DH32, EH32	45.5	315	71–90	490–620					
		Grades AH36, DH36, EH36[5]	51	350	71–90	490–620					

(continued)

Table 6 continued

Group	Steel Specification Requirements							Filler Metal Requirements				
				Minimum Yield Point/Strength		Tensile Range			Minimum Yield Point/Strength		Tensile Strength Range	
	Steel Specification[1,2]			ksi	MPa	ksi	MPa	Electrode Specification[3,6]	ksi	MPa	ksi	MPa
								SMAW AWS A5.5[7]				
								E8015-X, E8016-X	67	460	80 min	550
								E8018-X				
								SAW				
	ASTM A572	Grade 60		60	415	75 min	515 min	AWS A5.23[7]				
III		Grade 65		65	450	80 min	550 min	F8XX-EXX-XX	68	470	80–100	550–690
	ASTM A537	Class 2[5]		46–60	315–415	80–100	550–690	GMAW				
	ASTM A633	Grade E[5]		55–60	380–415	75–100	515–690	AWS A5.28[7]				
	ASTM A710	Grade A, Class 2	≤ 2 in.	60–65	415–450	72 min	495 min	ER80S-X	68	470	80 min	550
	ASTM A710	Grade A, Class 3	> 2 in.	60–65	415–450	70 min	485 min	FCAW AWS A5.29[7]				
								E8XTX-X	68	470	80–100	550–690

Notes:

1. In joints involving base metals of different groups, either of the following filler metals may be used: (1) that which matches the higher strength base metal, or (2) that which matches the lower strength base metal and produces a low-hydrogen deposit. Preheating shall be in conformance with the requirements applicable to the higher strength group.
2. Match API standard 2B (fabricated tubes) according to steel used.
3. When welds are to be stress-relieved, the deposited weld metal shall not exceed 0.05 percent vanadium.
4. Only low-hydrogen electrodes shall be used when welding A36 or A709 Grade 36 steel more than 1 in. (25.4 mm) thick for cyclically loaded structures.
5. Special welding materials and WPS (e.g., E80XX-X low-alloy electrodes) may be required to match the notch toughness of base metal (for applications involving impact loading or low temperature), or for atmospheric corrosion and weathering characteristics (see 3.7.3).
6. The designation of ER70S-1B has been reclassified as ER80S-D2 in A5.28-79. Prequalified WPSs prepared prior to 1981 and specifying AWS A5.18, ER70S-1B, may now use AWS A5.28-79 ER80S-D2 when welding steels in Groups I and II.
7. Filler metals of alloy group B3, B3L, B4, B4L, B5, B5L, B6, B6L, B7, B7L, B8, B8L, or B9 in ANSI/AWS A5.5, A5.23, A5.28, or A5.29 are not prequalified for use in the as-welded condition.
8. See Tables 2.3 and 2.5 for allowable stress requirements for matching filler metal.

Chapter 6

Structural Steel Plates

Strength Group	Toughness Class	Specification & Grade	Yield Strength ksi	Yield Strength MPa	Tensile Strength ksi	Tensile Strength MPa
I	C	ASTM A36 (to 2 in. thick)	36	250	58–80	400–550
		ASTM A131 Grade A (to 1/2 in. thick)	34	235	58–71	440–490
		ASTM A131 Grades B, D	34	235	58–71	400–490
I	B	ASTM A573 Grade 65	35	240	65–77	450–550
		ASTM A709 Grade 36T2	36	250	58–80	400–550
I	A	ASTM A131 Grades CS, E	34	235	58–71	400–490
		ASTM A242 (to 1/2 in. thick)	50	345	70	480
II	C	ASTM A572 Grade 42 (to 2 in. thick)	42	290	60	415
		ASTM A572 Grade 50 (to 1/2 in thick)*	50	345	65	450
		ASTM A588 (4 in. and under)	50	345	70 min	485 min
		ASTM A709 Grades 50T2, 50T3	50	345	65	450
		ASTM A131 Grade AH32	45.5	315	68–85	470–585
II	B	ASTM A131 Grade AH36	51	350	71–90	490–620
		ASTM A808 (strength varies with thickness)	42–50	290–345	60–65	415–450
		ASTM A516 Grade 65	35	240	65–85	450–585
		API Spec 2H Grade 42	42	290	62–80	430–550
		Grade 50 (to 2-1/2 in. thick)	50	345	70–90	483–620
		(over 2-1/2 in. thick)	47	325	70–90	483–620
		API Spec 2W Grade 42 (to 1 in. thick)	42–67	290–462	62	427
		(over 1 in. thick)	42–62	290–427	62	427
		Grade 50 (to 1 in. thick)	50–75	345–517	65	448
		(over 1 in. thick)	50–70	345–483	65	448
		Grade 50T (to 1 in. thick)	50–80	345–522	70	483
		(over 1 in. thick)	50–75	345–517	70	483
		API Spec 2Y Grade 42 (to 1 in. thick)	42–67	290–462	62	427
II	A	(over 1 in. thick)	42–62	290–462	62	427
		Grade 50 (to 1 in. thick)	50–75	345–517	65	448
		(over 1 in. thick)	50–70	345–483	65	448
		Grade 50T (to 1 in. thick)	50–80	345–572	70	483
		(over 1 in. thick)	50–75	345–517	70	483
		ASTM A131 Grades DH32, EH32	45.5	315	68–85	470–585
		Grades DH36, EH36	51	350	71–90	490–620
		ASTM A537 Class I (to 2-1/2 in. thick)	50	345	70–90	485–620
		ASTM A633 Grade A	42	290	63–83	435–570
		Grades C, D	50	345	70–90	485–620
		ASTM A678 Grade A	50	345	70–90	485–620
III	C	ASTM A633 Grade E	60	415	80–100	550–690
		ASTM A537 Class II (to 2-1/2 in. thick)	60	415	80–100	550–690
		ASTM A678 Grade B	60	415	80–100	550–690
		API Spec 2W Grade 60 (to 1 in. thick)	60–90	414–621	75	517
		(over 1 in. thick)	60–85	414–586	75	517
		API Spec 2Y Grade 60 (to 1 in. thick)	60–90	414–621	75	517
III	A	(over 1 in. thick)	60–85	414–586	75	517
		ASTM A710 Grade A Class 3 (quenched and precipitation heat treated)				
		thru 2 in.	75	515	85	585
		2 in. to 4 in.	65	450	75	515
		over 4 in.	60	415	70	485
IV	C	ASTM A514 (over 2-1/2 in. thick)	90	620	110–130	760–890
		ASTM A517 (over 2-1/2 in. thick)	90	620	110–130	760–896
V	C	ASTM A514 (to 2-1/2 in. thick)	100	690	110–130	760–895
		ASTM A517 (to 2-1/2 in. thick)	100	690	110–130	760–895

*To 2 in. Thick for Type 1 or 2 Killed, Fine Grain Practice

Note: See list of Referenced Specifications for full titles of the above.

Structural Steel Pipe and Tubular Shapes

Group	Class	Specification & Grade	Yield Strength ksi	Yield Strength MPa	Tensile Strength ksi	Tensile Strength MPa
I	C	API Spec 5L Grade B*	35	240	60	415
		ASTM A53 Grade B	35	240	60	415
		ASTM 139 Grade B	35	240	60	415
		ASTM A500 Grade A (round)	33	230	45	310
		(shaped)	39	270	45	310
		ASTM A500 Grade B (round)	42	290	58	400
		(shaped	46	320	58	400
		ASTM A501 (round and shaped)	36	250	58	400
		API Spec 5L Grade X42 (2% max. cold expansion)	42	290	60	415
I	B	ASTM A106 Grade B (normalized)	35	240	60	415
		ASTM A524 Grade I (through 3/8 in. w.t.)	35	240	60	415
		Grade II (over 3/8 in. w.t.)	30	205	55–80	380–550
I	A	ASTM A333 Grade 6	35	240	60	415
		ASTM A334 Grade 6	35	240	60	415
II	C	API Spec 5L Grade X42 (2% max. cold expansion)	52	360	66	455
		ASTM A618	50	345	70	485
II	B	API Spec 5L Grade X52 with SR5, SR6, or SR8	52	360	66	455
III	C	ASTM A595 Grade A (tapered shapes)	55	380	65	450
		ASTM A595 Grades B and C (tapered shapes)	60	410	70	480

*Seamless or with longitudinal seam welds

Notes:
1. See list of Referenced Specifications for full titles of the above.
2. Structural pipe may also be fabricated in accordance with API Spec 2B, ASTM A139+, ASTM A252+, or ASTM A671 using grades of structural plate listed in Exhibit 1 except that hydrostatic testing may be omitted.

+ with longitudinal welds and circumferential butt welds.

Table C2.6
Structural Steel Shapes (see C2.42.2)

Group	Class	Specification & Grade	Yield Strength ksi	Yield Strength MPa	Tensile Strength ksi	Tensile Strength MPa
I	C	A36 (to 2 in. thick)	36	250	58–80	400-550
		A131 Grade A (to 1/2 in. thick)	34	235	58–80	400-550
I	B	A709 Grade 36T2	36	250	58–80	400-550
II	C	A572 Grade 42 (to 2 in. thick)	42	290	60	415
		A572 Grade 50 (to 1/2 in. thick)	50	345	65	450
		A588 (to 2 in. thick)	50	345	70	485
II	B	A709 Grades 50T2, 50T3	50	345	65	450
		A131 Grade AH32	46	320	68–85	470-585
		A131 Grade AH36	51	360	71–90	490-620

*To 2 in. Thick for Type 1 or 2 Killed, Fine Grain Practice

Note: This table is part of the commentary on toughness considerations for tubular structures (or composites of tubulars and other shapes for offshore platforms. It is not intended to imply that unlisted shapes are unsuitable for other applications.

Caution

Earlier the importance of maintaining the proper tungsten electrode tip to work distance was stated. Welders will often employ the technique of "walking" the cup along the sides of the groove in order to help maintain that critical electrode tip to work distance. There is however a danger of losing effective shielding gas coverage because of the tendency to lay the gas cup over so that it is more parallel to the joint rather than pointing down into the groove. This occurs due to the curve of the basic torch path as it circumnavigates the pipe and as the welder tries to extend his vision before finally stopping and repositioning the torch. The welder must realize just how critical inert gas shielding is to the soundness of the weld.

The inert gas or gasses which are conveyed through the gas cup, must be so directed that both areas, the molten pool and the area which is in the solidification stage be exposed to inert blanket of protective gases which is supplied through the gas cup. Therefore, the angle in which it is held should be able to provide ample back wash of inert gas to prevent oxidation and other reactions within the grain boundries.

From a welder's standpoint, the indication of these drawbacks will be the appearance of the bead surfaces, which may be is dark and dull. A weld which was fully protected from oxidation at high temperature is a weld with a sheen and show no unusual amount of discolloration.

The seriousness of oxidation as described here is based on the fact that temperature of the weld metal one hundred degrees below the critical range is weak, and with gains boundaries further apart as compaired to much lower temperatures. Without proper protection from the atmosphere, oxygen may be absorbed within the grainboundries and combining with other residual elements form compounds that will weaken the grain structure as temperature decreases, with construction taking place simultaneously, which leads to separation along grain boundaries.

CHAPTER 7

The Intermediate and Cover Passes

Multilayer welds are used to weld all thick-wall and most thin-wall pipes. The multilayer weld is more ductile and free from defects than a large single-layer weld would be. A multilayer weld is also easier to make because it is more difficult to control the large puddle of molten metal of a single-layer weld.

Since a large weld bead cools more slowly than a small bead, excessive grain growth occurs, which causes a decrease in the ductility of the weld. In the case of a weld consisting of normal-size beads, the ductility is improved because of the heat treating effect that each succeeding bead has upon the others. When a large bead cools slowly, the hot metal is exposed to the atmosphere longer causing oxides to form and this can lead to harmful effects.

This chapter is concerned with welding the intermediate and the cover passes on heavy-wall pipe. As before, each bead is started at the lowest part of the pipe and, welding uphill, the bead is welded to the top of the pipe. Since the joint is now closed by the root bead, a different welding technique is used. This is a slant weave, which is used at all positions around the pipe.

The Multiple Layers. The first layer, or bead, in a multiple-layer butt joint is the root bead. This is followed by one or more intermediate layers (also called filler layers). The final layer is called the cover pass. Each intermediate layer or bead is identified by the order in which it was welded, starting with the second pass.

As shown in Fig. 7-1, the number of beads or passes that are welded around the pipe joint depends upon the thickness of the pipe wall. Heavy beads should be avoided for reasons given earlier in this chapter. For this reason it is obvious that thick-wall pipes will require more beads than will thin-wall pipes.

The recommended placement of the various layers or beads across the section of the pipe wall is shown in Fig. 7-1. This illustration can be used as a guide when deciding how to place the beads.

Each bead must be firmly fused to the metal with which it is in contact, whether it is another bead or the base metal at the walls of the joint. In effect, the entire weld should be a solid body of metal, free from voids and other defects. The joint must possess strength

USING LOW-HYDROGEN ELECTRODES

Wall Thickness .250  Uphill 5G	1st Pass E6010 1/8" dia. 2nd and 3rd Passes 3/32" dia. Low-Hydrogen electrode	1. When X-ray quality weld is needed grind root bead. 2. Use proper restarting procedure (see page 85)
Wall Thickness .375 to .406  Uphill 5G	1st Pass E6010 1/8" dia. 2nd to 4th Passes Use 1/8" dia. Low-Hydrogen electrode	Grind or prepare the surface of the root bead as shown on page 79
Wall Thickness .250  Horizontal 2G	1st Pass E6010 1/8" dia. 2nd to 4th Passes use 3/32" or 1/8" Low-Hydrogen electrode	1. Use short arc and smooth movement with Low-Hydrogen electrodes 2. Avoid arc strikes on the surface of the pipe
Wall Thickness .375 to .406  Horizontal 2G	1st Pass E6010 1/8" dia. 2nd to 5th Passes use 1/8" or 5/32" dia. Low-Hydrogen electrode	1. Keep Low-Hydrogen electrode free from oil, grease, and moisture 2. Remove moisture from joint before welding

USING E6010 ELECTRODES

Wall Thickness .250  Uphill 5G	1st to 3rd passes use E6010 1/8" dia. electrode	Read information on cover pass on thin-wall pipe (see page 93).
Wall Thickness .375 to .406  Uphill 5G	1st Pass 1/8" dia. 2nd Pass 1/8" dia. 3rd and 4th Passes 1/8" or 5/32" dia. electrodes	1. Use proper arc length (see page 11). 2. Maintain smooth electrode manipulation. 3. Clean each layer of deposit properly.
Wall Thickness .250  Horizontal 2G	1st to 3rd passes 1/8" dia. electrode	1. See page 134 for weave pattern and electrode angle. 2. Clean each pass properly. 3. Avoid depositing cover pass when pipe is very hot.
Wall Thickness .375 to .406  Horizontal 2G	1st and 2nd passes 1/8" dia. electrode 3rd and 4th passes use 1/8" or 5/32" dia. electrodes	1. Study the information on page 150, "Why stringer beads are used." 2. Clean each layer properly. 3. Maintain proper arc length and speed.

Fig. 7-1. Recommended placement of weld layers on multiple-pass pipe joints using low-hydrogen and/or E6010 electrodes.

and ductility sufficient to withstand any load to which it might be subjected.

The intermediate beads should fill the joint and be flush with the outside surfaces of the pipes. This is a very important condition prior to welding the cover pass. It is very difficult to weld a good cover pass unless the metal over which it is welded is flush with the outer surfaces of the pipes. The cover pass should be slightly crowned and the sides should blend smoothly into each pipe without undercut.

Preparation of the Root Bead. A root bead that is perfectly formed internally can be very rough on the outside, as shown in Fig. 7-2A and B. Depending on the skill and care used by the welder, it may have humps and undercuts, especially where restarts occur. To clean and to prepare a surface such as that shown in Fig. 7-2 requires more than simple chipping and wire brushing.

The root bead should be prepared by grinding out all of the undercuts, rough spots, and humps to avoid the risk of having an invisible defect after the second pass is finished. Visible defects can be corrected, but this is costly.

Under ordinary circumstances, root bead grinding can be somewhat overemphasized and removing an unnecessary amount of weld

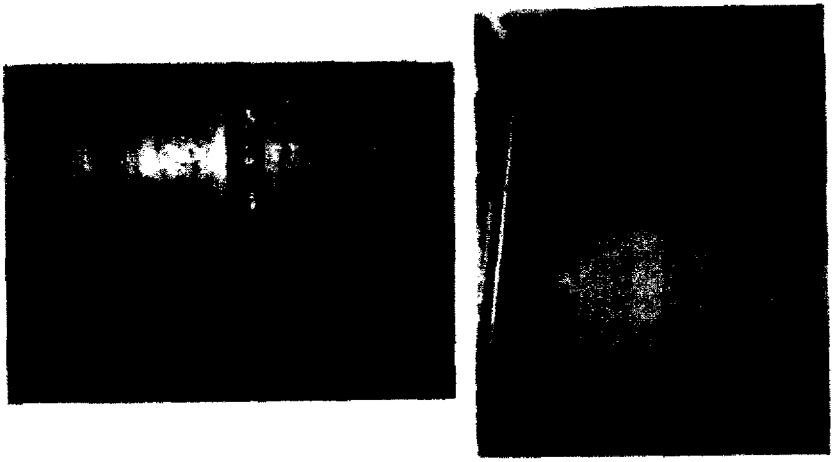


Fig. 7-2. Root bead that is perfect internally, but rough externally. A. Outside surface; B. Underside of root bead.

metal should also be avoided. Deep penetrating type electrodes, such as E6010, E6011, and E7010, will easily melt the metal in any defective areas and fill the voids at undercuts. When these electrodes are used, the smallest humps can be removed by melting; only the most serious defects will require grinding to correct them.

When shallow penetration type electrodes, such as low-hydrogen electrodes, are used to weld the joint, much greater care must be exercised in preparing the joint. Since these electrodes are used to weld high-pressure pipe joints, extra work and care are required in the preparation of these joints.

Because of their lack of penetrating power, it is much more difficult to melt humps and to fill-in undercuts with weld metal when using low-hydrogen electrodes. To maintain the short arc used with these electrodes, the surface over which the weld is made should be smooth.

For these reasons, the surface of the root bead must be ground to a flat contour, as shown in Fig. 7-3. The root bead surface is widened by grinding to remove undercuts at the fusion line between

Fig. 7-3. Root bead ground to flat contour in preparation for welding second pass with a low-hydrogen electrode.

the weld metal and the base metal. Since the low-hydrogen electrodes have a heavier coating, widening the root bead also provides more space for electrode manipulation and the flat contour will enable the welder to maintain a constant arc length.

In summary, the degree of preparation of the root bead for welding the second pass depends upon the type of electrode being used. When high-pressure joints are to be welded there can be no compromise in preparing the joint. In other cases, the welder must exercise a certain amount of judgment; he must decide which defects are serious enough to affect the quality of the second pass, and remove them leaving only those minor defects that can be corrected on the second pass.

The same conditions prevail when preparing the joint for welding the beads that will be made following the second pass. When welding with low-hydrogen electrodes, the surface over which the weld is to be made must be smooth and free of all defects. When welding with deeply penetrating electrodes, however, only major defects must be removed.

The Current Setting. Because of the varying conditions of the job location, the machine, and other factors detailed in Chapter 3, it is not possible to give an exact current setting that can be used in all cases. In order to provide a relative idea of the current setting to use for the intermediate passes, the current setting for the root bead will be used for comparison.

For the second pass and for subsequent passes, the current setting will depend primarily on the temperature of the pipe joint. If the pipe is still very warm (about 200 to 300F) when starting to weld the second bead, it is possible to use the same current setting that was used to weld the root bead. At this temperature the pipe joint is too hot to touch with the bare hand. If the temperature of the pipe joint has dropped significantly below this temperature, the current setting must be increased to provide more heat to melt the parent metal and to maintain the puddle.

When the welding operation has been suspended for a longer period of time, such as overnight, the weld joint will be at the temperature of the surrounding air. In this event it is advisable to preheat the joint with an oxyacetylene torch. In many instances, such as when welding highly alloyed pipe, preheating is mandatory. This reduces the thermal shock on the joint when welding is resumed, and also reduces the severity of the residual stresses locked in the weld when it has cooled to the temperature of its surroundings.

When several layers of weld beads have been deposited, the heat will transfer out of the weld at a slower rate. In other words, they tend to store heat, at least for a short time. When this occurs, there is no need to change the welding current. However, if these layers have been allowed to cool to the temperature of the surrounding air, they will act as a heat sink by rapidly withdrawing heat from the weld. In some cases, the cooling rate of the weld may be so fast that it will act like a quench. Moreover, more heat is required to raise the temperature of the layers of cold weld metal, often more heat than can be supplied by the arc.

For this reason, preheating with an oxyacetylene torch is highly recommended when several layers have been deposited and which have been allowed to get cold. If several layers have been deposited in pipe having a wall thickness of ¾ inch or more, preheating is almost mandatory.

In summary, the current setting depends on the temperature of the pipe joint. If it is warm (about 200 to 300F), less current can be used than if it is at the temperature of the surrounding air. If the pipe joint has been allowed to cool, preheating is very advisable and often mandatory in certain cases.

Electrode Angle. The correct electrode angles for welding the intermediate and cover passes around the pipe joint are shown in Fig. 7-4A and B. The side angle should be such that the electrode is perpendicular to the surface of the pipe.

Figure 7-4C shows one error that is sometimes made, even by experienced welders, when welding from the 9 o'clock to the 12 o'clock positions. The electrode angle in this case is too great. By facing upward, the arc will cause the puddle to be less fluid causing slag inclusions and improper fusion at the edges of the weld.

When the molten pool of metal is mushy, it will not fuse properly

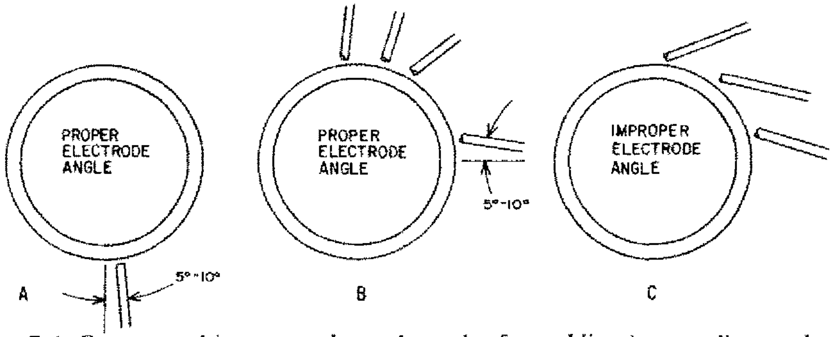
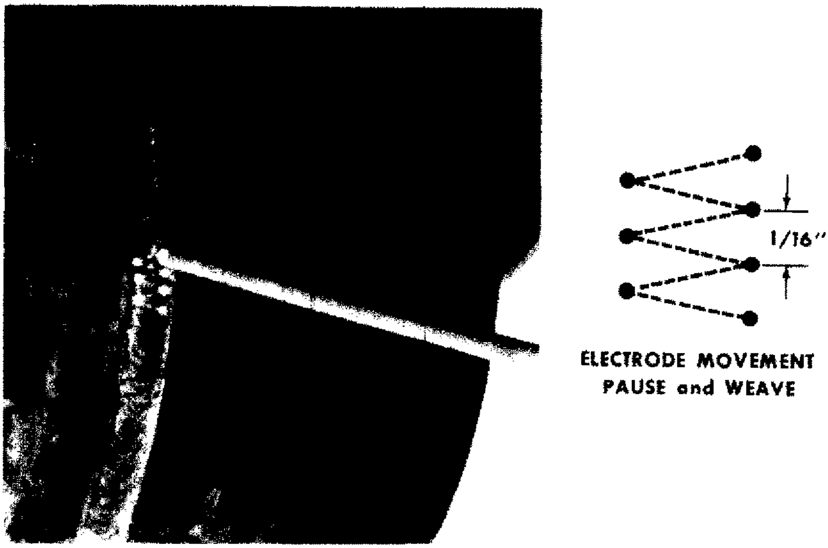


Fig. 7-4. Correct and incorrect electrode angles for welding intermediate and cover passes. A. Correct electrode angle for 6 to 9 o'clock positions; B. Correct electrode angle for 9 to 12 o'clock positions; C. Incorrect electrode angle for 9 to 12 o'clock positions.

nor will it flow readily. The slag, having a lower melting point than the metal, will be very fluid and it will flow swiftly to the edges of the weld where it will become trapped between the base metal and the weld metal. Therefore, it is necessary to prevent the molten pool of metal from becoming mushy while welding. While several factors affect the fluidity of the puddle, one that must not be ignored by the welder is the electrode angle; it should always be as shown in Fig. 7-4A and B.

Welding the Intermediate Passes. Before each pass is welded, the joint must be cleaned and prepared as described previously in this chapter. Each layer should start in a different position on the joint; i.e., no two layers should be started in the same position. For example, the root bead was started in the 6:30 position; thus the second layer should then not start in this position but in the 6 o'clock position.

The arc should be struck on the bead over which the weld is to be made. It should be struck ahead of the weld to preheat the metal over which the first part of the weld is to be made. As usual, a long arc should be held in this position until it has stabilized and the gaseous shield has formed. It is then held at the 6 o'clock position and shortened. After the puddle of molten metal has formed, the electrode is moved on to form the bead.



Courtesy of the Hobart Brothers Co.
Fig. 7-5. Electrode movement for making slant weave used to weld all intermediate and cover beads.

All of the intermediate beads are made by using a slant weave, Fig. 7-5. This weave is used in all positions around the circumference of the pipe joint. The arc should be moved along at a smooth and steady pace by operating the electrode with a wrist movement. At the end of each weave there should be a slight pause, after which the direction of the arc is reversed. Because the surface of the pipe is curved, care should be exercised to maintain a uniform arc length and electrode angle. Varying the arc length can have a significant effect on the depth of fusion and the size of the puddle. By maintaining a steady movement and a uniform arc length the electrode is seldom away from the edge of the puddle which results in a uniform depth of fusion and a bead with a neat appearance.

It is important to pause momentarily at the end of each weave. This allows the filler and base metals to mix properly, and it also allows the bead to fuse properly to the side of the joint. Any slag that is trapped in the corner of the weld will be remelted and will flow toward the rest of the metal where it will not interfere with the fusion of the puddle and the side of the joint. The molten metal in the puddle will also fill any undercuts in the corners, and will solidify when the arc is moved on.

The puddle must be maintained at all times and should not be allowed to become mushy, or small particles of slag may become entrapped in undercuts at the corners or in cavities. The welding speed should be adjusted to maintain a fluid puddle, yet care must be exercised not to allow the puddle to sag when welding from the 6 o'clock to the 3 o'clock positions. As the weld advances beyond the 3 o'clock position, the tendency for the puddle to sag decreases and, for this reason, the speed of welding can be gradually decreased to maintain a uniform build-up of weld metal.

For light coated electrodes (E6010, E6011, E7011), the arc length should be about $^3/_{32}$ to $^1/_8$ inch. This will provide enough heat so that the puddle of molten metal will be large enough to accept the globules of filler metal without excessive build-up. If a short arc ($^1/_{16}$ inch) is used, the size of the puddle of molten metal is decreased considerably. In this case the size of the pool of molten metal in which the filler metal can be deposited is limited. When the globule enters the smaller body of liquid metal, it will rise and, at the same time, cool more rapidly causing the bead to have a high crown (Fig. 7-6) and, perhaps, lack good edge fusion.

The use of an excessive amount of current must also be avoided. When this occurs the welder will increase the welding speed and the rate of electrode manipulation to keep the molten metal from sagging or from overflowing. He will tend to become erratic in the manipulation of the rod, varying both the arc length and the weave. To control the puddle he will often resort to a U-weave which periodically will remove the gaseous shield from the molten metal and produce a harmful effect on the quality and appearance of the weld.

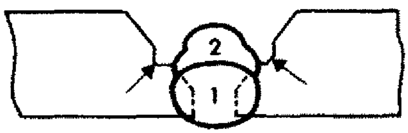


Fig. 7-6. Bead with high crown and lack of edge fusion caused by welding with a short arc.

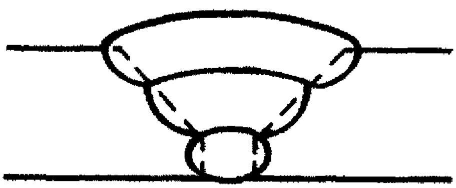


Fig. 7-7. Width of root bead, second pass, and third pass.

The third pass should be made wider than the second pass and it should fill the groove from side to side, as shown in Fig. 7-7. This pass is made by using the same slant weave as before, pausing at the end of each weave. The width of subsequent weaves will depend on the thickness of the pipe and upon the judgment of the welder. The manner of placing these beads in relation to each other was shown in Fig. 7-1. A bead may be deposited by making the center of the electrode pause over the edge of the bead below, or the weave may be widened by making the electrode pause one electrode diameter beyond the edge of the bead below. The appearance of each bead should be smooth and without undercut.

Stop and Restart. When the end of a bead is reached or when the electrode is consumed, the weld must be stopped. This is done by simply reversing the direction of the electrode travel for a short distance and then breaking the arc with a quick movement. The molten metal in the puddle should solidify in the form of a crater, as shown in Fig. 7-8.

Before restarting, the end of the weld should be chipped and wire brushed for a distance of at least ½ inch beyond the crater. All traces of the slag coating must be removed from this area.

To resume welding, the arc should be struck ahead of the crater and a long arc maintained, as shown in Fig. 7-9. When the arc has been stabilized and the gaseous shield has formed, it is brought into the crater and shortened to the normal length for welding. The arc should be moved slowly, from side to side in the crater, until a pool of molten metal has formed; only then can the bead be continued by resuming the slant weave.

Fig. 7-8. View of bead that has been stopped to change electrodes, showing the crater.

The arc should not be struck in the crater. This practice would cause the first few globules of filler metal from the electrode to build up like humps because the pool of molten metal had not formed when they were deposited. It has also been found that porosity results in the restart zone when the arc is struck directly in the crater. This is probably caused by the absence of an adequate gaseous shield to protect the hot metal, and the absence of enough slag from

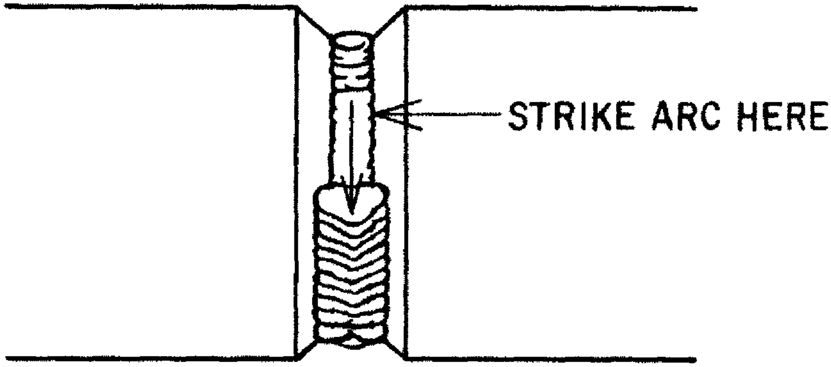


Fig. 7-9. Restarting the weld bead.

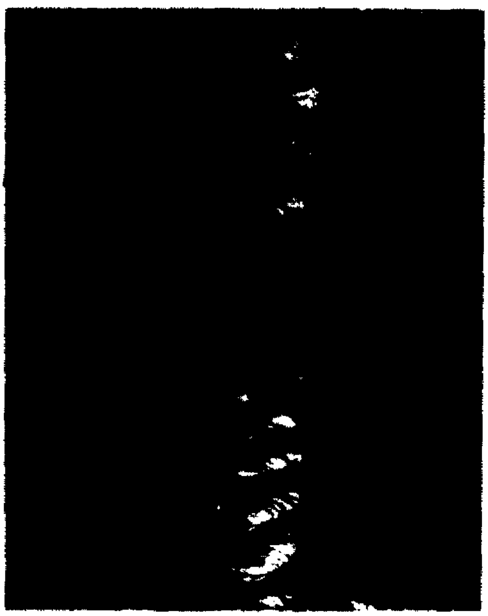


Fig. 7-10. View of a good tie-in.

the electrode coating, in time to thoroughly deoxidize the molten metal.

Tie-in. It is not difficult to make a good tie-in (Fig. 7-10) when welding intermediate and cover beads if care and attention are given to this matter during welding. When approaching a tie-in, the weave may be slowed down slightly to allow the molten metal to build up somewhat. Then, when the built-up pool of molten metal reaches the other bead, the welder must watch to see that the molten metal fills the crater and blends smoothly with the other bead; if necessary, he may have to run the arc a very short distance ($\frac{1}{16}$ inch) over the other bead in order to achieve a smooth tie-in. When the smooth blend of the two beads occurs, the arc is broken with a sudden movement.

The Cover Pass. The cover pass is the final pass or bead to complete the weld. It must have a smooth and uniform appearance. As shown

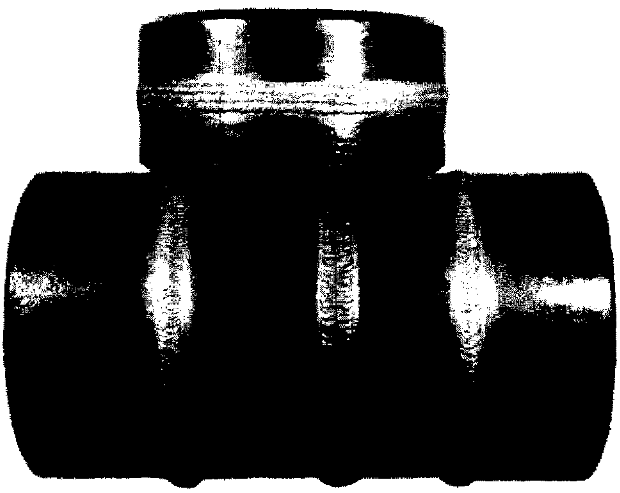


Fig. 7-11. Perfect cover passes. (Top) Horizontal (2G) weld made with E6010 electrode. (Bottom) 5G position cover passes, with joint in center made with E7018 low-hydrogen electrode and the two end welds made with E6010.

in Fig. 7-11, it should have a slight crown. When the pipes are in the 5G position, as shown by the lower pipe in Fig. 7-11, a single bead is used to make the final cover pass. Since this is difficult to do, however, when the pipe is in the 2G position, as shown by the upper pipe in Fig. 7-11, the cover pass usually will require three separate beads to be made. Welding in the 2G position will be treated later, in

Chapter 8; this chapter will treat welding of the cover pass in the 5G position only.

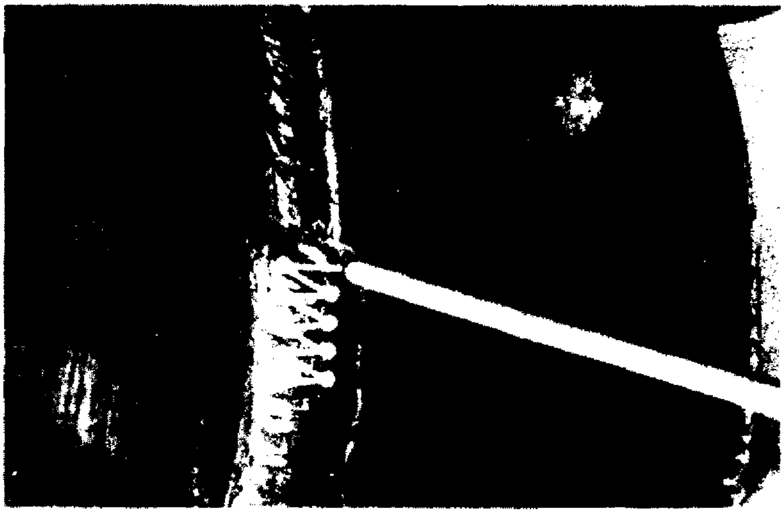
Welding the last intermediate layer, or layers, is a preparation for welding the cover pass. It is important that they be welded flush with the surfaces of the pipes. Undercut and poor edge fusion should be avoided; if they occur, they should be removed and the damaged areas rewelded before welding the cover pass.

In preparation for welding the cover pass, the weld joint must be thoroughly cleaned. If low-hydrogen electrodes are used, any humps on the surfaces of the beads over which the weld is to be made must be removed. Normally, the cover bead should overlap the edges of the bevel for approximately 1/16 inch.

Since the weld must be uniform and have a good appearance, the welder should always be in the most comfortable position that circumstances will allow in order to be able to manipulate the electrode smoothly and accurately. Whenever the welder senses that the manipulation of the electrode is impaired, he should stop welding and change position.

The arc should be struck ahead of the weld and brought back to the 6 o'clock position while holding a long arc in order to stabilize the arc and form the gaseous shield. It is then shortened to a normal arc length. The welding process begins by weaving the electrode two or three times at a slow rate in order to form the molten pool of metal and to obtain good fusion.

As shown in Fig. 7-12, a slant weave should be used to make the entire cover pass. Close attention to the job and careful workman-



Courtesy of the Hobart Brothers Co.

Fig. 7-12. Slant weave used to make the cover pass.

ship are required in order to obtain a neat appearing bead. The electrode angle must be correct and a uniform arc length maintained.

When making the weave, the welder should watch the edges of the underlying bead. They serve as a guide in order to maintain a uniform width of the cover bead around the entire pipe. At the end of each weave, the electrode should pause to prevent undercut and to obtain good edge fusion.

The welder must also watch the puddle and maintain a welding speed so that the crown (also called the bead reinforcement) of the solidified bead remains between $\frac{1}{32}$ and $\frac{1}{16}$ inch above the surface of the pipe. Care must be exercised not to permit the crown to build up too high, especially in the vertical and overhead welding positions.

Difficulties can be encountered in welding the cover pass for the following reasons:

1. The pipe is too hot
2. The joint was not cleaned properly prior to welding
3. The intermediate beads have not filled the pipe joint completely
4. There is undercut and poor edge fusion of the previous bead.

If the pipe is too hot the molten metal will solidify more slowly and it will be very difficult to control the puddle. As a result there will be a rough-looking weld which is unsatisfactory as a cover pass. The remedy would be to allow the pipe to cool until it is warm (about 200 to 300F) before starting to weld. Sometimes it is possible to weld a hot pipe satisfactorily by reducing the welding current.

Cleaning the joint properly prior to welding is the welder's responsibility. Undercut, poor edge fusion, and improperly filled joints are also the welder's responsibility. He should not start to weld the cover pass until these matters are corrected. Better yet, he should exercise greater care when welding the intermediate passes so that these conditions do not occur.

Low-Hydrogen Electrodes. As already explained, low-hydrogen electrodes are not a deep penetrating type of electrode and for this reason the surface over which they weld must be smooth. Before each pass, the surfaces of the joint should be cleaned, have all defects removed, and be ground smooth. Proper preparation is an important part in welding successfully with low-hydrogen electrodes.

The general procedure for welding the cover bead with low-hydrogen electrodes is the same as for more deeply penetrating electrodes; however, there are some differences. When the arc is struck it should be shortened immediately. The whipping procedure should never be used to control the puddle. The weld should be made by using the slant weave described in this chapter. At the end of each weave the welder must be sure to pause in order to avoid undercutting. It is very important to maintain a short arc at all times in order to avoid sagging and to prevent pinholes from occurring in the weld.

The electrode coating must be kept dry and electrodes with a chipped coating should not be used. Wet joints must be preheated with an oxyacetylene torch. Welding should never be done in the rain when using low-hydrogen electrodes. If the welding area becomes wet, the electric arc will break down the water, forming hydrogen, which will enter the weld metal with very harmful effect.

Shielded Metal Arc Welding—Electrode

The shielded metal-arc welding process has been widely used for many years to weld pipe material. It is still used, even in the most modern industries. The process is used with various types of alloy pipe materials in constructing power plants, oil refineries, chemical plants, nuclear power plants, and oil and gas transmission lines. Specifically it is used to make or join welds that meet the requirement of the industries' respective codes and specifications for piping systems and materials. These requirements cover various conditions such as high strength at elevated temperatures, corrosion and oxidation resistance, steels for cryogenic services, and high alloy steel that must resist chemical attack or require high tensile strength.

The ability of the steel to achieve its needed mechanical properties in the various environments, depends on proper steel making practices such as degassing, removal of impurities, hot rolling within the critical range, grain control, and even controlling the cooling rate and heat treatment. When the welding is applied, the filler metal on the electrode must be formulated so that the completed weld meets the required strength and other properties for which the system was designed.

Shielded metal-arc covered electrodes are formulated in a way analogous to process metallurgy. However, the challenge of formulating electrode coatings involves knowing that the filler metal will be transferred in the intense arc heated column as fine particles to the base metal molten pool. Many of the materials used to make slag, in connection with refining metal in a furnace, are also used in fluxes for welding. Limestone, flourspar and rutile are used make steel. There are many other suitable minerals compounded to make a flux. For example, certain precautions must be taken to ensure protection during the transfer of the alloying element, and to guard against the pick-up of elements that could affect weld properties. Furthermore, weld metal is susceptible to oxidation when the metal is exposed to oxygen. Other problems include porosity and blow holes caused by the effusion of gases. These are some of the same problems that are experienced with ingots and casting during steel making.

Most flux-bearing arc welding electrodes contain additional elements to function as deoxiders. They are supplemented by adding alloying elements in the electrode coating. The molten pool is protected by deoxiders and fluxing agents that remove the oxide formation of the hot metal ahead of the arc. Numerous types of coated electrodes are available for welding various pipe alloy.

Electrode coatings have many functions, including:

(1) maintaining a stable arc
(2) controlling depth of penetration
(3) adding bulk to the weld deposit
(4) increasing the ionization potential, and stabilizing the arc
(5) depositing welds with a uniform ripple
(6) production suitability
(7) durability and storage
(8) slag that is easily removed

Mild steel material has a low carbon content as well as small amounts of manganese and silicon. Welding such material offers little challenge to its microstructure; in fact, the microstructure is basically perlite, which is soft and ductile.

The appropriate electrode for welding this grade of material is the E-6010 electrode. There are many variations of this basic electrode type. For example, the covering of the E-6020 electrode has a high iron-oxide content, as much as 30 percent. The amount varies substantially in the series, with little or no gas shielding provided by the covering. The primary purpose of this covering formulation is to provide a heavy layer on the metal, thereby obtaining a satisfactory operation with high current. The welder is then able to obtain a deep penetration in the butt and fillet welds in the horizontal and flat position. E-6020 electrodes are used most often on relatively heavy sections where deep penetration and high metal deposit rate is sought.

The E-6010 electrode has a thin layer of (flux) coating that barely covers the entire weld. This thin layer offers a higher viscosity than the heavy covering on other electrodes. It thus makes the E-6010 an electrode most suited for depositing root bead on pipe without dripping either inside or outside, once the root bead technique is adapted. The E-6010 electrode does have limits where it can be applied, as follows:

(1) It is effectively used for deposited root bead on carbon steel—uphill and downhill welding.

(2) It is limited to welding on low alloy steels because of its low content in alloying elements. However, it is sometimes used for depositing the root bead, which is then filled and capped with the low-hydrogen electrode, E-7018.

(3) Welding thinwall and low-to-medium carbon steel pipe with E-6010 is acceptable.But if the wall thickness exceeds half an inch, only the root bead is deposited by the E-6010, with fill ing and capping by the E-7018 electrode.

(4) E-6010 is considered a high cellulose electrode. Therefore, it generates a high level of hydrogen not accepted for welding high carbon and medium alloy steel.

(5) As a last resort, the E-6010 electrode can be used for depositing a root bead on high carbon steel, but not without preheating and maintaining interpass temperatures.

(6) Because E-6010 is considered a high cellulose electrode, the final gaseous product from the volatilization and combustion of the cellulose results in a covering of carbon monoxide, car bon dioxide, water vapor, and hydrogen. In turn, because of the high inducement of hydrogen, E-6010 is not used for depositing root bead on either medium alloy steel or steel with high tensile strength.

The electrode E-7047 has a low hydrogen type of coating. Because it is lightly coated, this electrode can be used for downhill welding, of root beads.

There are instances when a low or medium alloy pipe needs to be welded, and the root bead becomes a matter of concern because no other process is available and no electrode available other than E-6010 is available for depositing the root bead. Pick-up, also known as dilution, becomes a factor. Pick-up relates to the welding of an alloy steel with a filler metal of a lower alloy content than the base metal content. In a multilayer weld, the first pass (root bead) naturally picks up the greater amount of alloying elements from the base metal. When, for example, welding a chrome alloy pipe. The root pass deposit made with the available E6010 electrode will gain as much as 50 percent chromium due to dilution or pick up from the base metal.

The viability of this proceedure must be proven by the welder, as the root bead alone is deposited by this type of electrode. The welder must then prepare the surface of the root bead deposit by grinding and removing one third of its thickness, with smooth fusion edges on both sides of the root bead. The welder's next objective is to use one electrode of reasonable size in diameter, and an adjustment in the current allowing penetratation of the root bead as deep as possible, but avoiding burn through the root bead.

A small crater should be apparent after the first electrode is consumed. The edge fusion will give the welder an indication as to the depth of penetration. The root bead can then certainly be enriched by the deposit from the second pass, using the correct electrode based on specifications. This procedure involves applying preheating temperature and maintaining an interpass temperature, knowing that the base metal and the filler are both of alloy type. An experienced supervisor or experienced welder should help with this procedure. This points out that solving variations in welding is not always based on the procedure itself, but often on the skill of a well-trained welder who understands all that is required.

The electrode coating may carry supplementary alloying elements that are needed; the core wire is not being of the same composition as the base metal. Thus, it has become a practice to use a supplementary addition to the coating when manufacturing electrodes. In addition, the electrode coating has other functions. These include protecting the transfer of filler metal within the arc stream by a blanket of gases that keeps the oxygen out or dissolves the oxidizing gas to a less active one like Co2 or Co, which can also serve as a protective atmosphere.

The electrode coating is made up of compounds and elements that are responsible in their own way to protect the molten weld metal acting as either slag, deoxider, or fluxes.

The slag must be less dense than the weld metal for obvious reasons. It must not freeze at a higher temperature than the weld metal; otherwise, the slag will remain dormant or stagnate on the face of the bevel, disturbing the welding process. In addition, the viscosity of the slag (its ability to flow) has an important bearing on the quality of the weld. When the viscosity is low, the slag is watery. It will flow, leaving the hot metal exposed to the atmosphere, and thus to become oxide. If the viscosity is high, the slag will be very sluggish. This in turn becomes a challenge to the welder, especially, when making welds in certain positions. When slag is formed on the weld, it will be impregnable to the gases from the atmosphere. Therefore, the weld metal will be protected. However, manufactures of electrodes have taken these variables into consideration allowing the welder to choose the optimum electrode for the job at hand.

A deoxider is a oxygen setter. It serves in molten metal to dispose of oxygen and oxygen-bearing compounds or it remains in the weld pool as a safeguard in case oxygen enters. When oxygen does enters the molten weld pool, it reacts with manganese to form manganese oxide (MnO). As long as manganese is present, this process will continue rather than the formation of iron oxide. In turn, manganese oxide reacts with the carbon to form the Co bubbles that cause porosity (blow holes). If aluminum and silicon are in the steel or the weld pool, there will be no blow holes. The silicon and the aluminum should react with the oxygen to form oxide preferable to FeO. Because it has lower density than the metal, the oxygen bearingslag will rise to the surface, joining the bulk of the slag.

During welding, the surface of the joint to be welded can develop an invisible oxide coating, even though it was brushed twenty-four hours earlier. While the weld is in progress, the heated metal ahead of the arc will be exposed to the atmosphere and the oxidation in progress. The object, then, is to protect the molten pool and to dispose of the oxide ahead of the arc by reducing them.

The method by which a flux deals with the oxide is by mixing or comingling with the oxide to form a slag that has a more favorable melting point and viscosity. Therefore, the electrode coating is also a slag that forms a blanket on the weld surface, shielding the metal from oxidation and disposing of oxide that forms from inefficient shielding caused by poor manipulation or other reasons.

There are many individual components in the electrode coating. There are some that combine with other compounds and become chemically active shielding the molten puddle and display of oxide. For example, limestone is a component that can help produce Co and Co2 gases that serve as a protection to the arc area and the arc stream; it produces 40 percent of its weight in gaseous form; the rest becomes calcined, that is, it changes to a white powdery lime. This latter product of the welding process is an example of a fluxing agent. It is secured from limestone after calcination. Other components that could be added to this list are flourspar, sodium oxide, feldspar, ferromanganese, graphite, ferrosalinium, ferrosilison, chloride, and fluoride salt.

These agents melt and gather as a liquid blanket on all parts of the weld puddle except the arc spot. The flow of the fluxing agent can be seen as a slight watery substance, a blanket extending the edges of the puddle and dissolving the oxide. The principle function of the flux is to dissolve or dispose of the high melting oxide that may form despite the protection afforded by the gaseous shield around the arc.

To obtain high quality welds the SMAW process requires careful storage and handling of the electrodes. An experienced supervisor can determine whether or not the quality of the weld is at risk based on the condition under which the electrodes are maintained in the work place.

Too often the welder draws the conclusion that using high current is the best way to address the tiny holes that appear on the surface of the previous pass (weld). Yet when the surface is removed by using a grinder, the holes are in fact larger in diameter. Therefore, high current is not a remedy for such a defect. Gases such as Co and Co2, by themselves or in combination with others, are very soluble in molten metal during welding. As the metal begins to freeze, gases in the weld seek to escape from the weld. As the heat dissipates or is conducted into the walls of the base metal, it also loses heat from the surface of the weld. If effusion of the gases from the weld is not completed before the weld puddle becomes solid, the gases will rise within the semi-molten weld, leaving what are called worm holes. Because of its viscosity at that stage, the metal will not be able to flow to fill these holes, which will remain as voids. If the surface of the weld is in a semi-molten stage, a portion of the gas will escape, and there will be the appearance of pin holes on the surface of the weld, known as porosity.

The coatings of properly baked electrodes are brittle. This coating can fracture quite easily during transportation to the work site, or when the electrodes are carelessly stored among tools such as chipping hammers and chisels. The cracks on the electrode coating can be so tiny that they cannot be seen by the naked eye. Often a welder will bend an electrode, to gain acess to a joint in constricted area. The coating then may be fracted or actually break-away from the core. As this damaged electrode is used the electrode coating can flake and fall into the weld, as well as to the ground. The problem then is that the electrode can be depleted of its alloying ingredient, which in turn will lead to inadequate mechanical properties, oxidation and loss of corrosion resistance, especially if the steel happens to be subjected to high temperature service. In addition, the weld will suffer from not having sufficient oxidizers, which is likely to cause porosity in the weld. Cracks due to rapid cooling shrinkage are another possibility.

CHAPTER 8

Welding Thin-Wall Pipe

Thin-wall pipes are categorized as having a wall thickness less than ⁵⁄₁₆ inch. The diameter of thin-wall pipes may be as small as 1 inch and as large as 42 inches, or larger, such as that used for cross-country pipelines.

When the pipeline is horizontal, or the pipes are in the 5G position, either the uphill or the downhill welding procedure can be used. Because it is a faster method, downhill welding is preferred for welding cross-country pipelines, where the pipes are usually made of low-carbon mild steel and this method of pipe welding will be emphasized in this chapter.

Not only the wall size but the diameter of the pipe affect the welding method that can be employed. Small-diameter pipes with thin walls present a problem because the heat resulting from the weld does not dissipate rapidly, thereby causing the heat to build up in the weld zone. In this case the heat input into the weld must be controlled.

To control the heat input, for welding small-diameter pipe the current setting is less, and a smaller-diameter electrode is used as compared to that used for large-diameter pipe having the same wall thickness. While welding small-diameter pipe, the welder must pay careful attention to the electrode angle and to the arc length. The electrode angle is more difficult to control on small-diameter pipe because the position of the electrode changes rapidly in order to maintain a uniform electrode angle while welding around the pipe. A drastic change in the electrode angle can have an adverse effect on the quality of the weld. While watching the electrode angle, the welder must also prevent the arc length from becoming too large as (1) this will increase the heat input into the weld, and (2) if excessive, it will decrease the weld penetration. Considerable practice is usually required of the welder before the technique of welding small-diameter pipe is mastered.

Uphill Welding

Very high-quality pipe joints can be made using the uphill welding method to weld both large- and small-diameter thin-wall pipe. It is recommended for welding high-alloyed pipe and in other cases where only the highest-quality welded joint will be accepted.

For large-diameter pipe, the procedure is exactly the same as that described in Chapters 5, 6, and 7. The root bead may be welded by the shielded metal-arc-welding process or by the gas tungsten arc-welding (GTAW) process. The procedure for welding the intermediate and cover passes is the same as previously described.

When welding small-diameter thin-wall pipe, the root bead and intermediate passes are welded as previously described; however, a slightly different procedure must be used to weld the cover pass. Because more heat is retained in the weld zone when welding small-diameter thin-wall pipe, the temperature of the weld is often very high when the cover pass is deposited.

In this case, a semicircular weave, shown in Fig. 8-1, is used. The current setting should be slightly decreased when using this weave pattern. It is made with a continuous motion, there being little or no pause at the end of each weave. This allows the area that is seen encircled in Fig. 8-1 to cool and lose a considerable amount of fluidity when the arc is on the opposite side. When the arc is returned

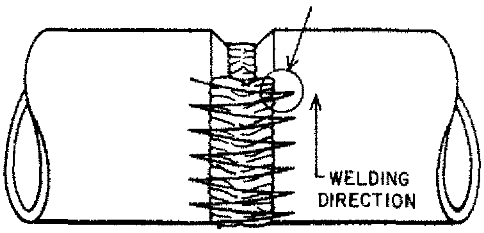


Fig. 8-1. Semicircular weave used to weld the cover pass when welding small-diameter pipes by the uphill-welding method.

to the encircled area and the filler metal is added, the metal will not drip as a result of overheating. The electrode angle remains constant when welding around the pipe, as shown in Fig. 8-2.

When this weave pattern is to be used, it is very important to clean the weld joint thoroughly beforehand. Since there is little or no hesitation at the end of the weave, some danger exists that slag may become entrapped, causing incomplete fusion to occur in this area. The welder, therefore, must take a position which enables him to manipulate the electrode comfortably and precisely. This is especially important when welding small-diameter pipe because of the continuous change in the electrode position. A perfect cover pass is shown in Fig. 8-3.

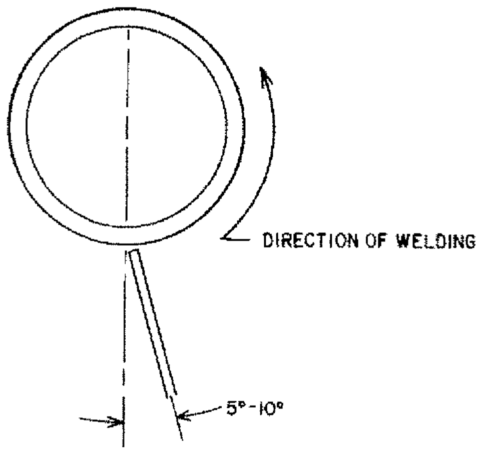


Fig. 8-2. Correct electrode angle when welding the cover pass on small-diameter pipe by the uphill-welding method.

Downhill Welding

Thin-wall pipe can be welded by the downhill weld method. Downhill welding is very fast and economical; consequently, it is used extensively to weld cross-country pipelines. In the majority of cases, the wall thickness of the pipes used for cross-country pipelines is within the range of thickness that can be welded by this method.

High-quality welds can be made on thin-wall pipe by the Downhill Weld method. No laxity in the quality of the pipe joint is permissible when the pipeline must transport crude oil, natural gas, and other fuels. Leaks and other defects can present a danger to life and property, as well as be the cause of environmental damage. Most cross-country pipelines are buried underground for almost their entire length. In order to be certain that they are sound, it is normal procedure to test over 50 percent of the welds.

The procedure for downhill welding is different from that for uphill welding. The molten puddle of metal tends to roll down the pipe in the same direction as the arc is traveling. Moreover, the fluid slag in the molten metal also flows in this direction and, unless this can be controlled, there is a danger of slag inclusions occurring.

In order to deposit a sound layer of weld metal, the arc must constantly be kept ahead of the molten pool of metal. This is done by using a high current setting and a fast speed of travel. As a result, the layers of weld metal are thinner, when compared to uphill welding.

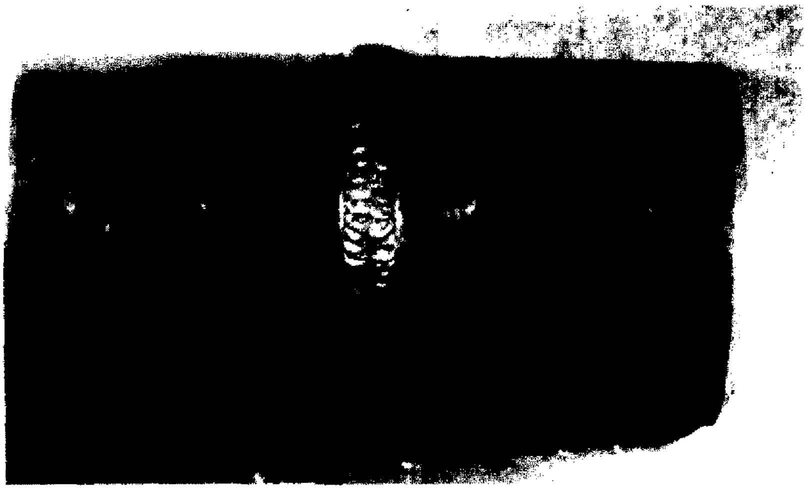


Fig. 8-3. A perfect cover pass deposited on small-diameter pipe by uphill welding.

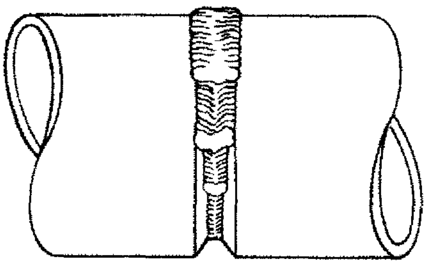


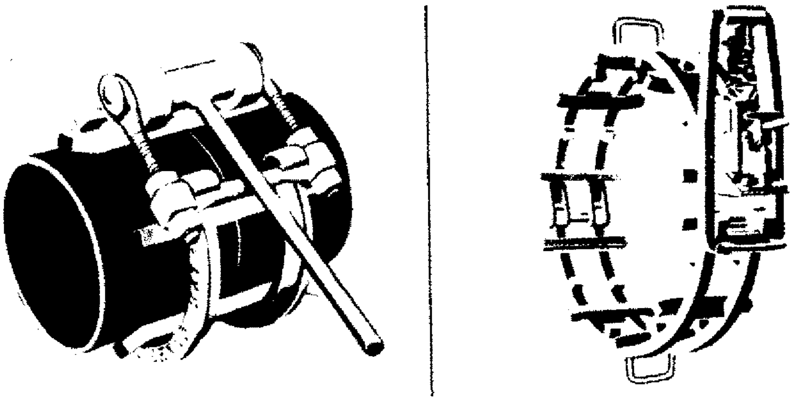
Fig. 8-4. Typical disposition of weld beads on a cross-country pipeline joint.

Figure 8-4 illustrates a typical disposition of the weld beads in a joint when welding a cross-country pipeline. As usual, four tack welds are made to hold the pipes in place, following which the root bead is welded, starting from the top of the pipe and welding to the bottom. After the root bead has been welded entirely around the pipe, the second pass, called the "hot" pass, is welded. The primary objective of this hot pass is to correct any defects in the root bead; a relatively small amount of metal is deposited by this pass. A third, intermediate, bead is then deposited, which is followed by the cover pass to finish the weld.

For practice-welding, two 7-in. long, 8-in. diameter, Schedule 30 mild steel pipes are recommended. The actual outside diameter of these pipes is 8.625 inches and the wall thickness is .277 inch. The instructions to follow apply to welding larger-diameter pipes, such as those encountered on cross-country pipelines, as well as the nipples.

Horizontal (2G) Welding. The procedure for welding thin-wall pipe in the horizontal (2G) position is exactly the same as for welding thick-wall pipe. For this reason, this subject will not be treated here and the reader should refer to Chapter 9 for information on horizontal pipe welding.

Outdoor Pipeline Welding. Much of the downhill pipe welding is done outdoors on cross-country pipelines. For this reason it is necessary to mention a few precautions that should be taken when welding under these conditions before treating the actual welding methods.



Courtesy of the H&M Pipe Beveling Machine Co. Inc.

Fig. 8-5. Typical line-up clamps used to clamp and align cross-country pipeline joint.

Weld cracking can be a problem when welding pipes outdoors, particularly when welding large-diameter pipes having a higher alloy content. Several different grades of steel are used in pipeline construction and are designated by the API Standard as X42, X52, X56, X60, and X65. The alloy content increases in these pipes with an increase in number designation. The tensile strength and other mechanical properties also increase in the higher numbered pipes. This progressive increase in properties is the result of the greater alloy contents, principally carbon, manganese, and, perhaps, silicon.

Line-up clamps, such as shown in Fig. 8-5, are used to align the pipes and to hold them in place while welding. The root bead is somewhat thin when welded by the downhill method and the pipe joint is weak, until sufficient metal has been deposited in the joint. Short tack welds alone would be apt to crack. For this reason, the clamps are left in place on the pipes until 50 to 100 percent of the root bead has been deposited.

Another form of cracking that occurs, particularly on pipe having a somewhat higher alloy content, is underbead cracking. A more detailed discussion of the nature of this form of cracking is given in Chapter 13; in the following paragraphs some of the precautions that must be taken to prevent its occurrence when welding outdoors are discussed.

Underbead cracking can occur in pipes having a higher alloy content when the weld is cooled too rapidly and when moisture is present. Therefore, the weld joint should not be allowed to cool to the temperature of the surrounding air because the heat retained in the weld will slow down the cooling rate of the next bead to be welded.

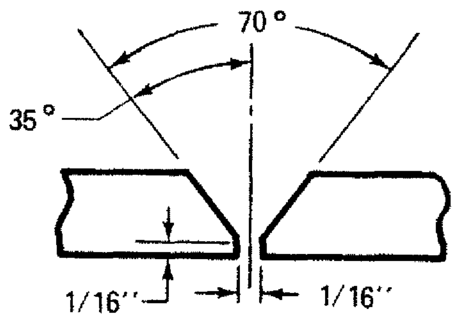
In the field, this means that the second layer should be welded as soon as possible after the previous layer is finished, preferably within five to seven minutes. On large-diameter pipes it is not possible for a single welder to weld fast enough to maintain the desired interpass temperature in the weld joint. In order to maintain this temperature, it is not unusual to see as many as two to four welders working on a single weld joint simultaneously.

High winds can also cause the weld to cool too rapidly to maintain the desired interpass temperature, especially if the air is cold. Unless a wind shield is placed around the welding area, welding should be stopped if the wind velocity exceeds 25 to 30 miles per hour.

Since moisture can cause underbead cracking, welding should be stopped if it rains or snow is falling. Of course, if a canopy is placed over the weld area to protect the weld joint from rain and snow, welding can be continued. However, the weld joint should be thoroughly dried with an oxyacetylene torch before welding and great precaution should be taken to keep the electrodes dry.

Ingredients in the coating of the electrodes used for downhill welding can contribute to underbead cracking if the weld cools too fast. This is another reason for retaining a fairly high interpass temperature. Ideally, low-hydrogen electrodes should be used because the coating on these electrodes does not contain the harmful ingredients. However, it is not possible to weld downhill with low-hydrogen electrodes because the very fluid blanket of liquid slag obtained will interfere with the weld and will result in a defective bead.

Preparation of the Pipe Joint. The standard joint specifications for thin-wall pipes are given in Fig. 8-6. In the field, the sections of pipe to be welded together have usually been beveled in a shop before



Courtesy of the Hobart Brothers Co.

Fig. 8-6. Standard joint specification of a thin-wall pipe joint.

they arrive on the job. Should this not be the case, then it will be necessary to cut the bevel with an oxyacetylene cutting torch and a grinding wheel. The surface of the bevel must be ground smooth and all traces of the tightly adhering oxide coating left by the oxyacetylene cutting torch must be removed.

Before any welding is attempted, the pipe joint must be thoroughly cleaned to remove all foreign matter, such as oil, grease, rust, paint, dirt, etc. On pipeline construction in the field, this work is usually done by a two-man crew working ahead of the welders.

On some jobs a second crew is sent to work ahead of the welders in order to fit-up the pipes in preparation for welding. Line-up clamps, such as are shown in Fig. 8-5, are used to align the pipes and to hold them in place during welding. As already mentioned, these clamps are not removed until a sufficient amount (50 to 100 percent) of the root bead is deposited, to avoid cracking.

For practice-welding, the short pipe nipples are aligned in the same manner as for welding thick-wall pipes, as described in Chapter 4. However, in this case, the diameter of the spacing wire should be $\frac{1}{16}$ inch, which is equal to the width of the root opening.

Welding the Tacks

When the pipe nipples are correctly spaced and aligned, they are ready to be welded together (see Fig. 8-7). For welding the tack welds and the root bead, an E6010, E6010IP, or E7010-A electrode should be used. When the wall thickness of the pipe is $\frac{1}{8}$ inch, or less, a $\frac{1}{8}$-inch electrode is used; for thicker-walled pipe a $\frac{5}{32}$-inch electrode is used. Low-hydrogen electrodes cannot be used for downhill pipe welding. A very high current setting should be

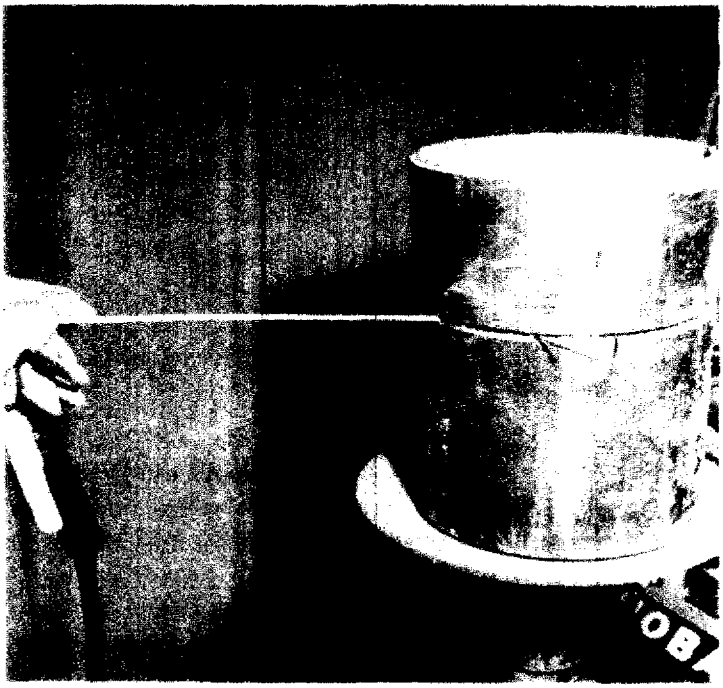
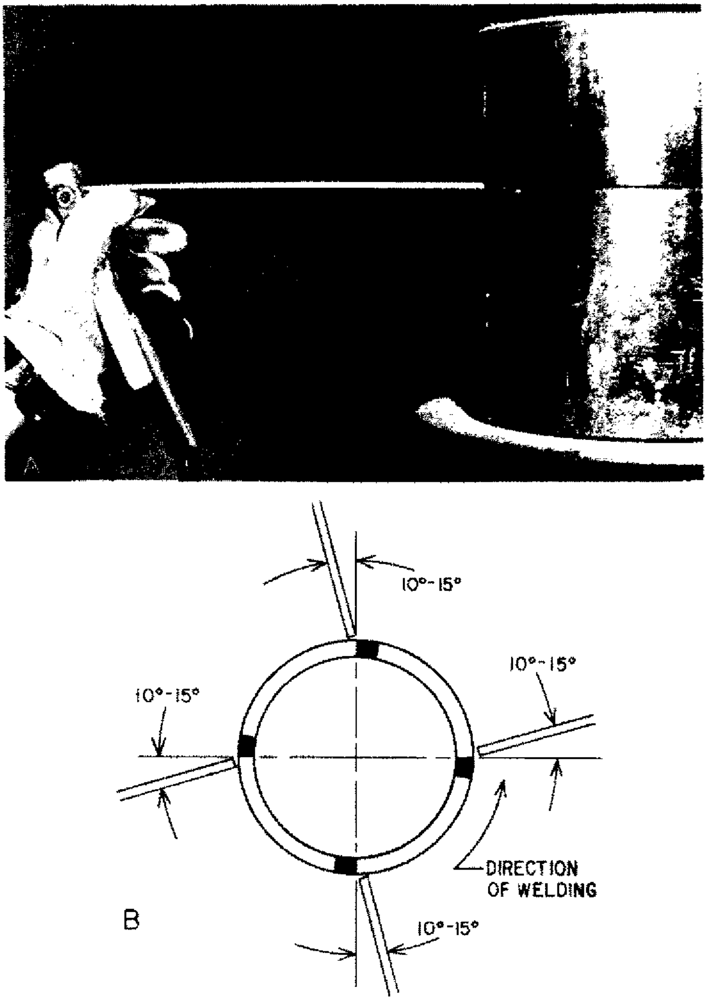


Fig. 8-7. Aligning and tack welding two thin-wall pipe nipples using a piece of bent wire as a spacer to obtain the correct root opening.

used when welding the root bead by the downhill method. As an estimate, it should be between 100 and 140 amps DC for the nipples used in practice welding.

The tack welding operation on the pipe nipples is shown in Fig. 8-8. Also shown in this illustration is the correct electrode angle that should be used, 10 to 15 degrees. The arc should be struck in the joint ahead of the weld and immediately lengthened to stabilize it and to form the gaseous shield. As shown in Fig. 8-9, when this has occurred, the arc is buried into the weld joint, meaning that it should be pushed into the joint, with the end of the rod held against the joint with a light pressure. Due to the very high current setting used to deposit the tack weld and the root bead, the arc will continue to burn even when the electrode is in contact with the base metal of the pipe.

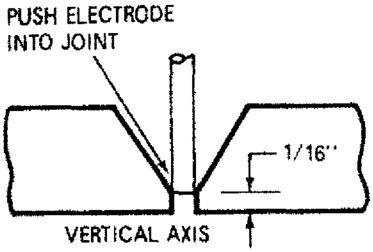
Holding the electrode at the correct angle while it is buried in the joint, the welder must observe the formation of the puddle and the keyhole. As soon as sufficient metal has been built up to bridge the gap opening, he must begin to move the electrode by sliding its end



TOP VIEW

Fig. 8-8. A. Welding the tack weld; B. Top view of pipe nipples showing the correct electrode angle for tack welding.

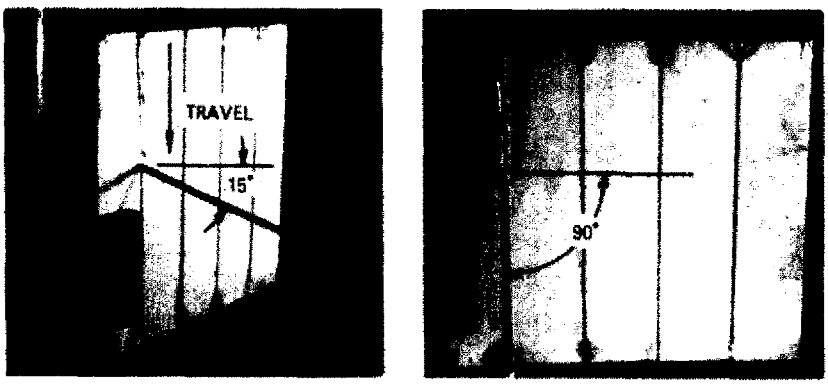
in the groove, constantly maintaining a slight pressure on the end of the electrode to keep it buried. The electrode may have a tendency to stick as it is dragged along in the groove, and if this occurs the electrode holder should be wiggled slightly, while keeping the end of the electrode buried in the groove. A small keyhole will form behind the electrode; and this should be watched as the weld progresses, as well as the molten pool of metal. When the bead is about ¾ inch long, the arc is quenched by a quick flip of the electrode away from the keyhole.



Courtesy of the Hobart Brothers Co.

Fig. 8-9. Position of the electrode for downhill welding a root bead. The electrode is buried in the pipe joint by holding it in the weld with a light pressure. The high current setting allows the arc to be maintained when the electrode is in contact with the pipe.

It is rather difficult for a beginner to master this method of welding; therefore, this procedure should be practiced by first welding some flat plates before any attempt is made to weld pipe. It is best to begin practicing with the plates in the vertical, or 3G, position as in Fig. 8-10. Before starting to practice-weld on flat plates, the following section, "Welding the Root Bead," should be read.



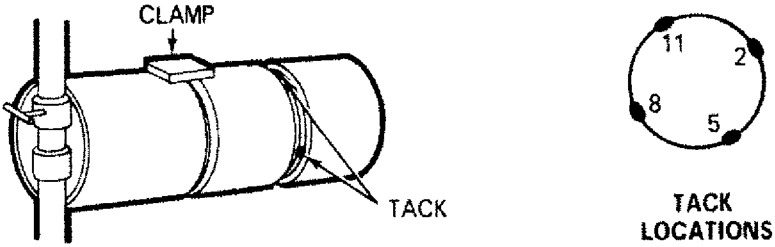
Courtesy of the Hobart Brothers Co.

Fig. 8-10. Set-up for practice-welding root beads by dragging the electrode in a downward direction. A. Side view; B. Welder's view.

On cross-country pipelines, the position of the tack welds and the procedure used to make them depends upon many factors. Moreover, different crews may vary the procedure. When the pipe is lying in a horizontal position or on a uniformly rising grade, it is lifted upward slightly by a crane to allow the welder to reach the bottom of the pipe. The first tack weld then is made in the 6 o'clock position. After the pipe is lowered, the second tack weld is made in the 12 o'clock position, followed by two additional tacks in the 3 and 9 o'clock positions. If the ground on which the pipes are lying curves upward or downward, the first tack weld is sometimes made in the 12 o'clock position, followed by a tack at the 6 o'clock and then at the 3 and 9 o'clock positions. For practice welding, the pipe nipples should be clamped in the stand in the position shown in Fig. 8-11, with the tacks in the 2, 5, 8, and 11 o'clock positions.

Welding the Root Bead. In preparation for welding the root bead the tack welds should be deslagged and cleaned thoroughly with a wire brush. The ends of the tack weld should be ground to a sharp feather edge with a grinding wheel, as shown in Fig. 8-12.

The procedure for welding the root bead is essentially the same as that for welding the tack welds. A high current setting is used, together with the same types and sizes of electrodes. The electrode



Courtesy of the Hobart Brothers Co.

Fig. 8-11. Method of clamping the pipe nipples in the pipe stand.

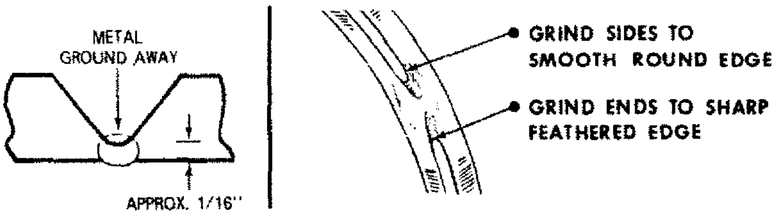
should be held at the angle shown (10 to 15 degrees) in the illustration, Fig. 8-13.

To start the root bead, the arc is struck in the 12 o'clock position. It should be struck ahead of the weld in order to preheat the part of the joint in which the bead is to be deposited. A long arc is held until the arc has stabilized and the gaseous shield has formed and then the electrode is buried in the welding joint and kept in place with a light pressure.

The welder must closely observe the formation of the puddle of molten metal and the keyhole. When the liquid base metal and the filler metal from the electrode have formed a bridge of molten metal across the gap, the welder then will start to move the electrode by dragging it in the groove. A small, crescent-shaped keyhole, shown in Fig. 8-14, will appear at the top side of the electrode.

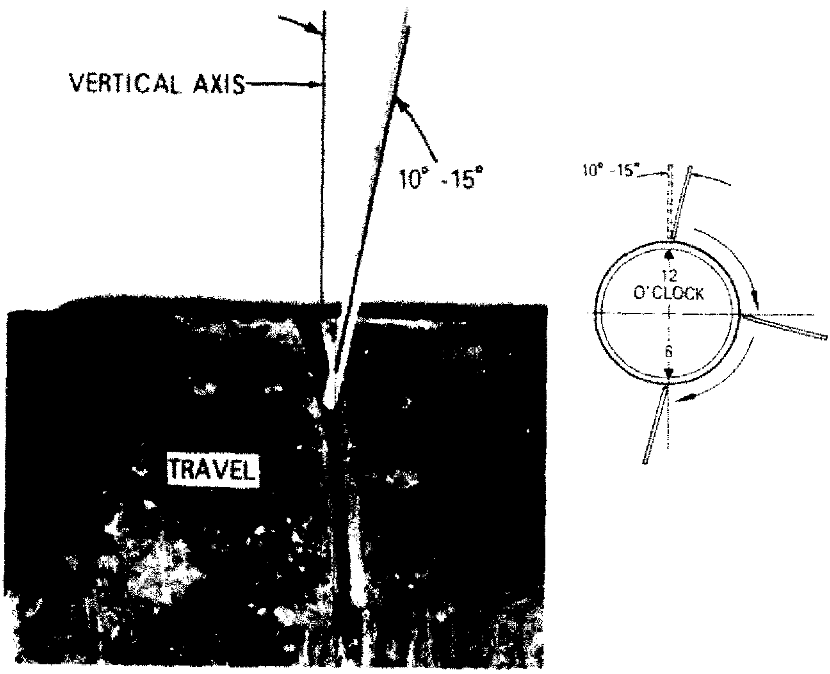
The keyhole is a necessary element in the formation of the weld bead. It is formed when the faces of the weld joint have melted and it provides the space for the molten metal to flow to the bottom of the weld joint, thereby assuring that the weld bead will penetrate to the root. The solid weld bead should extend below the surface to form a slight crown that must not exceed $\frac{1}{16}$ inch in height (see Fig. 8-15).

The arc force will cause some of the molten metal to flow upward to build the weld bead and to retard its downward movement along the pipe joint. By watching the action of the molten metal and the



Courtesy of the Hobart Brothers Co.

Fig. 8-12. Tack weld ground to facilitate making a tie-in.

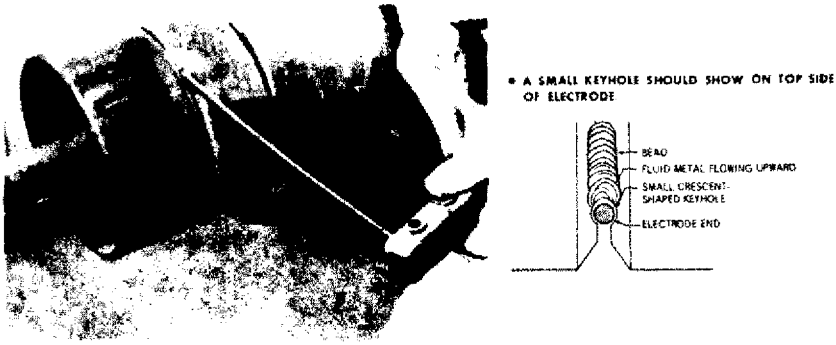


Courtesy of the Hobart Brothers Co.

Fig. 8-13. Correct electrode angle for welding the root bead using the dragging, or buried arc, method.

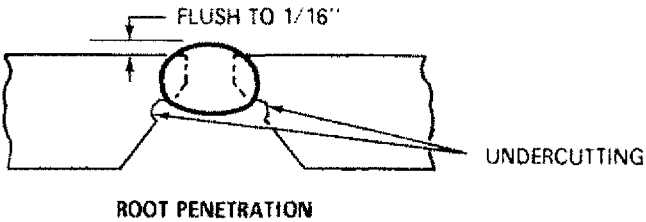
keyhole, the welder can determine the speed of travel at which the electrode is advanced.

Certain difficulties are encountered when this welding procedure is used. For example, there will always be a slight amount of undercutting at the edges of the weld, as can be seen in Fig. 8-15. However, the undercut is not harmful to the final quality of the weld



Courtesy of the Hobart Brothers Co.

Fig. 8-14. A small crescent-shaped keyhole that appears at the top side of the electrode when downhill welding the root bead by dragging the electrode in the weld joint.



Courtesy of the Hobart Brothers Co.

Fig. 8-15. Undercutting of root bead caused by dragging the electrode to deposit the bead.

in this case, because it will be removed by the second, or hot, pass, as explained later.

The high current setting together with the very short arc that is used with this welding procedure will cause more current to flow through the electrode than when a longer arc is held, because the resistance of the arc to the flow of the current is less. This will cause the electrode to get very hot. Often the heat will increase to such an extent that the electrode coating starts to break down beyond the end of the electrode. As a result, the arc will tend to blow and the electrode will have a tendency to stick instead of gliding smoothly along in the groove. If this occurs, the electrode should be oscillated slightly from side to side, as shown in Fig. 8-16, left and right.

Slight variations in the root opening often occur on pipe joints that have been fit-up properly. In some places the root opening may

Fig. 8-16. Sidewise wiggle of the electrode, to overcome its sticking when downhill welding the root bead.

be widened very slightly while in others it is slightly narrow. If the root opening is slightly narrow, the speed of travel and the electrode angle also should be reduced slightly. In places where a slightly widened root opening is encountered, the speed of travel should be increased slightly.

Increasing the speed of travel, however, can cause pinholes to form behind the arc, usually at a distance of about ⅛ inch. When this occurs, the welder must swiftly tilt the electrode holder in the direction of travel and then go back to the original position as in Fig. 8-17. Tilting the electrode causes the arc force to push some of the weld metal into the void. The welder must be alert to recognize pinholes and then immediately take the corrective action. Obviously, if the weld has progressed too far beyond the pinholes, they cannot be eliminated by this procedure.

As the weld progresses the welder must focus his entire attention on his work. He must hold the electrode at the correct electrode angle. He must watch the puddle and the build-up of the weld bead. At all times he must pay careful attention to the keyhole. Should the keyhole decrease in size, the welder must slow down the speed of welding and decrease the electrode angle slightly. If this maneuver does not enlarge the keyhole, welding should be stopped and the current setting increased before restarting the weld.

The keyhole must not be allowed to become greatly enlarged as this will result in excessive penetration or, possibly, burn-through, as

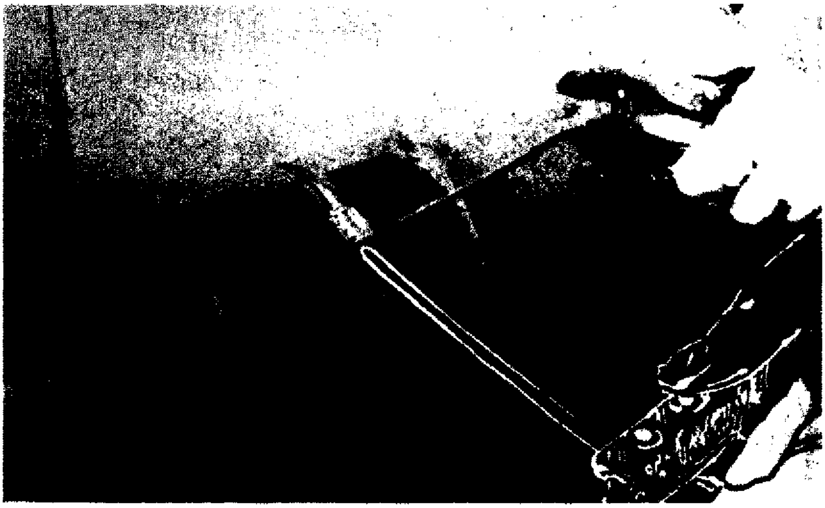


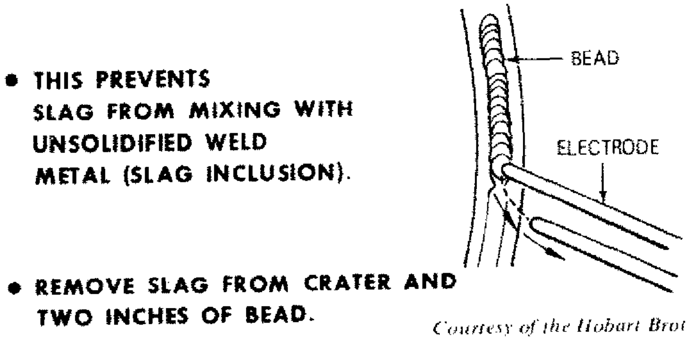
Fig. 8-17. Method of closing pinholes that can develop behind the arc when it is necessary to increase the welding speed. Swiftly tilt the electrode in the direction of welding and back, as shown.

Courtesy of the Hobart Brothers Co.

Fig. 8-18. Burn-through resulting from excessive current flow when drag-welding the root bead.

shown in Fig. 8-18. If burn-through occurs, the defective section should be removed before continuing to weld the root bead. The welding current setting should be reduced slightly when restarting the weld to prevent a recurrence of burn-through.

Stop and Restart. When it is necessary to stop the weld before the bead is completed, the arc is broken by quickly flicking the end of



Courtesy of the Hobart Brothers Co.

Fig. 8-19. Method of breaking the arc by quickly flicking the electrode downward, away from the crater.

the electrode downward, away from the keyhole, as shown in Fig. 8-19. This will prevent slag from mixing with unsolidified weld metal to form slag inclusions.

Before restarting to weld the bead, the slag must be removed from the bead and also from about 2 inches of the weld bead away from the keyhole.

To restart the weld, the arc is struck at a distance of about ½ inch back on the bead, and moved toward the keyhole, with a long arc length. After the arc has stabilized and the gaseous shield has formed, it is buried in the weld joint at the end of the previous bead. When a pool of molten metal reappears, the weld is continued as before.

Tie-ins. When the edges of the tack welds are feathered there is no difficulty in making the tie-in. The electrode is dragged along in the joint in the normal manner. As it approaches the end of the bead to which the tie-in is to be made, the electrode is moved up the sloping sides of the feathered edge. The welder must watch the molten pool of metal, and when it blends smoothly between the beads, he must reverse the direction of travel for a very short distance and then break the arc by quickly withdrawing the electrode away from the work.

Preparation for the Hot Pass. A finished root bead is shown in Fig. 8-20. The edges of the outside surface are undercut and particles of slag are buried along these edges. A high crown is usually produced on the top of the root bead when it is welded by the downhill method. This is caused by the temperature difference in the liquid metal, which is cooler at the edge of the bead than it is in the center. Filler metal that has not fused at the edge of the weld will tend to

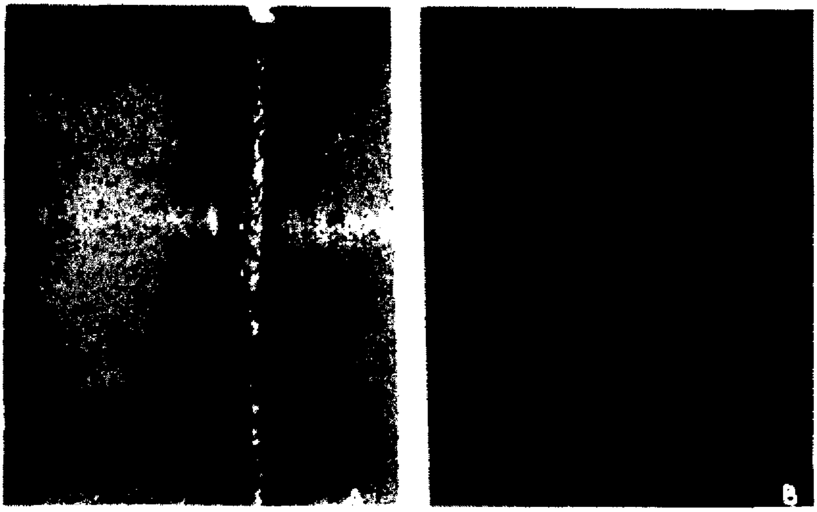


Fig. 8-20. A finished root bead deposited by downhill welding with the electrode buried in the weld joint. A. Outside of weld joint; B. Inside surface at the bottom of the joint.

flow toward the hotter region of the pool, which is at the center. Thus, the metal tends to gather in the center of the weld to form a crown.

The slag coating must first be removed from the root bead. The weld joint should then be ground to partially reduce the high crown and clean out the worst areas of undercut and slag inclusion at the edge of the weld to prepare these areas so that they can readily be filled by the next pass, as shown in Fig. 8-21. The root bead should not be ground excessively, and too much time should not be spent on this operation.

After the root bead has been ground, it should be thoroughly cleaned with a rotary wire brush to remove as much of the entrapped slag as possible. Any defects that remain will be corrected by the hot pass.

The Hot Pass. The primary objective of the second pass, usually called the hot pass in downhill pipe welding, is to burn out the remaining slag and to complete the edge fusion between the root and the base metal. Only a small amount of metal is added by this pass. As mentioned earlier in this chapter, the weld joint should be warm when this and all subsequent passes are deposited. The remaining passes should be made as soon as possible after the previous passes have been completed.

The current setting used to deposit the hot pass should be slightly

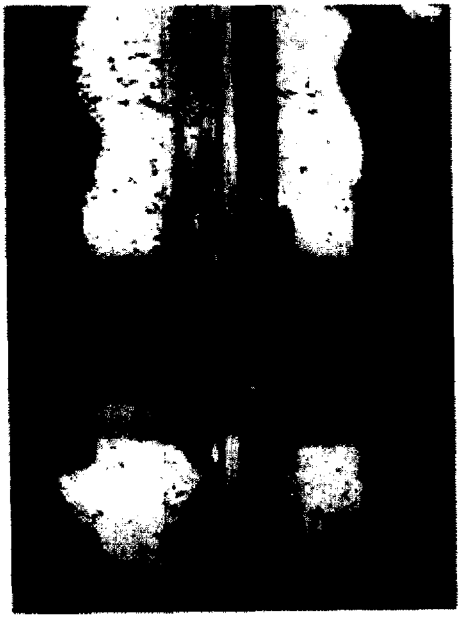


Fig. 8-21. A ground root ready for welding the hot pass.

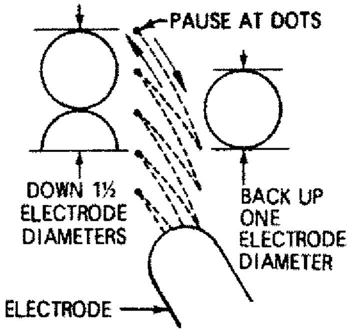
higher than for welding the root bead. While an exact recommendation cannot be given, the current setting should be in the range of 110 to 150 amps DC. The same type of electrodes used to weld the root are used here, namely, $\frac{1}{8}$ to $\frac{5}{32}$ in., E6010, E6010IP, or E7010-A. The electrode angle at which the electrode is held should be 10 to 15 degrees in all positions around the pipe.

In order to make a sound weld joint, each bead should start and end at a different position from the bead over which it is deposited. This means that the hot pass should not be started exactly at the 12 o'clock position, but at about 1 inch away, on either side of this position.

To start the weld, the arc is struck in the usual manner by holding a long arc until it has stabilized and the gaseous shield has formed. It should be struck ahead of the weld and then brought back to the starting point in order to preheat the metal over which it is to be deposited. At the starting point the arc is carefully shortened to the normal arc length, which, for the hot pass, is $\frac{3}{32}$ to $\frac{1}{8}$ inch. At this point the electrode should be held at the correct angle, or 10 to 15 degrees.

The normal arc is held at the starting point for a few moments to allow the molten pool of metal to form. The weld is then started by immediately starting to "whip" the electrode as shown in Fig. 8-22.

The purpose of the up-and-down whipping motion is to control the weld puddle and to force some of the liquid metal to flow into the corner of the weld, thereby filling the undercut. To reduce the fluidity of the puddle and to prevent overflowing, the whipping motion should be about 1½ electrode diameters long and made in



Courtesy of the Hobart Brothers Co.

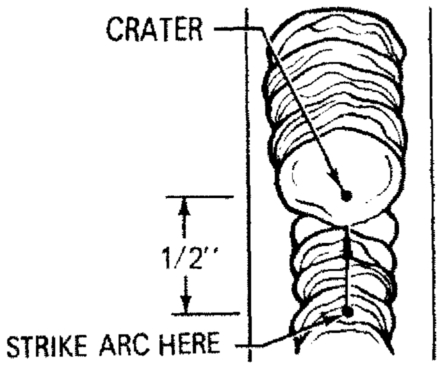
Fig. 8-22. Whipping procedure used to weld the hot pass.

the direction of welding without a change in the arc length. While whipping, the arc should be made to pause in order to deposit filler metal in the crater.

The entire hot pass is deposited using the whipping procedure. As the bead is being deposited, the welder must maintain the correct electrode angle in all positions around the pipe. He must watch the formation of the bead to see that the edges are well filled with deposited metal. In this step he has the assistance of the higher current flow which burns out the slag and promotes edge fusion.

When necessary, the arc is quenched by quickly flicking the electrode downward, away from the weld. Before restarting the weld, all of the slag must be removed from the crater and from the second pass for a distance of about 1 inch behind the crater. The arc should be struck on the root bead about ½ inch ahead of the crater, as shown in Fig. 8-23. After the arc has stabilized and the gaseous shield has formed, the arc is brought into the crater and shortened to the normal arc length. Here it is held until the crater is well filled with molten metal. The weld then can be continued by whipping the electrode as before.

There should be no difficulty in making the tie-in at the bottom of the joint. The first half of the deposited layer should be deslagged and cleaned before the weld on the second half is begun. As the weld deposit approaches the first layer at the bottom of the joint, the welder will not slow down the speed of welding. He must watch to



Courtesy of the Hobart Brothers Co.

Fig. 8-23. Restarting procedure for the second, or hot, pass.

see that the molten pool of metal fills up to blend together neatly with the first layer and he can then break the arc by quickly flicking the electrode away from the pipe.

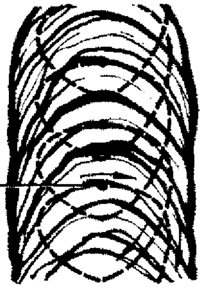
The Intermediate Passes. After the hot pass has been deposited, one or more intermediate layers are deposited to fill the weld joint with sound weld metal. The last intermediate layer should be flush, or $1/32$ inch below the top of the weld joint.

Since the objective of making intermediate layers is to fill the weld joint, slightly larger electrodes should be used, the actual size depending on the thickness of the pipe wall. For the practice pipe, a $5/32$-inch electrode is recommended as more current can be used with the larger electrode. The recommended setting is approximately 130 to 150 amps DC. Again, the electrode angle is 10 to 15 degrees, which should be maintained at all times. The arc length should be maintained at about one electrode diameter.

Before each new layer is deposited, the slag coating must be removed from the previous layer which should also be cleaned with a wire brush. When starting each intermediate layer, care must be taken to begin in a different place from the start of the layer below.

While the same welding procedures are used to weld all of the intermediate layers, the procedure does change in different positions around the pipe. These positions are: *flat*, 11 to 1:30 o'clock; *vertical*, 1:30 to 5 o'clock; and *overhead*, 5 to 7 o'clock. An especially difficult area to weld on the pipe is that between the 2:30 and 4 o'clock positions. On this portion of pipe, a different technique must be used to deposit the bead.

Welding in the flat position at the top of the pipe presents no great difficulty for an experienced welder. As shown in Fig. 8-24, the bead is deposited by manipulating the electrode in a loop-shaped weave.

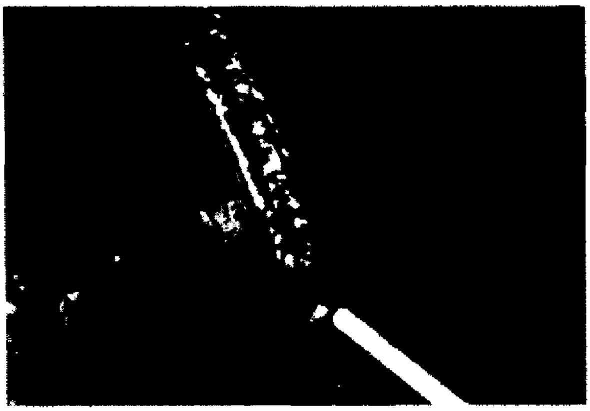


Courtesy of the Hobart Brothers Co.
Fig. 8-24. Loop-shaped weave used to weld the intermediate layer at the top of the pipe.

The "diameter" of the loop should be approximately 1½ to 2 times the diameter of the electrode so that a gaseous shield is maintained over the molten metal at all times. When the arc is in the puddle, the electrode should pause to allow time for the addition of filler metal.

Manipulating the electrode smoothly, this procedure is continued until the bead has reached the position where the weld starts to assume the characteristic of a vertical (3G) weld. At this time the weaving procedure must be changed to a slant weave, as shown in Fig. 8-25. The weave should advance downward about one electrode diameter per stroke, and the electrode should pause at the end of each stroke in order to obtain good fusion at the edges of the weld.

When the weld is at approximately the 2:30 position, the molten metal has a tendency to roll downward at a faster rate than before. To counteract this tendency, the speed of travel must be increased



Courtesy of the Hobart Brothers Co.
Fig. 8-25. Slant weave used to weld the intermediate layer at the side of the pipe.

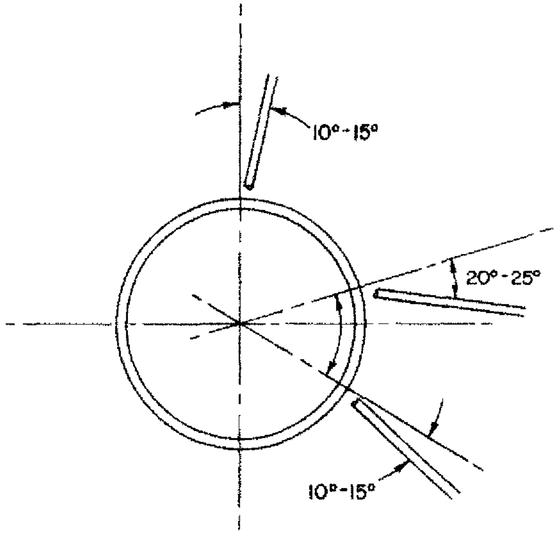


Fig. 8-26. Electrode angle used to counteract the tendency of the molten metal to roll at the side of the pipe.

slightly while weaving is continued as before, and the electrode angle must be increased to 20 to 25 degrees, as shown in Fig. 8-26. Changing the electrode angle is very important in order to control the puddle. By holding the electrode at the steeper angle and keeping the arc at the edge of the crater, the arc force helps to support the puddle by forcing molten metal near the arc to flow upward. It is also an important practice to maintain a smooth and even motion while weaving, keeping the arc ahead of the downward-moving puddle.

When the tendency of the puddle to roll downward lessens noticeably, the welding speed can be slowed down and the electrode angle changed back to the normal 10 to 15 degrees. Usually, this occurs near the 4 o'clock position. The slant weave is continued until overhead welding starts near the 5 o'clock position.

On reaching the overhead welding position the molten metal will naturally have a tendency to drip downward out of the weld. It is held in the weld joint by surface tension, assisted by the arc force. However, if the puddle is permitted to get too large and the molten metal too fluid, it can drip. To overcome this tendency and to control the puddle, a horseshoe weave, Fig. 8-27, is employed.

The objective of this weave is to reduce the size of the puddle and to decrease the fluidity of the molten metal, while at the same time promoting good edge fusion. The electrode is moved in the semicircular pattern shown in Fig. 8-27, with a pause at the end of each

Courtesy of the Hobart Brothers Co.

Fig. 8-27. Horseshoe weave used to weld the bottom of the intermediate layer.

weave to melt the edges of the joint and to deposit filler metal there in order to obtain good edge fusion. While pausing at one edge of the weld, the molten metal at the other edge solidifies, and at the center of the weld it either solidifies or becomes very mushy, thereby losing its fluidity. A smooth wrist motion should be used and the electrode advanced about one electrode diameter for each weave.

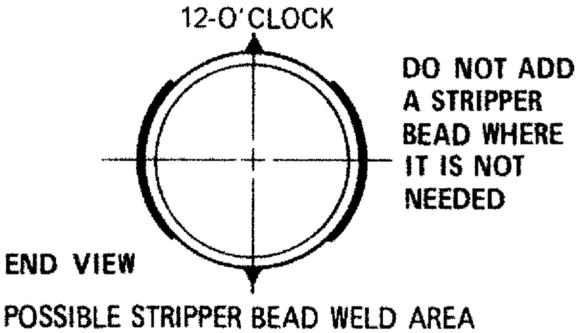
In the regions of the joint roughly bounded by the 2 to 4 o'clock and the 8 to 10 o'clock positions, the speed of travel must usually be faster than at the top and bottom of the weld, in order to control the puddle. Usually, for this reason, less metal will be deposited in this region. Thus, after depositing the next to the last layer, the weld joint will not be as thick in these regions as it is on the top and bottom of the weld.

The joint must be evenly filled with weld metal before the cover pass is made. Therefore, additional beads, called "stripper" beads, will frequently have to be deposited on the sides of the joint, as shown in Fig. 8-28. The same welding procedure is used to deposit the stripper beads as that described previously for welding in the 2 to 4 o'clock positions.

Cover Pass. The cover pass must be a bead with a neat appearance and having a slight crown (about 1/16 in.) to reinforce the weld joint. The electrode, arc length, and electrode angle will be the same as those used to weld the intermediate passes.

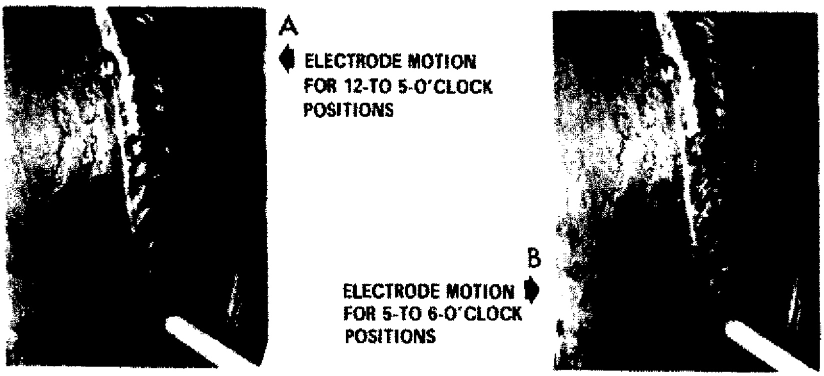
Two slightly different weaves, shown in Fig. 8-29, are used to weld the cover pass. In each case, the weave must be wider than the previous beads in order to cover the weld joint. At the end of each weave the electrode should pause when it is centered over the edge of the previous layer which will provide the correct bead width as well as fuse the bead with the edge of the joint without undercut.

As shown in Fig. 8-29A, from the 12 to the 5 o'clock positions, a slant weave is used. For overhead welding from the 5 to 6 o'clock positions a semicircular weave (Fig. 8-29B) is used. In each case the speed of travel should be such that the weld metal will build up to form the $^1/_{16}$-inch crown. To avoid undercutting and gas pockets the correct arc length, electrode angle, and speed of travel should be maintained while the electrode is manipulated with a smooth movement.



Courtesy of the Hobart Brothers Co.

Fig. 8-28. Stripper beads are used to fill in the weld joint where faster welding speed has resulted in the incomplete filling of the weld joint.



Courtesy of the Hobart Brothers Co.

Fig. 8-29. Weaves used to weld the cover pass. A. Slant weave used for 12 to 5 o'clock positions. B. Horseshoe weave used for 5 to 6 o'clock positions.

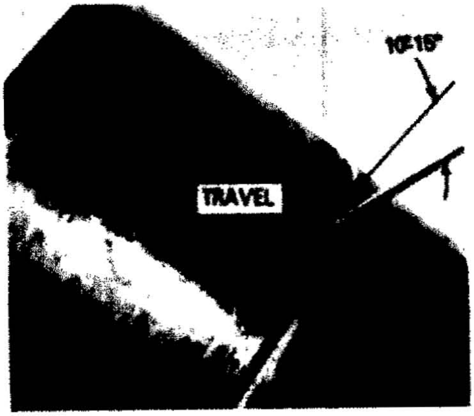
Poor Fit-up. When a poor fit-up is encountered, the necessary corrective action to be taken is similar to that used when welding by the downhill method. If the root opening is too wide, nuggets are deposited on both edges of the weld until a bridge is built across the wide gap, over which the arc can travel to tie the two edges together. The welding current should be reduced slightly when welding over-spaced joints. An important difference in the welding method occurs in welding the root bead. In order to be able to carry the arc across the wide root opening, the root bead should be started against a tack weld and the bead should be deposited by using a loop-shaped weave, as shown before in Fig. 8-24. After the root bead has filled the root opening with sound weld metal, the intermediate beads and the cover bead are deposited by using the same procedures as used over a normal size root opening.

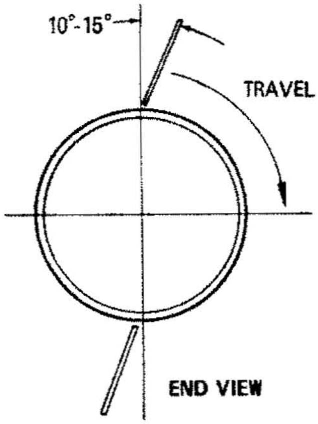
When the root opening is too narrow, the tack welds and the root bead are made by dragging the electrode as previously described; however, a higher current setting is necessary to obtain the required amount of weld penetration. Usually the current setting should be about 15 amps more than for a correctly spaced joint. During welding, the welder should pay attention to the penetration obtained. If overpenetration occurs, the electrode angle should be decreased slightly and the speed of travel can be increased. When insufficient penetration occurs, the speed of travel should be decreased slightly and, if this does not help, the current setting must be increased. Again, the remaining layers are welded in the manner described for a correctly spaced root opening.

When the root face is too wide, the root bead is deposited by dragging the electrode, using a sufficiently higher current setting to obtain the required amount of penetration. For a narrow root face, the electrode is dragged to deposit the root bead, using a current setting that is about 10 amps less than normal to prevent overpenetration. If excessive penetration or burn-through occurs, the welding current is further decreased.

Pipe Axis at 45-Degree (6G) Position. On some jobs it is necessary to weld a pipe joint with the pipes positioned at an approximately 45-degree angle. While the welding procedure used in this case is similar to welding in the 5G position, there are still some differences that will be described in the following paragraphs.

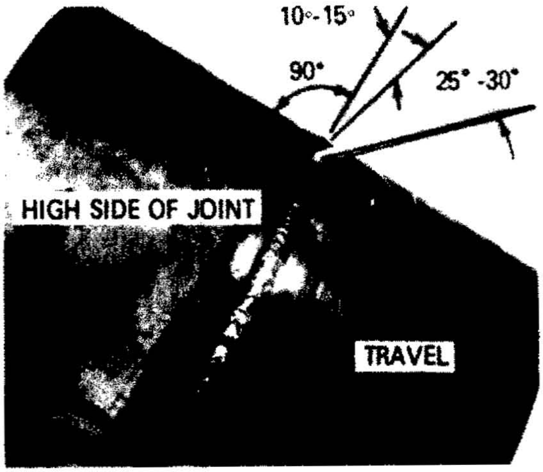
As shown in Fig. 8-30, the root bead is deposited by dragging the electrode from the top to the bottom of the pipe, as before. Depositing the hot pass is also done by using the same method as when the pipe is in the 5G position.





Courtesy of the Hobart Brothers Co.

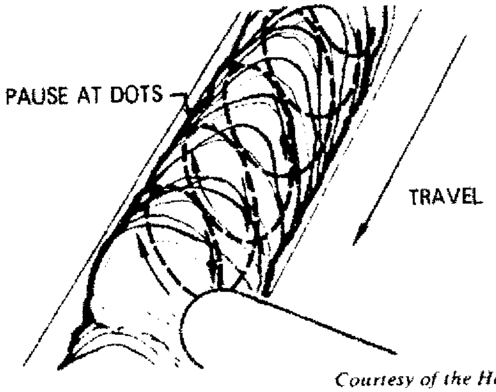
Fig. 8-30. Method of downhill welding the root bead when the pipe is positioned at 45 degrees. The electrode is buried in the pipe joint and dragged along the pipe joint to deposit the bead.



Courtesy of the Hobart Brothers Co.

Fig. 8-31. Electrode angles for depositing the intermediate and cover layers when downhill welding with the pipes positioned at 45 degrees.

Intermediate beads are deposited in a slightly different manner than in the case where the pipes are in the 5G position. First, the electrode must be held so that it points toward the high side of the joint, as shown in Fig. 8-31. With respect to a perpendicular line from the surface of the weld, the electrode angle in a plane cutting through the weld joint should be 10 to 15 degrees, as before. The side angle should be 25 to 30 degrees, as shown; as it is in respect to a plane passing through the weld joint. The current setting and the



Courtesy of the Hobart Brothers Co.

Fig. 8-32. Oval weaving motion used to deposit the intermediate and cover passes when downhill-welding with the pipes positioned at 45 degrees.

arc length (one electrode diameter) are the same as used when the pipes are in the 5G position.

In the flat welding position on top of the pipe, a loop or oval-shaped weave, as shown in Fig. 8-32, is used. The electrode should pause where the dots are shown at the upper edge in order to deposit sufficient metal there and to obtain good fusion against this edge. If possible, this weave should be continued around the side of the weld to the 5 o'clock position; however, in the vertical welding position between 2 and 4 o'clock, the puddle may start to roll downward excessively. If this happens, the electrode angle should be increased to 20 to 25 degrees and the weave pattern changed to a slant weave (see Fig. 8-25). It may also be necessary to increase the welding speed slightly, in order to keep the electrode ahead of the puddle. The arc force should be used as effectively as possible to hold back the molten metal, also the electrode movement should be kept slow and steady. When the overhead position is reached, a horseshoe weave, similar to that shown before, in Fig. 8-27, is used to finish the weld.

If necessary, stripper beads should be deposited on the sides of the weld before welding the cover bead. The same angles as in Fig. 8-31 are used to hold the electrode for depositing the cover bead. This layer is deposited entirely by using an oval weave, illustrated in Fig. 8-32. At each side of the bead, the center of the electrode should pass over the edge of the previous layer, pausing at the upper edge to obtain good edge fusion.

Downhill Pipe Welding—Heavy-wall and Large Diameter

The author originally planned to add a new chapter about downhill pipe welding, addressing the changes that have taken place over the years in the construction of cross-country pipelines, including the needed changes in welding procedures. After considering ways to incorporate the original text on downhill welding, it seemed the best approach was to complement existing material with this section,

The alloys used in pipelines today have led to larger diameters and increased wall thickness. Pipelines are expensive to construct. Long-term planning indicates the necessity for future capacity, and it is possible that the pressure at which larger volumes of natural gas and crude oil flow will also demand higher strength, ductility, and toughness of the pipeline material.

The pipe materials most encountered today for pipeline construction are the Lx60 and Lx65, as classified by the API standard. Tensile strength, hardness, ductility, and toughness have become the focal point of changes in the welding procedure. The piping materials are classified as low alloy materials. Attaining this higher strength, ductility, and toughness will be risky in terms of higher carbon and manganese content. Under bead cracking has been experienced when working with Lx56, which contains carbon and manganese near maximum acceptable limits. This pipe grade has a lower strength than the Lx65 and Lx60. Therefore, the composition of the steel used for pipelines must not only factor in weldability under hydrogen-induced conditions, but also the influence on toughness when the carbon and manganese content increase.

Certain steels, and all of the higher strength steels, are produced by some manufacturers by adding small amounts of columbium and vanadium to gain the required strength. These take the place of an increase in the carbon content, knowing that carbon has a detrimental effect upon fracture toughness. Fracture toughness is a much needed mechanical property that helps prevent running cracks from developing. This property is quite important in pipeline steel, where the initiation of a running crack can lead to destruction of miles of pipeline. Adding columbium or vanadium, or both, along with a relatively low, control finishing temperature in hot rolling, produces a fine-grain, stronger steel with adequate toughness.

The principle guide for welding pipelines is the API Standard 1104, a document written by representatives of the API, AGA, PLCA, AWS, and SNT. This standard provides the requirements for obtaining weld joints of adequate quality for gas and crude oil transmission pipe lines, or other high pressure services, using skilled welders and commercially-available material and equipment. API 1104 also outlines the methods of testing and the test requirement for qualifyied welding procedures, as well as materials for a specific kind and size of pipe joint.

When a contract is awarded, the contractor is required to prepare a document called a welding procedure. In this document, the contractor stipulates all variables, methods, and an overall plan for executing the work in order to achieve the objective of the client and responsible agencies. The following items must be stipulated:

(1) Material to be welded—chemical or alloying ingredients
(2) Welding process
(3) Diameter—group wall thickness, group combination
(4) Position—roll or fix position welding
(5) Direction of welding
(6) Number of welders
(7) Time laps between passes
(8) Preheating temperature
(9) Interpass temperature
(10) Filler metal classification
(11) Cleaning procedures (for the weld) and equipment used for such purposes

All these items and many more must be substantiated by the contractor in accordance to the code and specifications related to the job, in API 1104.

Depositing Root Bead—Heavy-Wall Pipe, Large Diameter Pipe

These pipes are known for their higher strength. These low alloy, higher strength pipe require the use of certain higher strength electrodes that include E-8010, E-7010, and E-7048. The last of these is a low-hydrogen electrode used for downhill welding. In all cases preheating to specified temperature of interpass temperatures is required.

The technique to weld the root pass with the E-8010 electrode is similar to using the E-6010 electrode, except the movement of the electrode from side to side is slightly limited. However, the speed of travel is directly in the hands of the welder. Therefore, the arc should not be allowed to get far ahead of where the weld deposit is or more than one sixteenth of an inch from where the fusion of the root openings is taking place.

On-the-job, welders are equipped with grinders that use thin blades (discs). Sometimes welders do not like the look of the edges of the root bead. When changing electrodes and restarting the root pass it is necessary to use the grinder to feather the leading edge of the crater. They can also use the grinder for quick touch-ups, then resume welding. The method for cleaning, wire brushing, and grinding is the same as previously described. After brushing, the welder should inspect the finished root bead, looking along the fusion line on both sides, and especially the extent of undercut. If undercuts along the fusion line exceed 10 percent of the weld, the welder may have to adjust the personal welding technique, as well as reduce the current setting slightly, and slow the speed of travel when making future welds. Welder helpers should be able to help ensure that the welder's need for higher or lower current is instantly met.

Controlling the amount of undercut is important because, like the electrode, the base metal has a high tensile strength. The undercut at the fusion line raises the stress. If the (preheating) temperature is allowed to drop, the stress in the areas of the undercut increases; the weld is likely to crack because it fails to withstand the applied load. Such stress also points to why preheating is so essential. Normally, if such a condition presented itself during the welding of a carbon steel pipe (undercut) with the same dimensions, it would not pose a problem, because the steel is of a lower carbon content with high ductility. Running or depositing root beads on today's pipe materials is quite different. On pipelines where the undercut must be very limited, preheating must be applied and maintained during welding. Considering the composition of the low alloy steel and its carbon content, there are reasons to believe that .without preheating and maintaining the required temperature, the unfinished weld is likely to crack. Grinding the surface of the root bead in preparation for depositing the hot pass compounds the problem.

Depositing: The Hot pass

The hot pass follows the root bead after the root bead is prepared. This weld layer is deposited with utmost care not to create an undercut, but a weld with proper fusion along the fusion line on both sides. The third pass is deposited in a similar fashion, using a controlled arc length and a very slight weave.

Filler Passes and Their Sequences

Filler passes that are deposited on heavy-wall pipes used in cross-country pipelines are welded by using stringer bead sequences. On the next page the diagram shows that the first three passes are single layer deposits, each extending across the bevel. The second diagram shows all the completed sequences.

Pipeline welds that use the stringer sequences often lack fusion on the bevel surface. Actually, this is often because welders fail to maintain the interpass temperature, which assists in having a fluid puddle.

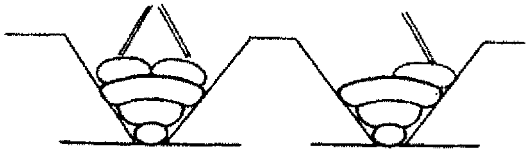


Figure 8-33A Figure 8-34B

Figure 8-35C

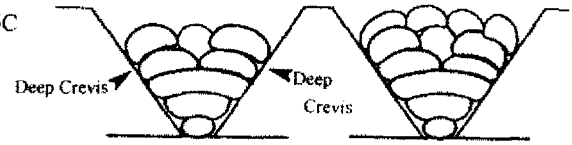


Figure 8-36D

Using the Proper Angle To Avoid A Lack of Fusion
B Slag Inclusion
C Porosity

However, the direction is downwards, and the puddle has the tenden-cyto run or sag in a downward direction. Therefore, welders have to use their wrists, not their entire arms. They should turn their wrists so that they are pointing the electrode as shown in Fig. 8-33A. Then they will be able to have the puddle wash-up on the face of the bevel more effectively each time the stringer bead is deposited, as shown in Fig. 8-34B.

This technique also removes any possibilities of having deep crevices. Such crevices are not easily corrected, even by depositing a bead with a very high current. The proper method for correcting such a problem is to use a grinder to slightly widen or open the crevice, then deposit a stringer bead, with the electrode slightly pointing toward the face of the bevel. This technique is very important for avoiding deep crevice altogether. See Fig 8-35 C above.

The term *stringer bead* has different meanings in different situations. For example, it may be used with a *bead on plate test*, when a stringer bead is deposited on the plate as straight as possible. Or, when hard-facing certain steel, the alloying element that is used in the core wire or the electrode coating should enter the weld and remain as hard particles, with limited dilution to the base metal. The hard particles become densely clustered, offering the effects of a hard surface for the purpose for which it was intended. By applying this metal using a stringer bead—with a heat value slightly above the brazing temperature—the welding is a straight line deposit, with no indication of a free puddle washing up at the edges from side to side. However depositing the stringer bead in pipe welding, the welder must see a definite indication of the puddle washing up to the sides of the groove, and a gradual transition along the edges of the weld, as shown in Fig. 8-36D. Using the stringer bead, welders need to use a slight oscillation when traveling downhill in order to achieve a homogeneous blending at the edges, and prevent peaks and valleys in situations when a few stringers are deposited side by side in such cases, the welding procedure can be adjusted to provide a higher heat input to the joint or preheat the joint area to a safe temperature.

The welder's position is gradually changing as he goes around the pipe. Therefore, his needs at any point in time is met by his welder helper and the attendent who must be trained.

This transmission pipe line material is considered to be of low alloy high strength steel which entails a welding procedure as follows...Preheating, maintaining interpass temperatures, depositing stringer beads and low hydrogen conditions. Yet the welding crew is fast moving and very well trained to meet the requirements of API-1104.

Welders who are properly trained will be able to complement the procedure. Therefore, they must be aware that the many adjustments they make instantaneously control many variables. Failure of a pipe weld is not always imminent, but success depends on the welder's ability to make adjustments at the right time.

Pipe welding crews move quickly, and have very little room for errors. But consideration must be given to the added activities that surround welding of higher strength piping, in accordance with the API-1104 Code. Procedure must also conform to the involvement of preheating and interpass temperature. Good quality welds are not the only requirement; preheating and interpass temperature are equally important to achieving the required toughness.

The high-strength, low-alloy pipe for gas and all pipelines requires preheating before welding is started. Preheating must be exercised uniformly where heat is applied by two heating burners, one on either side, and operated manually around the circumference, allowing the outer and inner walls to be brought up to the required temperature evenly in order to avoid stress.

Cover Pass

When the pipe joint is filled almost to the surface, a pipe weld is ready to be capped, using the downhill technique and stringer beads. The bevel edge should be visible on both sides to serve as a guide for depositing straight stringer beads side by side, as the weld is completed. When the first stringer bead has been completed using the bevel edge as a guide, the second stringer should use the inner edge of the first as it's guide. The electrode should be placed directly over the edge, allowing the puddle to wash up on the first. All other passes should follow the same pattern.

Welding large diameter and heavy-wall pipe requires two welders, one on either side of the pipe. They need to coordinate their starting of the weld at the top of the pipe. The tie-in at that point should be smooth and staggered two inches from the previous tie-in, as shown Fig 8-37.

An allowance should be made for the same procedure, staggering the stringer beads on all filler passes or when depositing stringers for capping. In addition, tie-in on the overhead can be difficult under certain conditions. For example, when the filler pass lacks the proper level in preparation for capping the weld. As the prceeding fill pass should be slightly below the surface. Therefore, the welder is able to maintain a constant speed of travel without having to worry about filling and capping at the same time.

As for the tie-in on the overhead when capping, the same practices are applied at the top as on the bottom. Regarding the overhead position, (a) welders can slightly lower their current setting, but maintain a smooth advancing arc at a continuous speed of travel, (b) one welder should reach the stop point, four inches ahead of the second welder, and (c) welders' view of the overhead position should be at 45 degrees; as the arc moves away from them, and they should maintain the oscillation process or movement. This allows for the slight wash-up at the edges of the puddle. The focus from that angle of viewing allows a welder to keep track of the build-up of the stringer surface, and to monitor the edges of the deposit. It is now easier for the welder to keep a uniform weld. Getting directly under the pipe with a clear view of the arc and the puddle ahead actually can add to confusion. However, by looking from the recommended angle, the welder can control the speed of travel, while maintaining a clear view of the puddle edges. The build-up and solidification pattern determines the speed of travel or any changes made during the welding process.

This chapter has covered several important steps, among them filling the pipe almost to the surface, and maintaining the straight bevel edges of the pipe. The straight edges can effectively be used as a guide line for making or depositing the first stringer bead, keeping the cap as straight as possible and uniform in width. The inner surface (edge) of the first stringer can be used as a guide for additional stringers and filler. The welder in training must continually strive for perfection, which is not easily achieved. Important considerations include:

(a) The instructor should continually help welders improve their efforts.

(b) The welders on both sides of the pipe must concentrate on making proper tie-in from the start of their training.

(c) A complete root bead should have little or no undercut; if undercut does occur, it is extremely important to maintain the preheating temperature.

(d) In some instances, porosity can be avoided by proper manipulative practices.

(e) Wire brushing is the first stage of preparing the root bead surface. Next, grinding removes the humps and other regularities on the surface of the root bead. Overheating due to friction of the grind ing disc on the weld surface should be avoided; it is indicated by discoloration on the surface of the weld (black, blue, or brown) caused by oxidation, which can lead to porosity when the hot pass is deposited.

Composition-based unweldability influences toughness. The steel has a tendency to develop higher levels of hardness when the cooling rate is faster then recommended. The heat-affected zone may not develop an entire martensite structure that would have the highest susceptibility to hydrogen embrittlement cracking. Nevertheless, this mix structure can develop or display cracking.

Attention should also be given to welding at ambient temperature. Circumstances often arise when the work is to be joined at a low temperature. Naturally, the question should be raised whether satisfactory results can be obtained by applying regular procedures. In addition to the metallurgical effects of welding at ambient temperature, there are other aspects of the joining operation that can affect weld quality under these conditions.

Suppose a weld is to be made applying the downhill technique with ambient temperature, or very low preheating temperature, on pipe material that has .25 percent carbon, .90 percent manganese, and small quantities of other alloying elements. The welder can make a valuable contribution to a weld that is defect free, and adequate both in ductility and toughness. The procedure in this case is not to ignore preheating, but to use another format that will have a preheating effect. When the first three passes are deposited, all of which are thin layers, the temperature built-up will be higher or equivalent to the required level.

This technique starts with two or three welders who expertly deposit the root bead with minimum time lost and with no defects. On completion, the welder helpers immediately grind the restarts areas. These two steps should be completed within 3-to-4 minutes. The hot pass then begins with two welders working on either side, starting at the 3 o'clock position, downwards to the overhead position. The welder at the top extends the hot pass from 12 o'clock to 2, and from 12 o'clock to 10.

After the welders have completed their respective sides to the overhead, where the tie-in has been made, the welder helpers brush that area. Time is important in completing those three passes, raising the temperature above the preheating temperature within ten minutes. Care must be taken that the root bead have no undercut. The hot pass should be properly deposited, fusing both sides of the bevel; likewise the third pass.

Porosity can develop from inadequate heat input on the bevel surface. Fortunately, this is not the case at this point. What is involved from here on is that when the stringer bead is deposited on the bevel face, the welder must supply ample heat input by angling the electrode towards the bevel surface, and then oscillating the electrode in order to have the fluid puddle wash-up on the third pass with adequate fusion, as shown in the figure on page 130. Angling the electrode also supplies sufficient heat to the bevel surface so that there is no cold surface in the close vicinity. Because of this, the slag that enters the puddle will quickly dissolve to form the weld surface coating. A fluid puddle indicates that there is fusion. The gases that enter the molten puddle will be able to escape, avoiding porosity.

The success of this approach requires (a), taking advantage of time, (b) using highly skilled welders, and (c) applying techniques that induce heat input to maintain the interpass temperature effectively. In short, angling the electrode by turning the wrist on the bevel is effective in eliminating defects, even when the pipe is preheated.

When preheating is stipulated for a procedure, the temperature must be maintained at the start of depositing the root bead, and continues even when the root bead is completed, as well as the time when the root bead is being brushed and grinded in preparation for depositing the hot pass. Effective preheating is based on understanding variables such as lapse of time between heating and starting the weld, the drop due to conduction, known as heat sink must also be taken into consideration. Furthermore, the wall thickness of the pipe also affects the drop in temperature. Thus, the actual preheating temperature specified in the procedure is likely to be higher when taking these variable into account.

Horizontal Pipe Welding (2G)

When the pipes are in a vertical position, the welding procedure used is essentially that which is used for horizontal welding and for this reason this chapter is entitled, "Horizontal Pipe Welding."

Horizontal pipe welding presents a few difficulties that are characteristic of welding in the 2G position. The molten metal in the puddle constantly tends to drip downward. The edge of the upper pipe, when in a fluid state, also flows downward causing undercuts and the development of a very large keyhole when welding the root bead. Therefore, certain correct welding practices, as described in this chapter, must be used to overcome this difficulty.

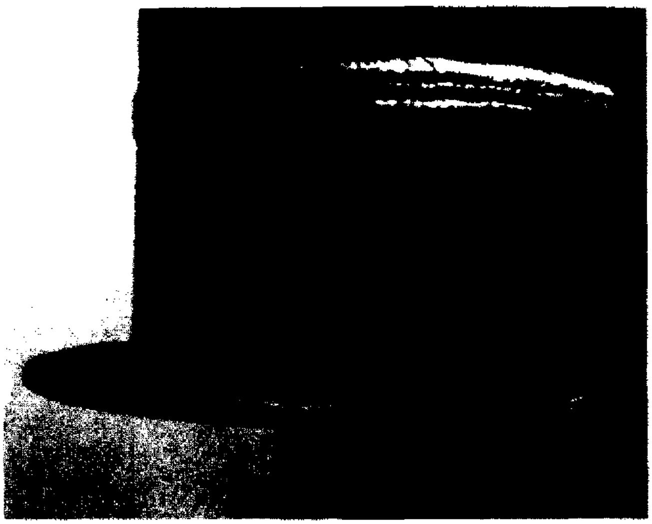


Fig. 9-1. Perfect pipe weld made in the horizontal (2G) position.

An illustration of a good horizontal weld made on a thick-wall pipe is shown in Fig. 9-1. The width of each bead or layer of weld metal should not exceed approximately three times the diameter of the electrode in order to avoid excessive weaving. For this reason more layers of weld metal are required when welding pipes in the horizontal position. After the root bead and the second pass are welded, the following beads are deposited in the manner of a bricklayer laying bricks in constructing a wall. A foundation layer is first welded in place and following layers are welded on top of it. Instead of having a single bead, the cover layer is built up in this fashion, using several beads.

In order to make high-quality welds, the welder must learn the correct technique and then apply it with consistency. The weave motion must be unchanging as the welder welds around the pipe. The same arc length, speed of welding, and electrode angle must be maintained. While welding the root bead the keyhole must be watched and during welding of all beads the welder must watch the pool of molten metal.

Preparation for Welding. Most of the procedures used to prepare the pipes for welding have been described in detail in Chapter 4 and need not be repeated here. The reader should review these procedures before going on.

For practice welding, it is best to use two 7-inch-long pipe nipples. The bevel must be cut to standard specifications and thoroughly cleaned. The pipes are then placed on end on the welding table with a bent wire spacer between them to obtain the correct root opening. After they are aligned, four evenly spaced tack welds are welded in the root of the welds as before.

HORIZONTAL WELDING OF THE ROOT BEAD

It would be possible to weld the root bead with the pipe nipples placed on end on a welding table. However, it may prove awkward to weld in this position, especially if the welding table is large. A better method would be to clamp the pipe nipples onto a welding stand, as shown in Fig. 9-2.

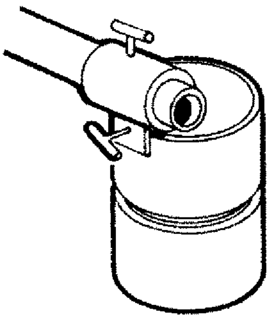


Fig. 9-2. Method of clamping pipe nipples in pipe stand for welding in the horizontal position.

The current setting should be adjusted so that it is just sufficient to provide good fusion of the base metal and the filler metal at the root opening. Usually, slightly less current is used when the weld is a horizontal weld (2G position) than when the pipe is in the 5G position. Too much current can cause serious trouble in welding by making the molten metal in the puddle and on the upper edge of the weld difficult to control. A safe procedure before starting to weld the pipe joint is to make a test weld on two pieces of scrap metal that have been beveled, to determine the best current setting.

The electrode angle for welding the root bead in the horizontal (2G) position is shown in Fig. 9-3. This angle should be

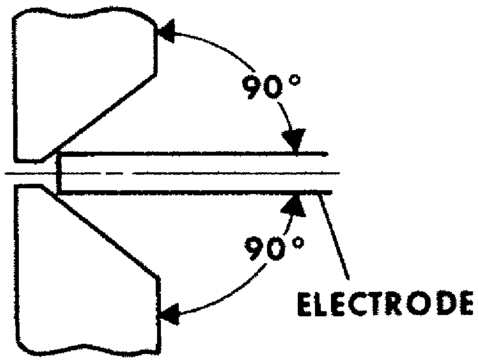


Fig. 9-3. Correct electrode angle for welding the root bead in the horizontal position.

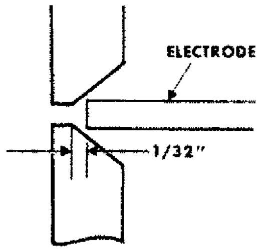


Fig. 9-4. Correct arc length for welding in the horizontal position.

maintained when welding around the entire pipe. The side angle of the electrode should not deviate more than 5 degrees from the horizontal plane. Any further deviation can result in undercutting, which, in turn, can cause cracking, especially on heavy-wall pipe.

For welding the root bead, the correct arc length is about $\frac{1}{32}$ inch above the edge of the root face (Fig. 9-4), which is shorter than that used to weld the root bead in the 5G position. The weld should not be started against a tack weld; usually it is started about 2 inches away from a tack weld.

The arc should be struck in the joint ahead of the weld. As usual, a long arc is maintained until it has stabilized and the gaseous shield has formed. It is then shortened to the normal arc length ($1/32$ inch above the edge of the root face) and held in place until the keyhole is formed. When this occurs the weld is started, using the whipping procedure.

Figure 9-5 illustrates the whipping procedure used to weld the

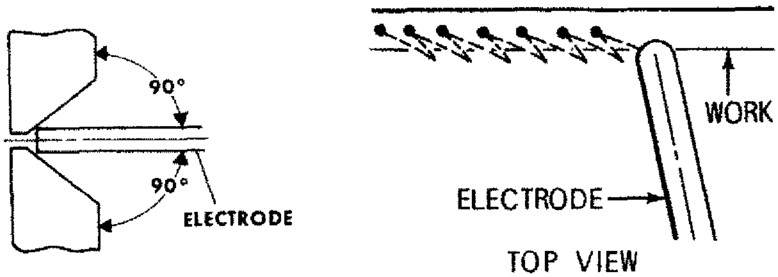


Fig. 9-5. Whipping procedure used to weld the root bead in the horizontal position.

root bead in the horizontal position. It is the same whipping procedure used when welding pipe in the 5G position. The arc is moved out of the puddle momentarily to allow the molten metal in the puddle to lose some of its fluidity. It is then returned to the edge of the keyhole, or that part of the keyhole that is adjacent to the weld bead. The arc is held in this position for a short period of time to allow filler metal to be transferred from the electrode to the puddle and to maintain the puddle in a liquid state. This action can be described as repeated "whip and pause." The arc should not be held directly over the keyhole, however, as this will cause excessive penetration, or possible burn-through.

The object of whipping is, of course, to control the pool of molten metal and prevent it from sagging. The length of stroke should be about one or two electrode diameters. An excessive stroke length should not be used as this will cause the gaseous shield to be removed from the liquid metal with a resultant harmful effect on the quality of the weld.

While welding the root bead attention must be paid to the keyhole and the molten metal. If the keyhole shows signs of increasing, the speed of welding should be increased slightly and the electrode angle decreased slightly. By increasing the speed of welding the heat is not retained in one position as long as when welding at a slower rate and the heat build-up in the weld is decreased somewhat. Slightly decreasing the electrode angle (see Fig. 9-3) allows some of the heat from the arc to escape through the root opening during whipping. To control the keyhole, the welder should maintain a short ($\frac{1}{32}$-inch) arc length at all times. By not using the prescribed shorter arc length the keyhole may become enlarged.

These measures, together with the whipping procedure, also help to control the size of the molten pool of metal. If they fail to control the keyhole and if sagging of the molten metal occurs, the weld should be stopped and the current setting lowered before continuing the weld.

The welder must avoid fatigue. If his arms become tired he is apt to slow the speed of welding and he will have greater difficulty in controlling the arc length. Fatigue can cause the welder to become erratic in his manipulation of the electrode. If fatigue should occur, it is best to stop work and rest for a few moments, rather than to continue and make a poor weld.

With practice, and by following the instructions given here, a good root bead can be made. Figure 9-6 shows the outer and inner surfaces of a good root bead.

Stop and Restart. It is necessary to stop and restart the weld several times when welding around the pipe joint. When welding a root bead the arc is quenched by a quick stab through the keyhole. For other beads the arc is reversed a short distance and then quenched by a quick withdrawal from the weld, leaving a crater behind.

Before restarting the weld, all of the slag coating should be removed from the end for a distance of about ½ inch. When welding the root bead, the arc is struck in the weld joint ½ inch in back of the keyhole. A long arc is maintained until it has stabilized and the gaseous shield has formed. The arc is then brought to the end of the bead and shortened. The welder then watches the development of the puddle of liquid metal. As soon as it is large enough, and certainly when it shows signs of sagging, he will start the whipping procedure and continue to weld as before.

When welding the intermediate and cover layers, the arc should be struck ahead of the crater of the bead being welded. After the arc is stabilized and the gaseous shield has formed, the arc is brought into the crater and shortened. The arc is slowly moved from side to side within the crater several times until a pool of liquid metal has formed. When the molten metal shows signs of sagging, the welder must start to manipulate the electrode, using the weave pattern described further on in this chapter.

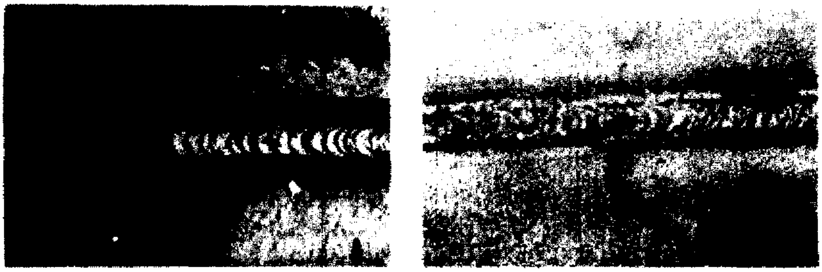


Fig. 9-6. A perfect root bead deposited in the horizontal welding position. A. Outside surface. B. Inside surface.

Making a Tie-in. Tie-ins must be made while welding toward the keyhole and toward the heavy end of a root bead. The procedures that are used in these cases are essentially the same as those for welding in the 5G position, described in Chapter 5.

When welding toward the keyhole, the weld can be continued at the normal speed of welding, using the whipping procedure. When the keyhole begins to close, the whipping motion is carried over the end of the bead to which the tie-in is being made. The welder must watch the molten metal as it fills the space between the two beads and when this space is neatly filled with metal the arc must be quenched by a sudden movement of the electrode away from the weld.

The procedure for welding toward the heavy end of a bead is very similar, except that the speed of welding must be reduced somewhat. This allows time for the heavy end of the weld to get hot enough to obtain good fusion with the oncoming molten metal. As soon as the bead that is being deposited gets close enough, the whipping motion should be directed toward the heavy end of the bead to which the tie-in is being made. It may even be advisable to pause momentarily a few times when the arc is over the heavy end. Again, as the weld metal begins to fill up the space between the beads, the welder will continue the whipping procedure. When the weld metal forms a good blend between the beads the arc is quenched.

Poor Fit-up. Poor fit-ups are also encountered when welding in the horizontal (2G) position. The welding procedures used when a poor fit-up is encountered are nearly the same as those used in the 5G position. These procedures are explained in detail in Chapter 5.

When a wide root opening occurs, a bridge across this opening must first be built by depositing several nuggets of weld metal on the root face. These nuggets need not be welded perfectly; their sole purpose is to form a bridge across which the arc can be carried to start the weld. Before the second half of the pipe joint is welded, the bridge of weld nuggets and a short length (about ½ inch) of the adjacent root bead must be removed by grinding or with a hammer and chisel.

The bridge must be built in order to weld the tack welds in place. When welding a bead across a wide root opening (which may be a part of the tack weld or the remainder of the root bead), the current setting should be reduced somewhat and a U-weave must be used. The tack weld is started at the bridge. Contrary to the procedure used for a normal root opening, when the root opening is wide, the regular root bead is started at the end of a tack weld.

The U-weave used to weld the bead should be long enough to carry the arc completely out of the puddle of molten metal. The puddle must be allowed sufficient time to solidify completely before the electrode is reversed and returned to the weld to deposit additional filler metal. When the arc is brought out of the puddle it should be made to travel up the face of the bevel, away from the edge of the bevel at the root face. If the arc is concentrated on the edge of the bevel at the root face, the edge can easily be melted away, thereby widening the root opening even more. As shown in Fig. 9-7, the electrode should be held so that it points directly at the pipe and the arc length must be kept short.

Difficulties can be encountered when welding the root bead across the wide root opening. Often they are the result of unsteadiness in manipulating the electrode while making the long U-weave. The arc length may have been irregular or the pipe bevel around the puddle

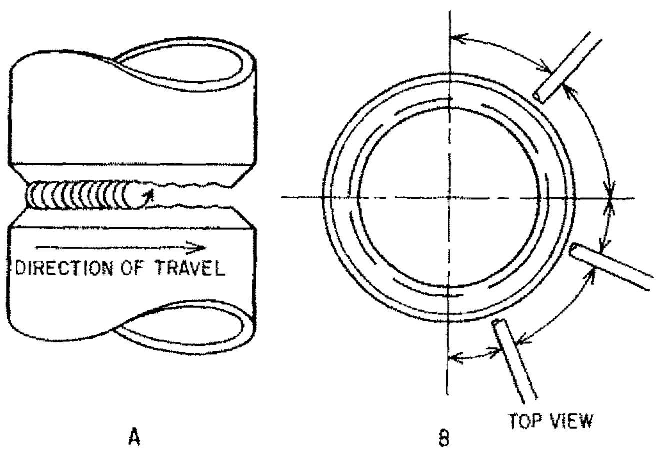


Fig. 9-7. A. U-weave used to weld a horizontal root bead when the root opening is too wide. B. Top view of electrode angle used when welding with a U-weave.

may have overheated. It is then necessary to discontinue welding for a short time to permit the weld to cool.

When the root opening is too narrow or is closed entirely, the root bead can be welded by using a higher current setting and a normal length arc. This will increase the heat input into the weld and the penetration. The puddle must not be allowed to become too large or it will sag. To prevent sagging, it may be necessary to resort to the whipping procedure.

A narrow root face can be welded by reducing the current setting and by using the U-weave to weld the bead. When the root face is too wide, the current setting should be increased slightly. If the puddle tends to sag, it may be necessary to resort to the whipping procedure or to the use of the U-weaye.

Root Bead with Low-Hydrogen Electrodes. Although low-hydrogen electrodes are seldom used to weld root beads, they can be employed if the correct technique is used expertly. An entirely different procedure is used as compared to that described for welding the root bead with E6010 and similar electrodes.

First of all, poorly fitted joints must be avoided. The heavy flux coating and the slow cooling rate resulting from the heavy blanket will cause the weld metal to sag if the root opening is too wide.

The electrode coating must be dry and it must not be chipped. Figure 9-8 shows the position at which the electrode must be held. It is held at an angle of approximately 10 degrees with respect to the horizontal plane, so that the end of the electrode points toward the upper pipe. When welding, the end of the electrode may be lightly dragged along the edges of the pipe. By positioning the electrode in this manner, the deposit of weld metal may droop slightly; however, it will very nearly have the proportion of a perfect root bead.

Low-hydrogen electrodes are not deeply penetrating and a short arc must be maintained at all times. For this reason a slightly higher current setting should be used. Moreover, the higher current setting prevents the electrode from sticking as it is being dragged along the edges of the pipe.

The arc should be struck ahead of the starting point and shortened as quickly as possible. It is then brought back to the starting point, where the root bead is started as soon as enough molten metal appears to form a puddle. A short arc must be used at all times but the whipping procedure must not be used. The bead is welded by lightly dragging the electrode along the edges of the joint while holding the electrode as shown in Fig. 9-8. By following these recommendations, an exceptionally good root bead can be welded.

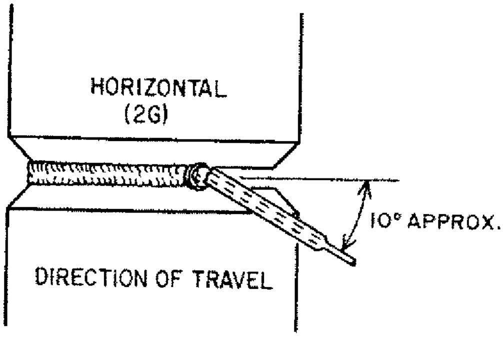


Fig. 9-8 Position of electrode when welding a root bead in the horizontal position with a low-hydrogen electrode.

The Second Pass. Before each layer of weld metal is deposited, the surface of the weld must be deslagged and thoroughly cleaned. All defective portions of the weld and extremely high humps should also be removed.

Again, the tendency of the molten metal to sag under the influence of gravity must be considered. The puddle must not be allowed to get too large. To achieve a good result, the welder must use the correct electrode angle, arc length, weave pattern, and speed of travel.

Figure 9-9 illustrates the correct welding technique that is used to weld the second pass. As before, a short arc length should be used to

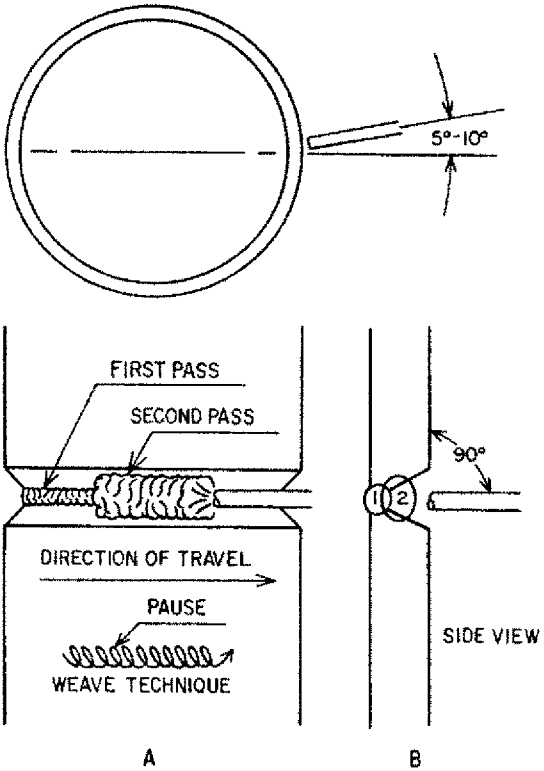


Fig. 9-9 Correct welding procedurefor welding the second pass of a horizontal weld. Note the slanted "loop" weaving technique.

weld in this position. Instead of pointing toward the upper pipe, the electrode should be held in a horizontal position, with an electrode angle of 5 to 10 degrees. The current setting should be higher than that used in the 5G position.

A slanted looped weave, shown in Fig. 9-9, is used to weld the second layer. This weave resembles a handwritten letter "l" that leans slightly toward the left. The electrode should be advanced about one-half of its diameter for each weave.

When this weave is used, the metal has a tendency to flow in two directions: the molten metal just deposited tends to trail the arc while that portion of the puddle not in the arc vicinity tends to flow in a straight downward direction. This combined action causes the puddle to flow sluggishly in any direction and sagging can be prevented if the electrode is advanced one-half of its diameter at every weave. The weave, then, is an important factor in controlling the puddle and in preventing it from sagging.

The width of the bead for the second pass is controlled by observing the edges of the root bead. The molten metal should be allowed to penetrate into the beveled surfaces of both pipes to obtain good fusion and to prevent undercut. For heavy-wall pipe (3/8 inch, and larger) the width of each layer of weld metal should not exceed three times the diameter of the electrode, when welding in the horizontal (2G) position.

On low carbon steel thin-wall pipe it is possible to use a somewhat larger weave, as shown in Fig. 9-10. In order to keep the puddle from sagging, the arc is moved downward, at a slant, and back to the upper edge of the pipe by weaving the electrode completely out of the puddle. When the arc is returned to the upper edge it is held in this position momentarily to allow the puddle to reform and the molten metal to flow into the corner of the joint. Because the heat is retained in the thin-wall pipe, the puddle usually does not freeze completely and reforms very rapidly.

This technique cannot be used on heavy-wall pipe because the

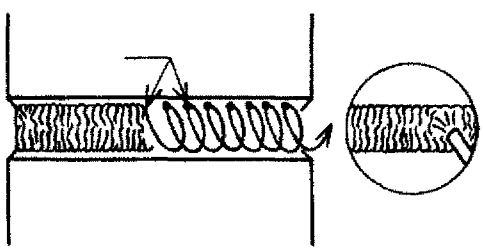


Fig. 9-10. Longer weave used to weld second pass on low-carbon-steel thin-wall pipe.

heat is withdrawn from the weld more rapidly by the thicker metal and the puddle cannot be maintained. Using this weave on heavy-wall pipe will result in incomplete fusion of the weld metal with the base metal and the metal in the adjacent weld beads. One other difficulty occurs when using this technique; when the electrode is completely out of the puddle, the weld metal is left exposed to the atmosphere, causing oxidation and porosity. This occurs very readily in high-alloy steel pipe and, for this reason, a large weave should never be used to weld such pipes.

Third and Fourth Passes. The third pass is deposited on the bevel of the lower pipe, as shown in Fig. 9-11A. A deep crevice is formed above the third bead in which the fourth bead is deposited, as shown in Fig. 9-11B.

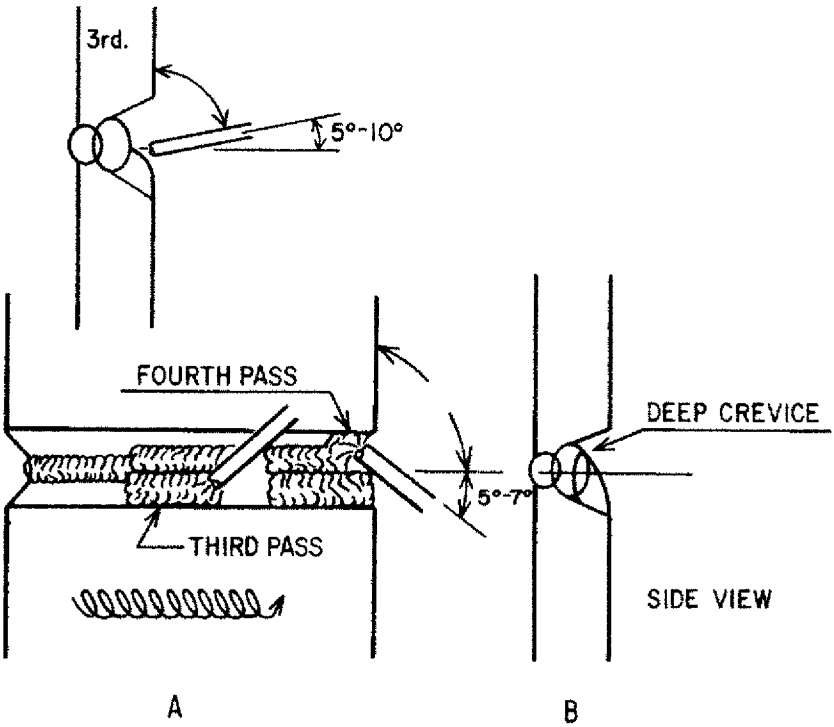
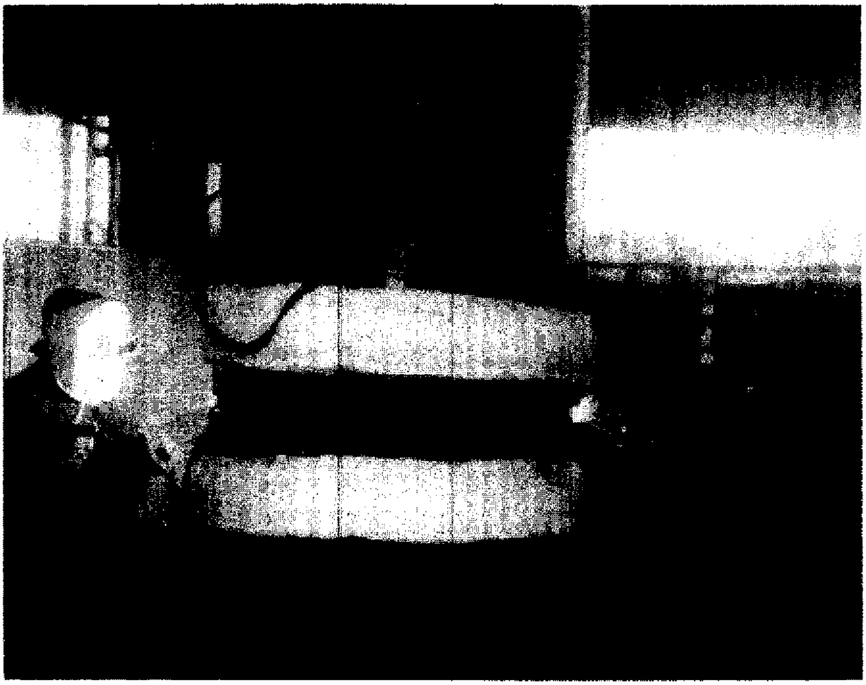


Fig. 9-11 Procedure for weldingthird and fourth passes in the horizontal position.

The end of the electrode should point slightly (about 5 to 10 degrees) toward the lower edge when welding the third layer as shown at the top of Fig. 9-11A. The electrode angle can be 5 to 10 degrees, as before.

The same slanted loop weave used to weld the second bead is used to weld the third bead. In fact, this weave is also used to weld all of the remaining layers because it enables the welder to control the pool of molten metal while at the same time depositing a sound bead.

When welding the third pass, care must be taken to prevent the third pass from being deposited close to the upper pipe. An open crevice must be left in which the fourth pass can be deposited. If this crevice is too narrow, it may not be possible to weld a sound fourth pass, as it may lack good fusion and have slag inclusions trapped in the weld.



Precautions- maintaining uniform preheating practices and maintaining for interpass temperatures during welding. (See page 140 for bead sequences.)

When the third and fourth passes are being deposited, the arc should be kept away from the extreme edges of the pipe bevel as they are easily burnt away by the intense heat of the arc, resulting in an undercut. The molten pool of metal should be allowed to wash *up to* these edges when the electrode is brought close to the edges, but not quite *onto* the edges. In this manner good fusion can be obtained at the edges without undercut.

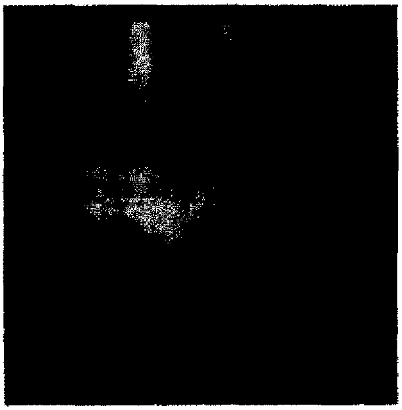
The fourth pass is deposited within the deep crevice that is located over the third pass. As shown in Fig. 9-11A, the side angle (5° to 7°) of the electrode is very important when welding the fourth pass because the force of the arc, or arc-force, must be used to help maintain the puddle of molten metal in the desired place within the crevice. If left to itself, the molten metal would spill downward, and out of this crevice. The arc-force pushes the molten metal upward, holding it in place.

The size of the puddle should be kept relatively small, about two or three times the diameter of the electrode. Then, by using the slanted "loop" weave with a steady speed of travel, a good-looking and metallurgically sound bead can be deposited.

Fifth, Sixth, and Seventh Passes (Cover Passes). These passes act as a cover pass when welding in the horizontal (2G) position. On very heavy-wall pipe the fifth, sixth, and seventh passes may be intermediate or filler passes, in which case they are welded in a manner similar to that used to weld the third and fourth pass. However, in the discussion to follow, it will be assumed that the beads to be deposited are cover passes.

The cover passes must be neat in appearance and they should form a crown, or reinforcement, of about ⅛ inch. As before, they are deposited by building from the bottom up; i.e., the fifth pass is deposited over the third pass as shown in Fig. 9-12. This pass should extend beyond the third pass about one electrode diameter at the lower edge of the pipe. Although not desirable, a certain amount of drooping of this weld will probably be unavoidable. It is important, however, that there is no undercut into the pipe when welding this bead.

The sixth and seventh passes are built up on top of the fifth pass, as shown. When welding all of these passes, the side angle of the electrode should be approximately as shown in Fig. 9-13. Again the slanted "loop" weave is used to control the puddle, which should be two or three electrode diameters in size, and a short arc length should be used. Since these beads must be sound and have a good appearance, the welder should get into the most comfortable posi-



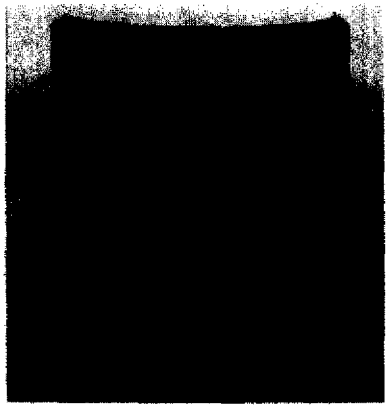
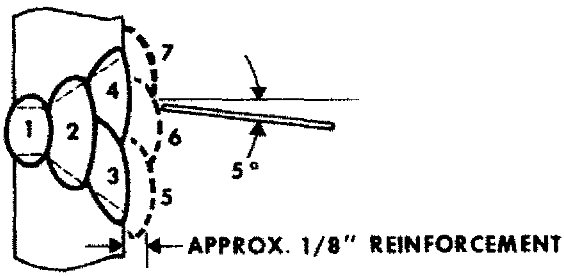


Fig. 9-12. (Left) Disposition of intermediate and cover passes when welding in the horizontal position. (Right) View of weld from inside.



Courtesy of Hobart Brothers Co.

Fig. 9-13. Correct side angle for welding the intermediate and cover passes shown in Fig. 9-12.

tion possible under the circumstances. Manipulating the arc smoothly and with consistency, the cover passes can be welded to fulfill all of these requirements.

The technique just described for depositing the filler passes and the cap, or cover pass, is the same for many types of welding, such as:

(1) Carbon steel of all composition and heavy-wall pipe
(2) Low-alloy, high-strength heavy-wall and thin-wall pipe
(3) Medium alloy, both heavy-wall and thin-wall pipe
(4) Heat-resistance steel (low- and medium-alloy steel pipe)
(5) Steel for very low temperature services (cryogenic services-pipe)
(6) High alloy steel (stainless steel pipe)

Caution is needed at all times. It starts first with the preparation of the base metal, in terms of oxyacetylene cutting and beveling, and second, with the tacking (short weld) of the pipe to be welded.

Many times, when preparing edges of heavy-wall pipe by flame cutting, the fabricator either forgets or ignores preheating the heavy-walls of low- and medium-alloy pipe. Without preheating, the effects of the alloy on high carbon pipe leads to a hardening of the bevel surface. This surface may then develop microcracks due to the very fast cooling rate. This effect is similar to other materials that are welded without preheating, though they should be preheated. With some pipe alloys the HAZ(Heat Affected Zone) may not be affected if no preheat is used. Yet, it is important to use a grinder, and remove the oxide and surface metal approximately .014 inches deep in order to avoid a hardened bevel surface.

The inside surface of the pipe edges at the root should be addressed first, before tacking the pipe together A file or stiff wire may be used to remove scale and rust. This will ensure proper fusion in the root. Tacking the pipe together for welding must not be undertaken as a temporary weld. Instead, it will be part of the entire weld or root bead. It should be given all the attention that allows it to be part of a perfect weld.

High carbon pipe materials, as well as those of the alloy type with the propensity to harden, should be preheated to avoid cracking of those short tack welds and to avoid shrinkage stress cracking. Before starting, the welder should examine both edges of the tacks to be certain there is no initial porosity or tear at the edges where the tack was discontinued.

These elongated tack welds, besides being part of the initial root pass, also serve to maintain the root opening as the root pass is subsequently completed. It is important for the welder not start or discontinue the rest of this root pass on one of these tacks. Not only is there a good chance for a cold lap to take place but the key hole penetration or reinforcement inside the pipe may not be continuously fused into that of the tack.

When welding in the 2G position, weld the pipe joint by using the stringer bead method, because stringer bead is smaller and is deposited at a faster rate. If the pipe material being welded has high hardenability, faster travel speed around the pipe ispossible so it will be important to determine if any stipulated preheat is adequate. When alloy elements capable of inducing hardenability are used in two different welded joints—with one weld being made in the 5G position at a speed of 6 inches per minute, and the other being welded in the 2G position at 11 inches per minute using the stringer bead method—there is a difference in the heat buildup in the joint.

When preheating is applied initially on hardenable steel, the interpass temperature is much higher. It should be maintained during welding to prevent a hardened microstructure and a weld with a high residual stress, which can lead to cracking. Preheating and the interpass temperature during welding slow down heat dissipation from the weld and the surrounding area, thus providing both an allowance for hydrogen diffusion and a weld with the required toughness.

It is well known that hydrogen gas, above a certain level in the welding electrode coating, and through other ways of inducement, can be observed in its atomic form in the molten metal during welding. In molten metal, its solubility is high. But as solidification or freezing begins, its solubility decreases as the temperature begins to drop. This process is slow; most likely hydrogen in its atomic form will become trapped. The second possibility would be for hydrogen to escape into the heat affected zone during welding. The heat affected zone is within the high and low critical range, and is itself a spongy reserve waiting the inducement of (atomic) hydrogen. The problem, however, is that hydrogen gas can find its way into micro fissures, slag pockets, inclusions, and other type of voids. The accumulation of this gas in its atomic form recombines to form molecules, and both the incubation and the diffusion phenomenon begins to exert tremendous pressures to produce cracking. Hydrogen and its activities alone may not cause failures in welds, but can contribute to cracking when the structure of a weld and its heat affected zone consist of hardened structure, high residual stress, and low toughness.

Low hydrogen electrodes are baked at high temperatures to reduce their moisture content. The material and clay used to manufacture electrodes are analyzed for their moisture levels before they are processed. Limestone is used in forming low hydrogen electrode coating; it gives out 40 percent of its weight in gaseous form, which protects the molten pool and the metal transfer with the arc stream. The rest of its content forms a white powdery dust, which helps form slag as well as being a fluxing agent.

The E-6010 electrode used for pipe welding is restricted to root bead on certain low-alloy steels. However, its use on carbon steel is quite popular; it can be used on any diameter size in the carbon steel category for completing the weld. Still, it is recommended that when the thickness of the pipe wall exceeds half an inch, its root bead should be deposited by the E-6010 electrode, then filled and capped by the low hydrogen E-7018 electrode. The reason is that a low hydrogen weld deposit is ductile. The E-7018 electrode has a low hydrogen content and its heavy coating is an excellent insulation to oxidation. In terms of low-alloy steel, with respect to the E-6010 electrode, the root bead dillution will depend on the percentage of alloying element in the particular steel. The dilution of the weld deposit is given consideration accordingly.

Parts of this text have described the effects of carbon and other alloying elements on steel. The discussion of carbon steel has considered steel containing as much as .10 to .25 percent carbon. Above this range, there is little doubt that precaution must be taken to plan a welding procedure that avoids cracking, brittleness, and hardening in the heat affected zone.

The properties that obviously exert the greatest influence on the weld are the propensity to harden when heated to a high temperature and quickly cooled, the manner in which the hardness in the heat-affected zone is controlled by the carbon content, and the ability to harden when cooling was controlled by the carbon, manganese, and silicon content. The formation of the martensite structure is also a factor.

The carbon range over which steel appears to face the greatest changes appears to be.25 to.50 percent. Below this range, there appears to be little cause for concern about the hardenability of the steel, under bead cracking, or a brittle heat affected zone, unless small quantities of other carbide forming elements, such as columbium, vanadium, chromium, and molybdenum, are present. When alloying elements are added, they influence hardenability.

Higher strength, toughness, and other properties are achieved by adding alloying elements and heat treatment. The welding engineer must continually seek ways of welding steel without risk of cracking and without impairing ductility and toughness. There are no simple procedures or systems to predict the behavior of a steel or alloy pipe during welding, although some progress has been made. Whatever the reason for their presence, the addition of alloying elements should be considered in any appraisal of the steel's composition from the standpoint of hardenability.

There is a comprehensive formula that takes into consideration the carbon content and its influence on hardenability as well as the martensite structure that contributes to short range stress and becomes intensified as the carbon content increases. The formula also factors in other alloying elements that add to hardenability, such as manganese, nickel, and silicon. This carbon equivalent (CE) formula is:

$$CE = \%C + \frac{MI}{6} + \frac{NI}{20} + \frac{Cr}{10} + \frac{CL1}{40} + \frac{MO}{50} + \frac{V}{10}$$

When CE exceeds .40, cracking is possible.

Welding most high carbon pipe material, and those that incorporate alloying elements in the low-alloy and medium steel, requires controlling the cooling rate. As welding progresses, welds cool at a rate known as the critical cooling rate, increasing the hardness of the heat affected zone. The structure known as martensite is known for its hardness, poor ductility, toughness, and short range stress, eventually leading to cold cracking.

The application of supplementary heat to the joint before welding is an important part of the welding procedure. It elevates the temperature of the pipe immediately before welding, and is called preheating. Preheating lowers the cooling rate as the welding arc moves along. For a given set of welding conditions such as current setting, speed of travel, and material thickness, the cooling rate will be faster for a weld made without preheating than with preheating. If the preheating is high, the cooling rate will be slower. When a piece of metal heated to 1100°F, its terminal conductivity is half its capacity at room temperature. When preheating is applied to a joint to be welded, the heat dissipation by dilution from the heat affected zone and the surrounding area is lower. Therefore, the slow drop in temperature allows for transformation, by diffusion, to a final structure called perlite instead of the hardened structure called martensite, which is more likely to form if the joint was not preheated.

This treatment in the welding operation is due to a number of reasons, the principal ones being as follows (a) to avoid cracking in the heat affected zone, (b) to increase the toughness and improve the ability to withstand adverse conditions involving impact loading at low temperatures, (c) to reduce residual stress and internal stress from shrinkage, phase transformation and reaction to restraint, (d) to minimize shrinkage and distortion, (e) to prevent cooling at elevated temperatures that would allow a ductile structure that is softer with higher toughness, and (f) to slow down the cooling rate in order to give time for hydrogen to diffuse from the hot weld, and thus avoid cracking.

When a welding procedure is stipulated as requiring preheating, it is complemented by a stated interpass temperature as well. When working with an alloy steel, the interpass temperature has an effect on grain refinement of the weld metal. The time between beads affects the extent to which the grain size is refined. Depositing weld metal immediately after another may result in no grain refinement of the weld metal. Allowing the previous bead to cool to room temperature before depositing the next bead will yield less grain refinement than depositing the next while the previous one is hot, but below the critical range.

The significance of refining successive weld beads is reflected in the notch toughness impact value.

An important question to consider asks what interpass temperature should be maintained when welding an alloy pipe. Establishing appropriate preheating and interpass temperatures depends on certain factors: (a) the carbon content and the alloying element in the particular steel, (b) the temperature at which martensite structure begins, and (c) the temperature at which 90 percent of the martensite structure has formed. An interpass temperature should be maintained at a higher temperature than that at which the martensite begins.

With regard to hardenability, a steel that is considered to be shallow hardened will have a faster cooling rate, and a steel that is considered to be deep hardened will cool at a slower rate. The alloying elements in steel, starting with those most effective in increasing the hardenability, are carbon, manganese, molybdenum, chromium, nickel, vanadium, and silicon. These elements in various quantities will determine the cooling rate, applicable to the particular alloy. In addition, heat treatment plays an important role in complementing the needed microstructure. Many formulas and booklets published by steel manufacturers and agencies establish other important criteria.

While the maniplitive techniques used when welding mild steel are similar to those required when welding the alloy steels, the welder must be aware of the unique problems that can appear as the alloy steels are subjected to the heat of welding and then the subsequent cooling down. The job operation sheet as developed by the welding engineer must be carefully followed. Not only in regard to the proper joint preparation, but also in respect to preheating and the maintaining of inter-pass temperatures.

In most cases, the root bead on medium alloy piping and other alloy materials are welded by the gas tungsten arc welding process. This process is considered hydrogen free. It protects the molten metal from oxidation by the inert gas used for shielding. In most instances when thin-wall pipe (alloy) is being welded—which requires just one or two passes—the entire joint is welded by this process. Heavy-wall pipe is most likely to have the root bead deposited by the gas tungsten arc welding process, while the rest of the weld is completed by the shielded metal-arc welding process.

Alloy Steel in High Temperature Services

Welding at high temperatures demands that the weldment be made of alloy steel because of two property limitations of iron and carbon steel, which grow weaker as temperature rises. These are a decrease in strength and an increase in corrosion and oxidation.

Chromium and molychrom steel, also known as chrom-moly, were originally developed for elevated temperature services. They have been extensively used in power plants, pressure vessel, heat exchangers, and other applications where very high temperatures are involved. Molychrom steel is used because it maintains strength at high temperatures and also resists creep, which means that it does not stretch or deform under load after long periods of use with high pressure and temperatures. Carbon steels, on the other hand, tend to stretch at high temperature service; they will become brittle in time.

A number of compositions have become popular. The molychrome steel is hardenable; therefore, the welding procedure must includes postheat treatment. The preheating temperature depends on the specific steel composition, thickness of material, and compacted joint designs.

Preheating and postheat treatment are important part of any welding procedure. But welding in itself brings out certain important factors. For example, molychrome has high strength and creep resistance. Therefore, welds made on this alloy should not contain any defects such as undercut, poor restart, or humps along the fusion line and edges, where a smooth transition into the edges of the base metal is needed. In addition, after the weld is completed, the slag covering on the finish weld should be properly cleaned by using a wire brush, preferably stainless steel. The reason for this is that chromium in steel combines with oxygen to develop an oxide on the surface of the weld. As a protective coating to prevent further oxidation and scaling, a completed weld must be clean of its slag and wire brushed so that, within a given period of time, the oxygen in the atmosphere will react with the weld metal and the surrounding area to develop such a protection.

A critical aspect of the SMAW process is the proper angle of the electrode in relation to the work. The electrode angle should never be more than 10 to 15 degrees off the perpendicular tangent to the pipe surface as it travels around the pipe. It is this requirement among all others that make the art of pipe welding so difficult to master. If the electrode angle is excessive, the arc energy is not focused properly on the work. In addition, and most importantly in the welding of the alloy steels, excessive electrode angle causes erratic burning of the flux coating which is often the cause of surface porosity and difficulty in maintaining the proper arc length. This occurs because as the electrode burns, an extreme angle to the work causes unconsummed coating to hang over the tip of the electrode much like a finger nail and actually drop off into the weld puddle. As 50 to 70% of the weight of an alloy electrode consists of supplementary alloying material contained in the coating, flakes of the electrode coating falling into the weld puddle can remain as permanent slag inclusions rather than enhancing the weld metal as it was intended to do.

Welding Steel For Low Temperature Service (Cryogenic Services)

Steelmaking plays an important role in securing the properties needed for cryogenic services. It produces steels with features such as (a) fully deoxide steel (fully killed steel), (b) fine grain, (c) heat treatment, quench and tempered (d) alloy with nickel, (e) minimal use of carbon, and (f) reduction in the sulfur and phosphorus content to a lower level than will normally be found in other alloys used at room temperature. Steel that contains nickel, with controlled grain size, heat treatment, and other features mentioned above, can improve fracture toughness.

Steel Nickel Content	Lower Service Temperature
2%	-75 F
3%	-150 F
5%	-200 F
9%	-320 F

The increasingly strong demand for cryogenic service has focused on the need for strength, toughness, and assurance against brittle failure when services temperatures decrease toward absolute zero or lower. Construction welds for cryogenic services has become a specialized science.

When making welded pipe joints on the three category of alloys, attention must be given to the preparation, which is similar to that for material or alloys discussed for high temperature and pressure in service. The root bead must be uniform all around. Both pipes to be welded should be properly aligned, with the internal alignment consistent in terms of the internal walls. During the welding, all efforts must be made to avoid undercut, poor restart, and deep crevices along the fusion line closest to the bevel, In addition, the cover pass should not have a high crown with a sharp transition into the base metal, but instead a gradual transition. This will depend on the size of the electrode being used and the technique. The root pass should be made with the GTAW process along with pulsed current control. There should be no internal defects. Any sign of undercut on the surface of the filler should be ground away.

Nickel Steel of the 9% Grade

This grade of steel was initially developed to provide strength and extreme toughness at very low temperatures. It would provide an alloy with the required toughness and strength at very low temperature, 262°F, needed for tank that store liquified natural gas. These tanks are heat treated and supplied as quench and tempered steel, with a maximum thickness of two inches. The welds are not subjected to any heat treatment. Preheating is very seldom applied unless the temperature has dropped to temperatures lower than 70°F.

The electrodes used for welding this type of material are high nickel-chrome iron electrodes specified as AWS-E-NIC, Fe-2 and E-NiCrFe-3. The SMAW, combined with the electrode specified above, requires less heat and the application of stringer beads. The flow of the puddle is not as fluid as those from either low alloys or high alloys such as stainless steel. In addition, the puddle will not wash up to the sides to any appreciable degree. Therefore, the welder will have to deliver the weld metal in the area where it is needed by manipulation of the electrode. If the electrode size is large, it may compromise the quality of the weld. Supervisors should be cautious finding the appropriate size electrode to use; a large size can end up requiring a lot of time grinding.

CHAPTER 10

Welding Complicated Pipe Joints

The principles of pipe welding have been treated in the last six chapters. Much emphasis has been placed on small, but important, details, such as the preparation of the pipe joint, striking the arc, the arc length, the electrode angle, and controlling the molten pool of metal. Procedures for welding root beads, intermediate layers, and cover passes have also been explained in detail. These same principles and procedures are used when welding more complicated pipe joints, with some slight differences.

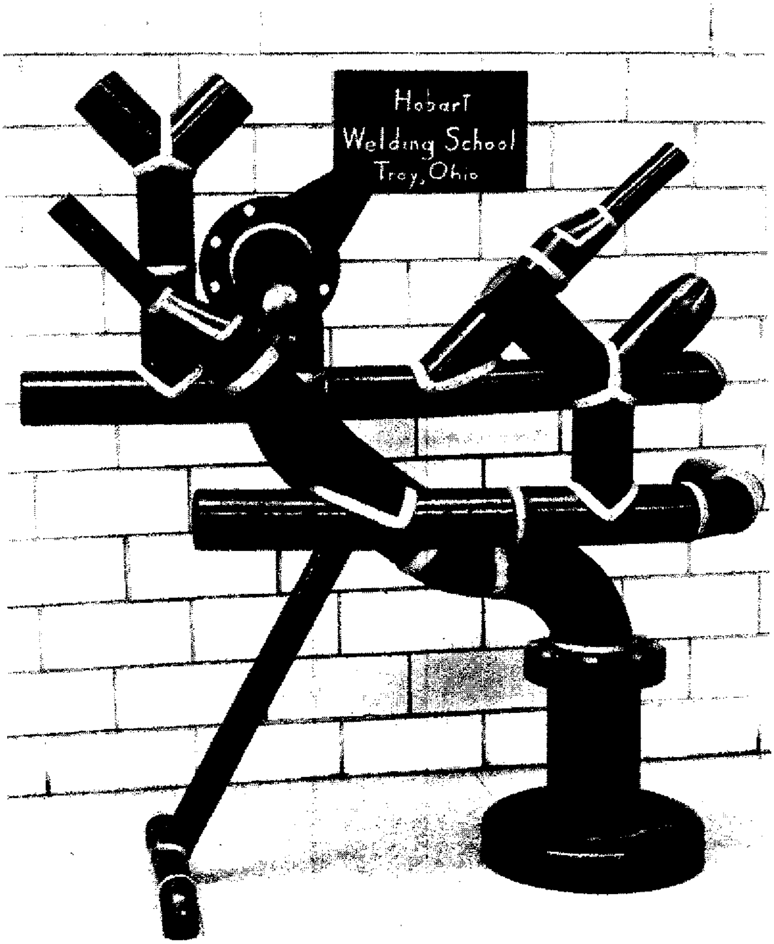
Welding Variations for Complicated Pipe Joints

In this chapter, emphasis will be placed on slight variations in the procedures, which are required for welding more complicated pipe joints, as those illustrated in Fig. 10-1. This does not mean that details such as the preparation of the pipe joint, striking the arc, etc., can be neglected. On the contrary, they are just as important as before, and if the weld is to be sound throughout, they must be performed in a craftsmanlike manner.

Root Beads. The foundation of any successful pipe weld is the root bead. When welding more complicated pipe joints the same holds true and procedures are exactly the same as those described in previous chapters.

The welder must determine whether to weld the root bead uphill or downhill. Usually, uphill welding is preferred. By this method it is easier to control the weld metal and to obtain a good weld, especially when consideration is given to the various directions in which the weld must be deposited on some of the pipe joints. Moreover, root beads deposited by the downhill method must be ground and grinding certain parts of some of the more complicated weld joints, such as in sharp corners, is difficult.

When welding a root bead on a complicated pipe joint, the welder must also decide in advance what procedure to use. Usually, he



Courtesy of the Hobart Brothers Co.

Fig. 10-1. A variety of perfectly welded pipe joints.

should start to weld at the lowest part of the pipe joint. If this requires overhead welding, the electrode should be advanced at a slow, steady pace, with or without whipping the electrode. When the joint requires welding in the vertical uphill or in the flat position, the whipping procedure is used to control the puddle. Whipping is also used to weld in the horizontal, or nearly horizontal, welding position; here the arc length must be shortened somewhat.

This is but a brief review of root-bead welding. For more details, the reader should refer to previous chapters. In the remainder of this chapter, root bead welding is not discussed in detail; however, when actually welding a more complicated weld joint this part of the weld must be given as much attention as welding the filler layers. Failure to do so will most certainly result in a defective pipe joint.

Intermediate and Cover Passes. There are also great similarities between the procedures already described and those used to weld the intermediate and cover layers on more complicated joints. A welder who has mastered the principles and procedures treated up to this point should have no great difficulty in learning how to weld the filler passes on the pipe joints to be treated further on.

The intermediate and cover layers on the more complicated pipe joints might be called weave layers because a weave is usually necessary to control the pool of molten metal and to fill the weld joint with sound metal. The weaves to be described in the following pages have all been used to make high-quality weld joints. Other techniques have also been used, but they are not likely to produce better welds. The beginner should first master the procedures described in this chapter; then, if he chooses, he can experiment with other techniques.

There are exceptions when the following procedures should not be used. These exceptions will be treated at the end of this chapter. However, when these procedures *are* used, the welder must not neglect the following details:

1. Remove the slag from the previous layers and clean the weld joint thoroughly.
2. Supply adequate heat input by having the correct current setting for the weld to be made.
3. Strike the arc in the joint, allow it to stabilize, then allow time for the gaseous shield to form before the arc is shortened; continue to maintain the correct arc length at all times.
4. Maintain the correct electrode angle.
5. Manipulate the electrode smoothly and maintain the correct speed of travel.

Some of the joints will require welding in two or three directions. In such cases the welder must be alert to change the electrode manipulation and angle as required. He determines when these changes are required by the behavior of the molten pool of metal. He must avoid undercuts, sagging, and a bead of poor appearance.

The recommended procedures to follow are described by illustrations which show the weave pattern to be used as in Fig. 10-2. In studying the illustrations of the weave pattern on the following pages, the lines that describe these patterns have the following meaning:

1. Heavy lines indicate a normal speed of travel, where filler metal is, therefore, deposited.
2. Light lines indicate a faster speed of travel to avoid any regular deposit of filler metal and, at the same time, to temporarily remove the arc from the puddle in order to cool the molten metal and prevent it from sagging.

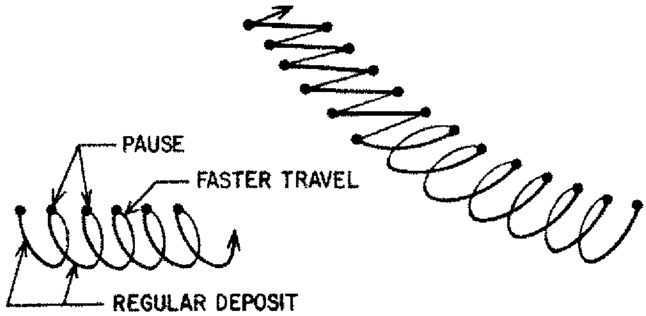


Fig. 10-2. Designation of weave pattern symbols. Heavy lines: normal welding speed; light lines: faster speed of travel; dots: pauses.

3. Dots indicate a pause in the movement of the electrode in order to heat the metal and to deposit filler metal. Often this is done to prevent undercutting.

Uphill Welding with Pipes in an Angular (6G) Position

The procedures shown in Fig. 10-3 are used when the pipes to be welded are at an angle, or approximately in the 6G position. In this case the joint is a butt joint. The bead is started by overhead welding at the lowest part of the pipe. As the bead progresses around the pipe, the welding procedure changes slightly. The welder must pay careful attention to the electrode angle, which is 10 to 15 degrees, and to the side angle, which is 15 degrees, as shown in Fig. 10-3B. By pointing the electrode toward the upper edge of the joint, the arc force assists in preventing the puddle from drooping downward. Also, by pausing when the arc is against this edge, sufficient metal is deposited to assure good fusion and to prevent undercutting.

Starting at the 6 o'clock position, the bead is welded by using a slanted "loop" weave, as shown inside the circle in Fig. 10-3A. This

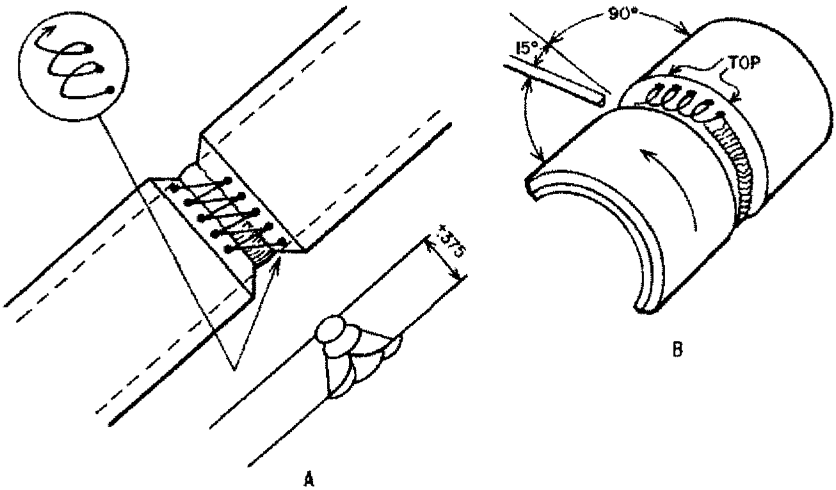


Fig. 10-3. Weave patterns used for uphill welding of pipe joints in angular (6G) position.

weave allows the puddle to cool slightly, thereby preventing the molten metal from dripping. A pause is made against the upper edge.

Along the side of the joint, the weld will assume the characteristic of an uphill vertical weld. As shown in Fig. 10-3A, a slightly modified slant weave should be used here, while pausing at both edges of the joint.

When the tendency of the metal to sag diminishes near the top of the joint, the welder should revert back to the slanted "loop" weave, pausing only at the upper edge. Both sides of the pipe are welded in this manner.

If the wall thickness of the pipe exceeds ⅜ inch, a weave should not be used. In this case, the joint should be filled by welding a series of stringer beads, made by moving the electrode upward, at a slow, steady pace without extensive weaving, as in Fig. 10-4.

Full Lateral Joint

When two pipes are joined together as shown in Fig. 10-5, the edges of the joint are beveled and a root bead is first deposited in the usual way to close the joint. The intermediate layers and the cover layers, however, assume the characteristics of a fillet weld.

In effect, four separate joints, two on each side, must be welded.

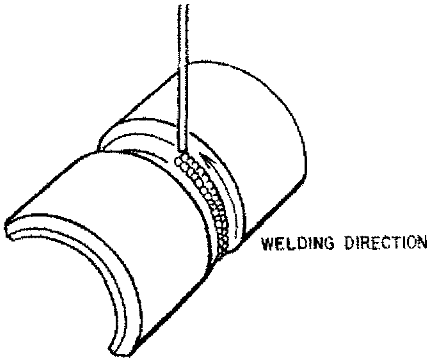


Fig. 10-4. Stringer beads deposited when welding heavy-wall pipe in the 6G, or similar, position.

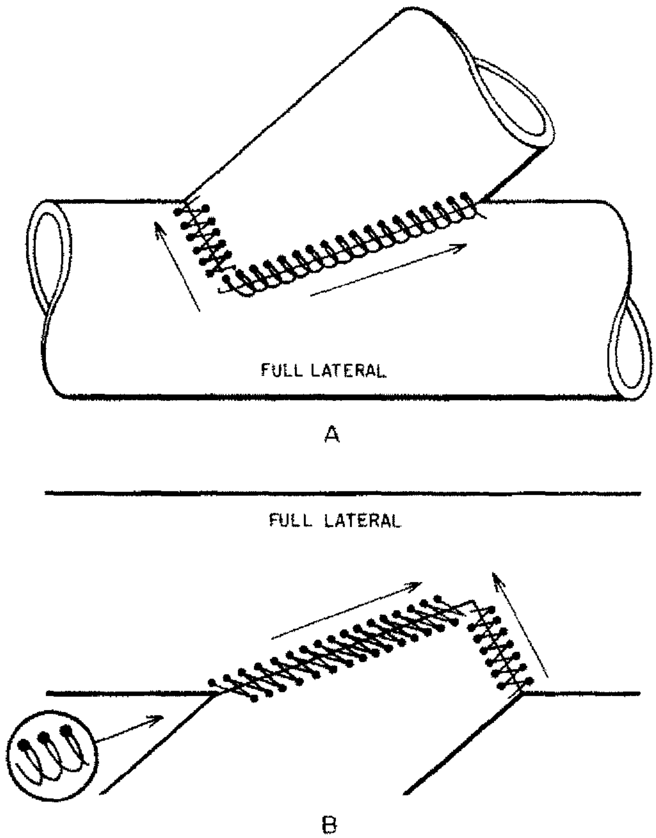


Fig. 10-5. Weave patterns used to weld a lateral pipe joint. A. With intersecting pipe on top of horizontal pipe; B. With both pipes in a horizontal position.

The weld is started at the bottom of the joint and proceeds toward the top of the horizontal pipe, where the tie-in is made.

In Fig. 10-5A, the intersecting pipe is located on the top of the horizontal pipe. The weld going up the steeper joint is made by using a slant weave, pausing at both edges. A slanted "loop" weave is used to weld up the other joint. The puddle will have a tendency to droop which is overcome by the slanted "loop" weave and by pausing at the upper edge of the joint.

In Fig. 10-5B, both pipes are in a horizontal plane. The bottom of the pipe involves overhead welding which gradually changes to vertical uphill welding. At the top of the joint the welding procedure becomes essentially flat welding.

To start the weld in the overhead position, a slanted "loop" weave is used to prevent the puddle from dripping. The electrode should pause at the upper edge of the joint. When the tendency of the puddle to droop diminishes, the weave pattern should be changed to a modified slant weave, which is continued to the top of the joint.

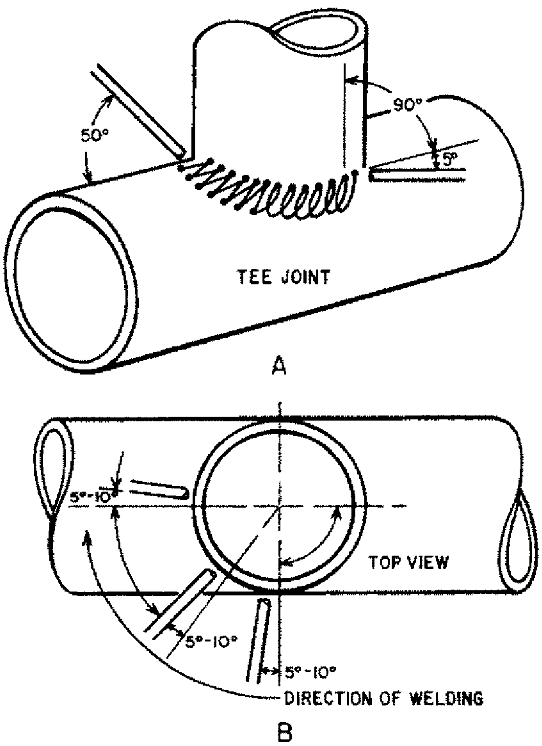


Fig. 10-6. A. Weave pattern for welding a T-joint with intersecting pipe on top: B. Electrode angle for welding the T-joint.

The welder must be alert when welding around the 3 o'clock position on both sides of the joint. He must pay close attention to the electrode manipulation and, if possible, he should not stop the bead in this position.

T-Joint with Intersection on Top

A typical T-joint is shown in Fig. 10-6. The joint must be very carefully prepared by beveling the edges so that a good fit-up is obtained. After the root bead is welded, additional filler beads are deposited to fill the joint and give it more strength.

On both sides, the weld is started at the lowest part of the joint. The tie-in of the beads is made at the two highest parts of the joint. While welding around the joint, it is important to maintain the correct electrode angles, which are shown in Fig. 10-6.

A slanted "loop" bead is used to weld the lowest part of the joint in order to prevent the puddle from drooping. The electrode should point slightly upward (see Fig. 10-6A) to allow the arc-force to assist in controlling the puddle. To allow the bottom of the joint to cool slightly, thereby reducing the tendency to droop, the electrode should pause momentarily at the top of the weld joint. This also provides additional metal at this part of the joint.

When the tendency of the puddle to droop decreases, the weave pattern is changed to a slant weave and the electrode pauses again at both edges of the weld. The slant pattern is continued until the bead reaches the top of the joint.

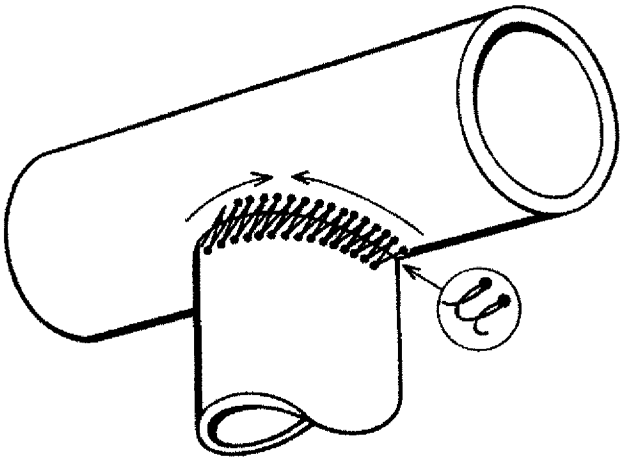


Fig. 10-7. Weave pattern for welding T-joint with intersecting pipe below horizontal pipe.

T-Joint with Intersection on Bottom

The procedure for welding the T-joint shown in Fig. 10-7 is similar to welding the previous T-joint, where the intersection is at the top of the horizontal pipe. First a root bead is welded, starting at the lowest part of the joint. This is followed by several additional beads that also start near the lowest part of the joint; however, all of these beads must overlap each other. A bead should never be started at the same place where the next lower bead was started.

Starting the filler bead in the lower region of the joint, a slanted "loop" weave is used since this portion of the joint is in the overhead position. A slight pause is made at the upper part of the joint when making this weave.

As the weld progresses around the joint, and when the molten metal loses its tendency to drip, the weave is changed to a modified slant weave pattern, as shown in Fig. 10-7. The electrode should pause at both edges of the joint when this pattern is started. This pattern is used until the layer is stopped at the top of the joint.

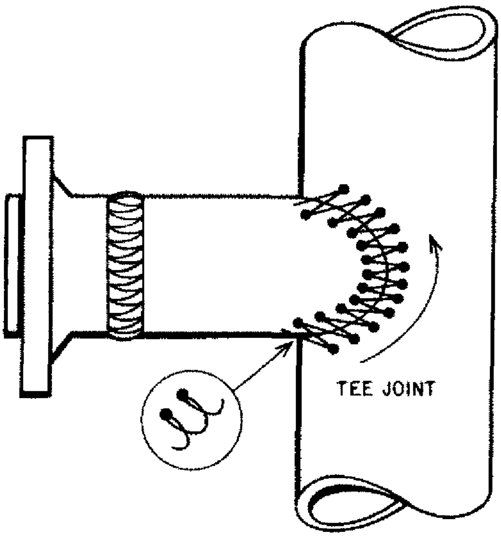


Fig. 10-8. Weave pattern for welding T-joint with intersecting pipe located at the side of the vertical pipe.

T-Joint with Intersection at the Side

Another common orientation at which T-joints must be welded is shown in Fig. 10-8. In this case, the weld must be made in three welding positions, namely: overhead, vertical uphill, and flat, in the order given. The overhead weld is made using a slanted "loop" weave while for the other two welding positions, a slant weave is used.

Y-Joint

A Y-joint is illustrated in Fig. 10-9. The pipes are first joined together by a root bead after which the filler beads are added. Welding is done by working from the bottom toward the top of the joint. Three tie-ins must be made. One tie-in is made at the highest part of the joint and two are made at the sides of the joint (one on each side) at the point of intersection of the three pipes.

It is best not to start a bead at the point of intersection of the three pipes because the heat will be withdrawn more rapidly at this point than anywhere else. For this reason, one of the beads should be continuously welded past this part of the weld. This bead should be

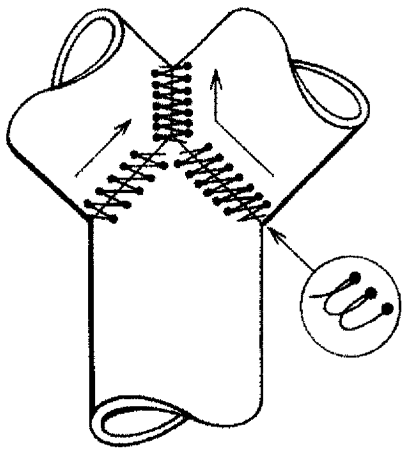


Fig. 10-9. Weave pattern for welding a Y-joint.

deposited first. The bead below the other pipe then can be welded up to this point, where the tie-in is made.

This joint requires welding to be done in three basic welding positions. A slanted "loop" weave is used to weld in two places where overhead welding is required. The parts of the joint that require vertical uphill and flat welding are welded by using a slant weave, as shown in Fig. 10-9.

Special Precautions

Portions of the pipe joints that require welding in the horizontal (2G) position, in some instances, should not be welded by using a weave. While the recommendations given in the preceding pages usually can be used, they must sometimes be modified when it is necessary to weld a bead in the 2G position.

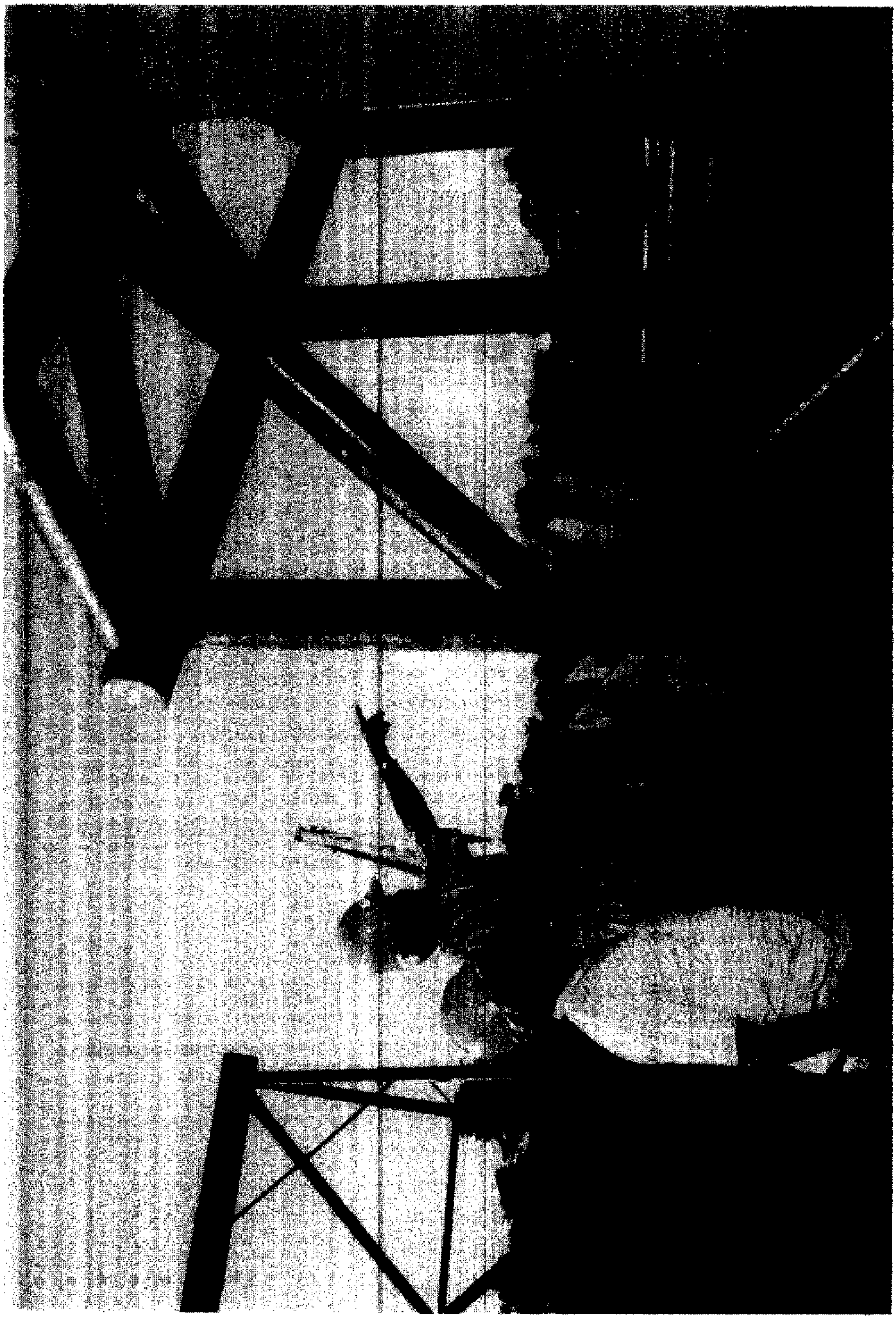
When the weaving procedure cannot be used in the horizontal welding position, the weld is made by depositing a series of "stringer" beads in this portion of the joint. Stringer beads are deposited by moving the electrode at a slow, steady pace, with very little weaving. The situations where a weave pattern cannot be used in the 2G position are listed below:

1. When welding high-alloy pipe joints
2. When using low-hydrogen electrodes
3. When welding very heavy-wall pipe joints.

Using a wide weave pattern to weld in the horizontal position will momentarily expose the hot metal to the atmosphere. When welding pipe having a higher alloy content, this pattern will result in oxidation and porosity in the weld metal. Welding stringer beads provides better protection against oxidation and porosity as the gaseous shield will be maintained over the hot metal. Therefore, stringer beads instead of a weave should be used to deposit the bead when welding higher alloy pipe in the horizontal welding position.

The weld metal deposited by heavily-coated, low-hydrogen electrodes is very fluid and cools very slowly. When the deposit is in the horizontal welding position, it will tend to sag and entrap slag. Also, the temporary removal of the gaseous shield resulting from a wide weave pattern will cause the slowly cooling metal to absorb oxygen, forming oxides. For these reasons, stringer beads should be used to weld in the horizontal position when welding with low-hydrogen electrodes.

Heat will dissipate more rapidly and the molten metal will solidify more rapidly in thick-wall pipe than in thin-wall pipe. Moreover, more heat is required to melt the metal in thick-wall pipes because a larger amount of heat from the arc is lost to the walls of the pipe. To overcome this difficulty the current setting is increased to provide more heat input, which creates a larger pool of molten metal. In the horizontal welding position the large pool of molten metal will tend to sag and, if a wide weave is used, difficulty will be experienced in preventing cold lap and undercutting at the upper edge of the weld bead. Therefore, heavy-wall pipe should be welded with stringer beads when in the horizontal, or similar, positions.



CHAPTER 11

Introduction to Welding Metallurgy

The materials used by pipe welders are primarily metals. It is, therefore, logical that a better understanding of the properties and the nature of metal will be useful in pipe welding and the objective of this chapter is to enlarge upon this subject.

Metals have distinguishing characteristics that are important to know. In the solid state they exist in the form of crystals and they can be deformed plastically. All metals are good conductors of heat and electricity, and have a metallic luster that readily reflects light.

A few metals, such as copper and aluminum, are used commercially in their pure form. Most commercial metals, however, are not pure metals; they are usually a mixture of metals called alloys. For example, brass is an alloy of copper and zinc, and the so-called silver brazing alloys are mixtures of silver, copper, and zinc, with amounts of cadmium and tin sometimes added. Most of the aluminum used in industry is in the form of aluminum alloys containing manganese, magnesium, silicon, zinc, or copper. Plain carbon steel is an alloy of iron and carbon. Alloy steels contain additions of other alloying elements (chromium, tungsten, vanadium, nickel, etc.) to enhance their properties. The properties of complex metal alloys can best be learned by first studying the basic concepts of metallurgy.

Properties of Metals

In the following paragraphs the basic properties of metals are defined and discussed. However, the testing procedure used to obtain values of these properties is not treated. Information on these procedures is available elsewhere.

A characteristic of metals is their ability to resist large external loads. Although, perhaps, it is not correct to speak of internal loads in metals, it is a useful idea to consider stress an internal load. In this sense, an external load applied at one point in a metal will result in an internal load at many points inside the metal. It is really the ability to resist these internal loads, or stresses, that provides metal with the ability to resist externally applied loads.

Stress. If in Fig. 11-1A, a load of 1,000 lbs is acting downward on the rectangular column, and if the area at the end of the column is 2 sq in., the stress on the bearing plate on which the column rests is 500 lbs per sq in. (1,000 lbs ÷ 2 sq in.).

Stress is defined as the load per unit area.

In countries using the English system of measurement stress is always given in pounds per square inch (lbs per sq in.). Where the metric system is used, stress is given in newtons per square millimeter (N/mm^2), where 1 lb is 4.44822 newtons.

There are several ways in which stresses act inside a piece of metal. In Fig. 11-1A, the stress is a compressive stress and, in addition to the bearing plate, every particle of the metal inside the column is subjected to a compressive stress. Usually other kinds of stresses in combination are also present; however, for simplification, it can be said that the stress in the column is compressive.

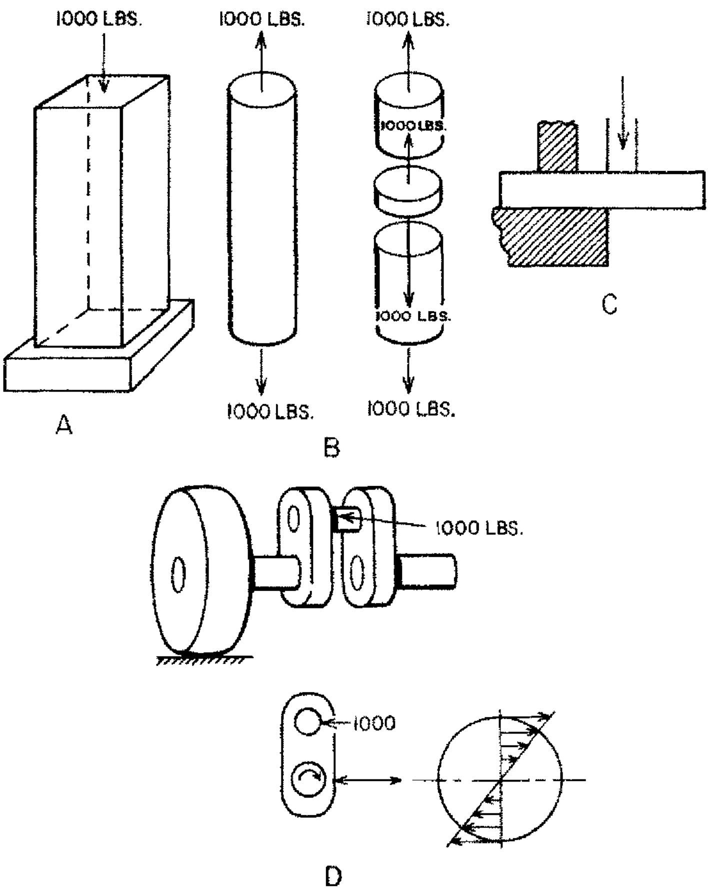


Fig. 11-1. Stresses in metals. A. Compressive; B. Tensile; C. Shear; D. Torsional (shear).

In Fig. 11-1B, a round rod is shown being pulled at each end by a 1,000 lb load. If the cross-sectional area of the rod is 1 sq in., the stress in the rod is 1,000 lbs per sq in., and it is in tension. If we can imagine a disc-shaped slice anywhere in the rod, this slice is being pulled by the metal to which it is attached on each side. The stress on the slice (any slice in the rod) is 1,000 lbs per sq in. tension.

Figure 11-1C shows another kind of stress, a "shear" stress. Each section of the metal in the area of the punch and the die is resisting the severance of the metal by the internal shear stresses that are set up by the load. When the internal shear strength of the metal is exceeded, it will fail or shear off.

When a shaft, such as the crankshaft in Fig. 11-1D, is subjected to a torsional load, internal torsional stresses are set up to resist the external load. Torsional stresses are not distributed uniformly across the entire cross section of the part carrying the load. They are greatest at the outside and are zero at the center of the round bar. Actually, the torsional stresses are shear stresses; however, the torsional strength is often reported separately and it is important in design.

Strain. All metals behave elastically, like a rubber band, up to a certain limit of stress. That is, they deform slightly when the load is applied and when the load is released they snap back to their original length. Technically, strain is the distance each unit length of the metal is changed as a load is applied. In the English system it is given in terms of inch elongation per inch length and in the metric system it is millimeter per millimeter. Strain then alludes to the elastic movement of the metal when a load is applied, whereas stress alludes to the resistance to this movement.

Strength. The strength of the metal from which a part is made depends on the load it must carry, its size, and its shape. Each size and shape of a given metal can carry a different maximum load; therefore a standard size and shape are necessary in order to be able to compare the strengths of different metals. Thus, a standard size is established for test pieces and the strength of these test pieces is reported in lbs per sq in. stress. This value can then, in many instances, be used to calculate loads non-standard sizes and shapes will stand.

The strength of the metal is usually given in tables and often is shown in stress-strain diagrams, such as Fig. 11-2. One must be careful in reading strength values in handbooks because there are two different values that can be reported, the ultimate strength and the yield strength.

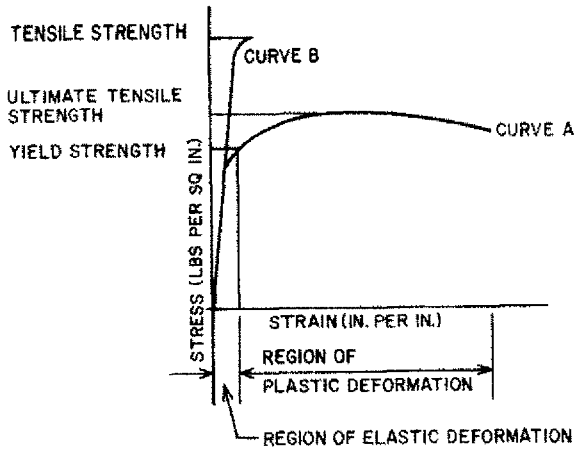


Fig. 11-2. Stress-strain diagram. Curve A is for ductile materials and curve B is for brittle materials.

Ultimate Tensile Strength. Most published figures on the tensile strength of metals refer to the ultimate tensile strength. It is the maximum tensile strength that the metal can withstand before failure by rupture occurs. One difficulty is that this stress occurs in the region of plastic deformation (see Fig. 11-2) and when the metal reaches this stress level, it has already been permanently deformed. For this reason an adequate factor of safety is required when using the ultimate tensile strength in design calculations.

Yield Strength. In machines and structures the metal must not deform permanently when subjected to a load. For this reason, the yield strength is often reported. The yield strength is the stress to which a metal can be subjected without permanent deformation. In ductile materials the yield strength is at a lower stress level than the ultimate tensile strength, as shown for curve *A* in Fig. 11-2.

A typical plot of the stress-strain characteristic of a very hard and brittle metal, such as hardened tool steel, is shown by curve *B* in Fig. 11-2. Such metals exhibit little or no permanent deformation before breaking. For this reason, the yield strength has no meaning for very hard brittle materials and the ultimate strength or breaking strength is used.

Hardness. Hardness is defined as the resistance to penetration. It is also sometimes defined as the resistance of the metal to plastic deformation. Both definitions are essentially correct. Most methods of measuring hardness do so by measuring the indentation made when a specified load is placed on a small penetrator. This measurement is then converted to a suitable hardness scale or reading.

Hardness is related closely to strength. Both properties involve the ability of a metal to resist permanent deformation beyond the elastic range.

Hardenability. This property is related to the depth below the surface to which a metal can be hardened. It does not relate to the maximum hardness that can be achieved in a given metal. There are several standard tests for hardenability with, perhaps, the Jominy End Quench Hardenability Test being the most popular.

Ductility. The relative amount that a metal will deform without breaking is what is meant by ductility. As shown by curve *A* in Fig. 11-2, ductile metals tend to stretch considerably before they break. This property enables metals to be bent, twisted, drawn out, or otherwise changed in shape without breaking.

Ductility is generally defined as percent elongation or percent reduction in area. However, these values provide only a rough indication of ductility and cannot be used in design calculations. Another rough measure of ductility is the bend test, whereby a specimen is bent, either to fracture or through a complete 180-degree arc.

Toughness. The ability of a metal to withstand a sudden shock is called toughness. This property is determined by the energy absorbed when a notched specimen is struck by a hammer blow delivered by a swinging pendulum.

Brittleness. This property refers to the ease with which a metal will crack or break without appreciable deformation. Brittleness is related to hardness. As a metal gets harder its brittleness also increases, and as the metal is made softer, its brittleness decreases. An example of the stress-strain curve of a brittle metal is shown in curve *B*, Fig. 11-2.

Malleability. Malleability is the property that relates to the ability of metal to be permanently deformed by compression, usually by rolling or hammering. Most ductile metals are also malleable.

Fatigue. This property refers to the ability of a metal to withstand repeated or fluctuating loads. Fatigue failures always occur at a stress level that is below the yield strength of the metal. Several standard tests are used to measure this property. From these tests the endurance limit of a metal can be determined, which is defined as the stress below which the metal will withstand an indefinitely large number of cycles of stresses without failure. Fractures due to fatigue are often the result of sharp corners, scratches on the surface of the metal, or tool marks.

Grain Structure

In the solid state, metals are in the form of crystals called grains. Some of the grains can be quite large and can be seen by the naked eye. However, most grains are very small and require powerful magnification to be seen.

These crystals are composed of a more or less orderly arrangement of atoms called a lattice structure. Each atom is in a fixed position; that is, it oscillates about a fixed position.

Although the atoms cannot actually be seen, if it were possible to magnify a crystal about 35 million times, it would be possible to see the space lattice. Each lattice structure is composed of a number of unit cells that are repeated over and over again to form the lattice.

Metals are composed of four basic unit cells which are shown in Fig. 11-3. The lines between the atoms do not actually exist; they are drawn to illustrate the geometrical arrangement of the atoms.

For example, chromium and tungsten have a body-centered cubic structure. Iron, when below about 1666F, and steel, when below 1660 to 1333F, also have a body-centered cubic structure. Aluminum, copper, nickel, silver, and gold have a face-centered cubic structure. When iron is above 1666F and plain carbon steel is above 1333 to 1666F, they have a face-centered cubic structure. Depending on its composition, steel may be partially face-centered cubic and partially body-centered cubic between 1333 and 1666F. The hard component of steel called martensite, that has been formed by heating and quenching, has a body-centered tetragonal structure. Actually martensite is iron which has carbon atoms trapped in its structure to elongate the body-centered cubic structure into a

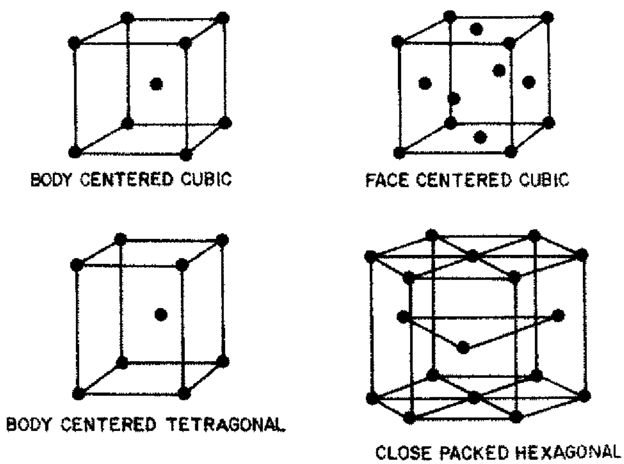


Fig. 11-3. The four basic unit cells in metals.

body-centered tetragonal structure. Indium and tin have a body-centered tetragonal structure. Magnesium and zinc have a close-packed hexagonal structure.

It will be noted from the above that iron and steel have two structures or phases, depending on their temperature. This important fact makes it possible to harden steel by heat treatment. When steel is cooled slowly it will transpose from one structure to another without difficulty, and is called "phase change." However, when this is done rapidly, carbon atoms interfere with this change, and the structure cannot assume its natural configuration at room temperature. As already mentioned, it is body-centered tetragonal (martensite) instead of body-centered cubic. This distorts the orderly arrangement of atoms, producing internal stresses which cause it to harden.

Anything that can be done to a metal that will disturb or distort the lattice structure will cause it to harden. In the case of steel, the lattice is distorted by a phase change brought about by heat treatment. Cold working a metal distorts the structure and thereby hardens it. Note that cold working does not crystallize the metal; it is always in the crystalline form. Inserting foreign atoms in the structure by alloy additions distorts the structure and hardens it. When atoms are dissolved in a structure in the solid state and are then precipitated out, the structure is distorted and hardened. This is the mechanism used to harden aluminum. It is called age hardening or precipitation hardening.

Metals are actually an aggregate of crystals, or grains, as shown in Fig. 11-4. Each grain is surrounded by other grains, except at the surface of the metal. When polished and etched with a suitable reagent and then viewed under a microscope, the grains can clearly be seen.

Fig. 11-4. The grain structure in metals.

Depending on the heat treatment received by the metal, the grains can have different sizes. Often the grains will be either large or small throughout the entire structure of a piece of metal. In some cases, where metal has been welded, for example, regions of large and small grains will exist side-by-side. When a metal has been cold-worked, the grains will appear distorted or flattened in the direction of the cold-working (see Fig. 11-17).

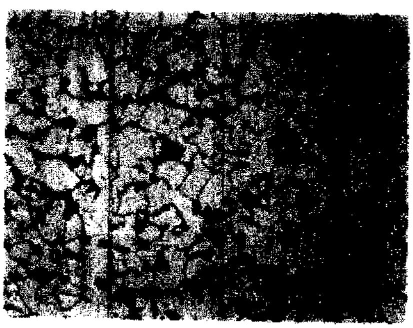
The grains in an alloy may or may not appear to be identical. In many alloys, different kinds of grains exist side-by-side in a structure. The structure of a metal, when viewed under the microscope, is called its "microstructure."

Structural Characteristics of Steel

The constituents in the microstructure of steel determine its properties, to a large extent. Some of the important constituents in steel will now be examined.

Ferrite. (Fig. 11-5.) This is a solid solution of a very small percentage of carbon in iron. It appears at a temperature below 1333F and the iron has a body-centered cubic structure. Ferrite grains appear when the carbon content is less than about .8 percent in plain carbon steel. The number of ferrite grains increases as the carbon content of the steel decreases. It is the softest constituent in steel and as the amount of ferrite increases, the steel becomes softer. In alloy steels, some of the alloying elements may be dissolved in the ferrite as a solid-state solution.

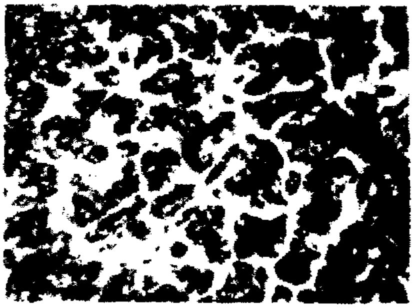
Cementite. (Fig. 11-6.) Iron-carbide (Fe_3C), a compound of iron and carbon, is called cementite. It is very hard and wear-resistant. Its composition will be varied when other carbide-forming alloys are



Courtesy of the Hobart Brothers Co.

Fig. 11-5. Ferrite. The white grains are ferrite.

present in the steel. Cementite may appear in several different ways in steel. In Fig. 11-6, it appears as a network surrounding the grains in the region of grain boundaries and also within the grain, where it is in the form of thin plates. Cementite may also appear as round, roughly globular-shaped particles in steel that has been spheroidized. In their softened condition, tool steels and other high carbon and alloy steels should be spheroidized because in this condition they are easier to machine.



Courtesy of the Hobart Brothers Co.

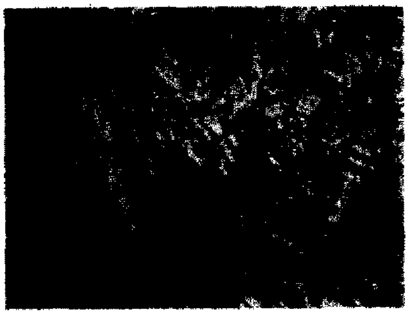
Fig. 11-6. Cementite. (Fe_3C) Also called iron carbide. The white grains are cementite.

Courtesy of the Hobart Brothers Co.

Fig. 11-7. Pearlite.

Pearlite. (Fig. 11-7.) This is a very fine platelike structure consisting of thin plates of ferrite sandwiched together with thin plates of cementite. The structure within the grains in Fig. 11-6 is pearlite. In Fig. 11-7, the white plates are ferrite and the darker plates are cementite. When the steel is cooled slowly, the pearlite is coarse; it becomes finer as the cooling rate is increased. Pearlite is a very strong and tough structure that adds to the strength and toughness of steel. The amount of pearlite in plain carbon steel increases until a maximum is reached at approximately .8 percent carbon.

Martensite. (Fig. 11-8.) This structure results when steel with a relatively high carbon content is cooled very rapidly. Small amounts of martensite may be obtained by quenching a steel having a lower



Courtesy of the Hobart Brothers Co.
Fig. 11-8. Martensite.

carbon content. The addition of alloys to steel makes it possible to obtain martensite at slower cooling rates. (Air-hardening tool steel can be hardened by cooling in air.) Martensite has a body-centered tetragonal structure in which carbon atoms are trapped. Martensite is a very hard and brittle structure. Usually it is tempered, forming a structure called "tempered martensite," which is body-centered cubic. Tempered martensite becomes increasingly soft as the tempering temperature is increased.

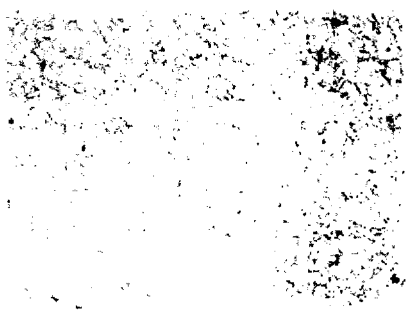
Widmanstätten structure. (Fig. 11-9.) This structure occurs in the weld zone of mild steels having a relatively low carbon content. It is made up of white interlaced masses of ferrite distributed throughout the grain, resulting from the formation of the ferrite in long, continuous plates. It is less ductile and has a lower impact strength than ordinary ferrite.

Courtesy of the Hobart Brothers Co.
Fig. 11-9. Widmanstätten structure.

Austenite. (Fig. 11-10.) This is the face-centered cubic form of iron occurring in plain carbon steels at temperatures above 1333F. It normally is not stable at room temperatures; however, in highly alloyed steels, such as tool steels and stainless steels, it can appear at room temperatures. In steels, austenite can dissolve all of the carbon that is present. This property is important in the heat treatment of steels. At room temperature it has a good tensile strength and a strong tendency to work-harden.

Spheroidite. (Fig. 11-11.) This structure consists of many small spheroidal-shaped particles of cementite dispersed in ferrite. It can be obtained through several different heat treatments. When highly alloyed steel and plain carbon steel are in the unhardened condition, it is the preferred structure because of the marked improvement in machinability obtained.

Bainite is another structure that can occur in steel. It may have either a feathery or an acicular appearance. Bainite is produced by quenching steel from an elevated temperature to some temperature above about 400F (depending on the composition of the steel) and



Courtesy of the Hobart Brothers Co.

Fig. 11-10. Austenite.

Courtesy of the Hobart Brothers Co.

Fig. 11-11. Spheroidite.

holding the steel at this temperature for a long time. It does not normally occur as a result of welding.

The Iron-Carbon Diagram

A slightly modified form of the iron-carbon diagram is shown in Fig. 11-12. The modification is in the naming of the constituents where, in this case, the names used in this text are inserted in place of the usual Greek names or symbols.

The iron-carbon diagram illustrates the temperatures at which the different constituents in an iron-carbon alloy exist under equilibrium (very slow heating and cooling) conditions. It is a most useful tool in predicting the final structure of these alloys.

The principal iron-carbon alloys are steel and cast iron. The region to the right of 2 percent carbon represents cast iron and that to the left represents steel (although the limit of carbon content of commercial steels is actually about 1.5 percent). Furthermore, this diagram represents only plain carbon steels. When large amounts of alloy additions are made to steel, the iron-carbon diagram changes considerably.

As an example, take a .2 percent carbon steel (AISI 1020); as it is cooled slowly from the liquid, the following changes occur on the

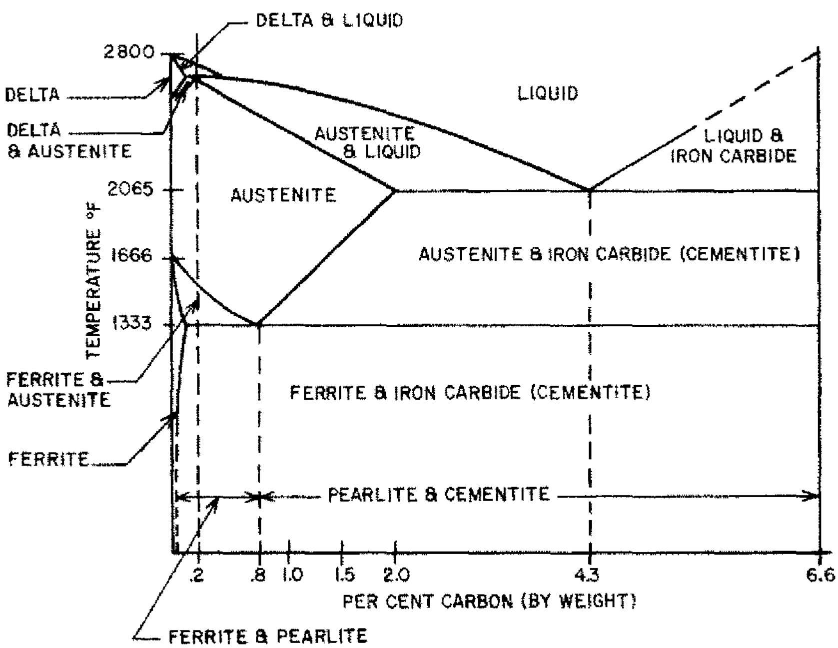


Fig. 11-12. Iron-carbon diagram.

iron-carbon diagram. First, some nuclei of delta iron form in the melt. Delta iron is a body-centered cubic form of iron that occurs only at very high temperatures and is shown in the small areas at the top left-hand corner of the diagram. As the liquid cools further, the nuclei form small crystals which continually grow larger.

When the temperature of 2720F has been reached, the melt becomes mushy and consists of many solid crystals and some liquid. At this temperature a change occurs in the solid crystals. The melt briefly enters the austenite + liquid region at this temperature and the solid crystals in the melt change from delta iron into austenite, which, it will be recalled, is the face-centered cubic form of iron.

At a slightly lower temperature (approximately 2700F) all of the liquid has solidified. The solidified metal now consists of a large number of individual grains of austenite. All of the carbon atoms are dissolved in the solid austenite crystals or grains.

No further change occurs until the austenite is cooled to approximately 1580F, at which time some of the austenite (particularly in the region of the grain boundaries) changes into ferrite, forming a number of small grains of ferrite. As the metal cools further, these ferrite grains continue to grow and additional grains of ferrite form.

At about 1333F the microstructure consists of almost 75 percent ferrite and 25 percent austenite. Then, at this temperature, the remaining austenite transforms to pearlite. No further changes occur as the metal cools to room temperature.

The final microstructure consists of grains of ferrite and pearlite. It should be remembered that pearlite consists of plates of ferrite and cementite (iron carbide).

Similarly, it is possible to predict the structure of other compositions of iron and carbon from this diagram when they are cooled slowly.

Grain Size

A fine grain size promotes both increased strength and increased ductility in a metal. The grain size in steel may be altered by heat treatment. When it is heated above certain critical temperatures, a phase change occurs and new grains will nucleate and grow within the old grains.

A part of the iron-carbon diagram is shown at the right in Fig. 11-13. The critical temperatures are labeled Ac_1, Ac_3, and $Ac_{3,1}$, and A_{cm}. It will be seen that these temperatures are at the boundaries of the different phases in steel.

The microstructure of an AISI 1020 steel (.2 percent carbon) will consist of grains of pearlite and ferrite. When it is heated no change

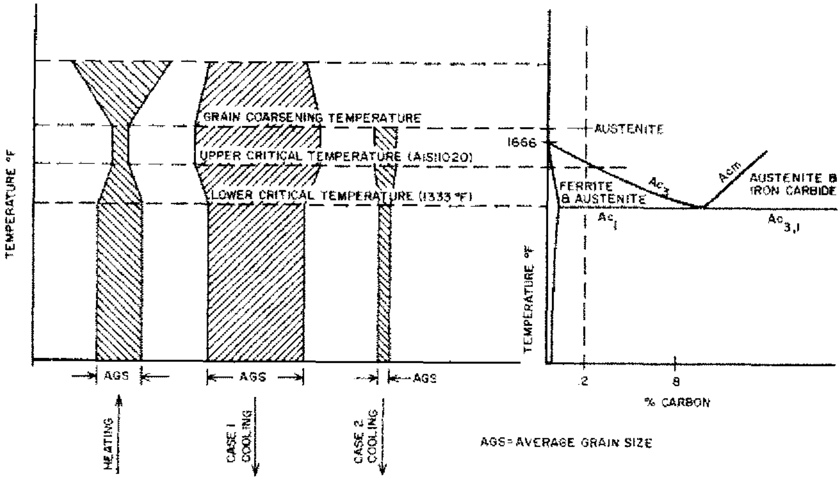


Fig. 11-13. Schematic drawing of grain-coarsening effect when heating and cooling a 2 percent carbon steel.

will occur until it reaches the lower critical temperature (Ac_1). At this temperature the pearlite will be transformed into austenite and in this process many new grains of austenite will form in the old grains of pearlite. As the temperature is increased further, more austenite grains are formed, this time within the remaining ferrite grains. This continues until the upper critical temperature for the AISI 1020 steel (Ac_3) is reached, at which the microstructure will consist entirely of austenite grains.

Because many new grains of austenite were formed within each of the former grains, the steel now has more grains which are finer than the previous grains. The fact that the average grain size has been decreased upon heating it above the upper critical temperature is shown schematically by the diagram at the left in Fig. 11-13.

If this steel is now heated to a temperature above the upper critical (Ac_3) temperature, little change in the average grain size will occur until the grain-coarsening temperature is reached. When this temperature is exceeded, the smaller grains will coalesce, or grow together, forming larger grains. Above this temperature, the average grain size will increase rapidly as shown in Fig. 11-13.

It is not possible to define a specific temperature that will be the grain-coarsening temperature for a specific class of steel. Much depends on how it is made; however, it is always above the upper critical (Ac_3) temperature.

If this piece of steel is now cooled from above the grain-coarsening temperature, there is apt to be a slight increase in the average grain size until the grain-coarsening temperature is reached, as shown in Case 1, Fig. 11-13. When the steel reaches the upper critical temperature, new grains of ferrite form in the austenite grains; this process continues until the lower critical temperature is reached. At this temperature, the remaining austenite transforms to pearlite. As in the case of heating the steel, the grain size was refined when the steel passed through the temperature region between the two critical temperatures. Cooling the steel below the lower critical temperature, however, does not change the grain size.

In Case 1, Fig. 11-13, the AISI 1020 steel was heated above the grain-coarsening temperature resulting in a very coarse austenitic grain size. When this steel is cooled to room temperature, the grains will be larger than they were prior to heating.

If this steel had been heated only slightly above the upper critical temperature and then cooled, a significant grain refinement would have occurred, as can be seen from Case 2, Fig. 11-13. In this case, the steel is cooled from a fine austenitic grain size. Sometimes steels are deliberately heat-treated in this manner to refine the grain.

When depositing a weld, the metal adjacent to the weld is heated and cooled in the manner just described. The result is that there will be regions of coarse-grain size and regions of fine-grain size adjacent to the weld. In welding, the metal is heated and cooled more rapidly than described, and for this reason, the grain coarsening and the critical temperatures will be different than shown in Fig. 11-13. However, the effects will be the same, with the changes described occurring at slightly different temperatures.

Size Change

It is a common experience that metals expand when they are heated. Like any metal, steel will also expand when heated; however, in the region between the critical temperatures, Ac_1, and Ac_3, a marked contraction occurs upon heating. This is shown schematically in Fig. 11-14 for a .2 percent carbon steel (AISI 1020).

When the steel cools slowly from an elevated temperature, like other metals, it will contract. However, here again, something unexpected happens: the steel expands in the region between the critical temperatures, as shown in Fig. 11-14.

The reason for this behavior is that a phase change occurs in the region between the critical temperatures. Austenite is a denser structure than ferrite and pearlite, so that upon heating to austenite the metal must contract. Upon cooling from austenite to pearlite and ferrite, the metal must expand.

When .8 percent carbon steel is rapidly cooled or quenched from a temperature at which it is austenite, ferrite and pearlite do not form. Instead, the hard martensite structure forms. Martensite is less dense than pearlite, ferrite, or austenite. Thus, when the martensite is formed, the metal must expand. As shown in Fig. 11-14, this always occurs at a lower temperature.

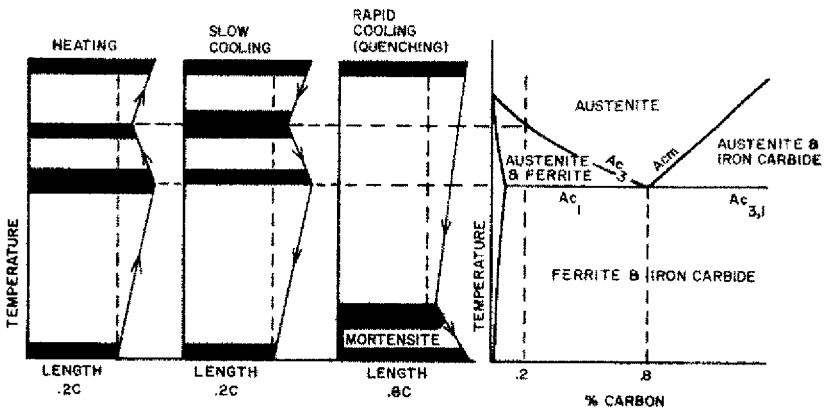


Fig. 11-14. Schematic drawing showing the effect on the elongation of plain carbon steel when heating and cooling.

Alloying Elements in Steel

Alloying elements are added to steel for the following purposes:

1. To increase hardenability
2. To increase strength at ordinary temperatures
3. To improve high-temperature properties
4. To improve toughness
5. To increase wear-resistance
6. To increase corrosion-resistance.

When alloys are added in the right amount and in the correct combination, it can be said that the steel will be improved in one or more of the above-mentioned characteristics. It is important, however, to have the right amount and the right combination of alloying elements. Merely adding more alloy does not necessarily improve the steel proportionately; it may even have a harmful effect. Two alloys when added to a steel are more effective than the same amount of a single alloy, if in combination, they enhance a property of the steel. The effect of a single element depends upon the effects of other elements, and this must be taken into account when evaluating specific compositions of steels.

To simplify the discussion to follow, each major alloying element will be discussed separately; however, the reader must not lose sight of the fact that these elements usually act in combination with other alloying elements.

Carbon. Carbon is the most important and effective alloying element in steel. Each small increase in the carbon content increases the hardness and tensile strength of the steel in the "as rolled" or "normalized" condition. When the carbon content exceeds .85 percent, the resulting increase in hardness and strength is less than in the lower carbon ranges; however, the wear-resistance continues to increase above this carbon percentage.

The presence of carbon accounts for the ability to harden steel by heat treatment. For plain carbon steel the maximum hardness that can be attained by heat treatment increases with increased carbon content until the carbon content is about .60 percent. Above this carbon content the rate of increase in hardness is very small. The effect of alloying elements is to lower the carbon content at which the maximum hardness occurs.

Only a very small percentage of carbon can be dissolved in ferrite; however, all of the carbon present in steel will dissolve in the austenite, which, it will be remembered, normally exists at a higher temperature. At room temperature the carbon is combined with iron to form the very hard and brittle iron carbide (Fe_3C), called cementite. Cementite strengthens the steel, increases its hardness, and increases its wear-resistance in the unheat-treated condition.

Manganese. Next to carbon, manganese is probably the most important alloy that is added to steel because it combines with the sulfur to form manganese sulfide. Sulfur, when not combined with manganese, is very harmful, causing hot shortness in steel. When combined with manganese, the sulfur is harmless. Therefore, manganese is an essential ingredient in all steels; for the purpose of combining with sulfur, in quantities ranging from .40 to 1.00 percent. When present above this amount, manganese is considered to be an alloying element; it also acts to deoxidize steel.

When present as an alloying element, manganese contributes to the strength and toughness of steel, and it greatly increases its hardenability. In very large amounts (12 to 15 percent) the steel will remain austenitic at room temperature. Austenitic manganese steel is an extremely tough alloy that is used for applications requiring severe impact and abrasion resistance, such as for power shovel blades. High manganese content adversely affects the weldability of steel by increasing its crack sensitivity.

Silicon. Silicon is one of the principal deoxidizers used in steel. It is a very important element in the metallurgy of gray cast iron. In steel it dissolves in the ferrite increasing its strength and toughness. Steel having less than .10 percent carbon and about 3 percent silicon has excellent magnetic properties and is used in the cores and poles of electrical machinery. A steel containing 1 to 2 percent silicon is used for structural applications requiring a high yield point.

Nickel. Nickel is another very important alloying element in steel. When present in appreciable amounts it improves the toughness and impact resistance of the steel, particularly at lower temperatures. It contributes to easier and more foolproof heat treatment of steel thereby reducing costly heat-treating failures. It dissolves in the ferrite and strengthens it. It causes more pearlite to form and the pearlite formed is finer; therefore, it is a stronger and tougher pearlite. Nickel steels are particularly suitable for case hardening. Other than making steels more hardenable, the presence of nickel in steel causes no difficulty in welding.

Chromium. Chromium increases hardenability and abrasion resistance. When present in quantities in excess of 4 percent, the corrosion resistance of steel is improved. It is one of the most effective alloys in promoting hardenability. High-chromium steels are air-hardening. Chromium forms a very stable carbide that has exceptional wear-resistance. It also promotes carburization of the steel.

The presence of chromium in steels presents problems in welding, however, as the increased hardenability can cause cracking in and adjacent to the weld joint. Steels containing 5 to 6 percent chromium can be welded only by using special techniques.

Molybdenum. Molybdenum, manganese, and chromium have a greater effect on hardenability than any other commonly used alloying element. Molybdenum has a powerful effect in increasing the high-temperature strength of steel and it retards grain growth at temperatures above the upper critical temperatures. Quench-hardened molybdenum steel is fine grained and very tough at all hardness levels. It is used as an alloy in many grades of high-speed tool steels.

Vanadium. Vanadium is used to inhibit grain growth in steel at elevated temperatures, thereby causing the steel to be fine grained at room temperature, adding to its strength and toughness. It improves the hardenability of medium carbon steels when present in amounts of .04 to .05 percent. Above this content, hardenability decreases when the steel is heated to normal hardening temperature; however, if a higher hardening temperature is used, the hardenability is increased. In high-speed steels used for cutting tools, vanadium is an essential alloying element to improve hardenability and to obtain a fine-grain size.

Tungsten. Tungsten is used in high-speed tool steels to promote the retention of the hardness, obtained through heat treatment, at high temperatures. It forms an extremely hard carbide that is very wear-resistant.
Cobalt. Cobalt is an unusual element because it decreases the hardenability of steel. It strengthens the ferrite and it is used in some high-speed steels to increase resistance to abrasion at high temperatures.
Boron. Boron is used in steel for only one purpose, to increase the hardenability of steels having less than .60 percent carbon content. It is effective when used in quantities of only a few thousandths of a percent. Perhaps, for this reason, the degree of effectiveness of boron steels is sometimes rather unpredictable.
Titanium. Titanium has a very strong tendency to form carbides and to reduce the ability of the steel to be hardened by heat treatment. It is used as a deoxidizer and in deep-drawing steels to prevent age hardening. It is also used for this purpose in stainless steels and in heat-resisting steels, to increase their strength.

Aluminum is used principally as a deoxidizer in steel although it also promotes a fine austenitic grain size. Copper is sometimes added to steel to improve its resistance to atmospheric corrosion. Lead is added to some steels to improve their machinability. While sulfur is normally considered to be an impurity in steel, it is sometimes intentionally added, along with the required amount of manganese to form manganese sulfide. This is done to improve the machinability of the steel. Phosphorus is considered to be an impurity.

Stress Relieving

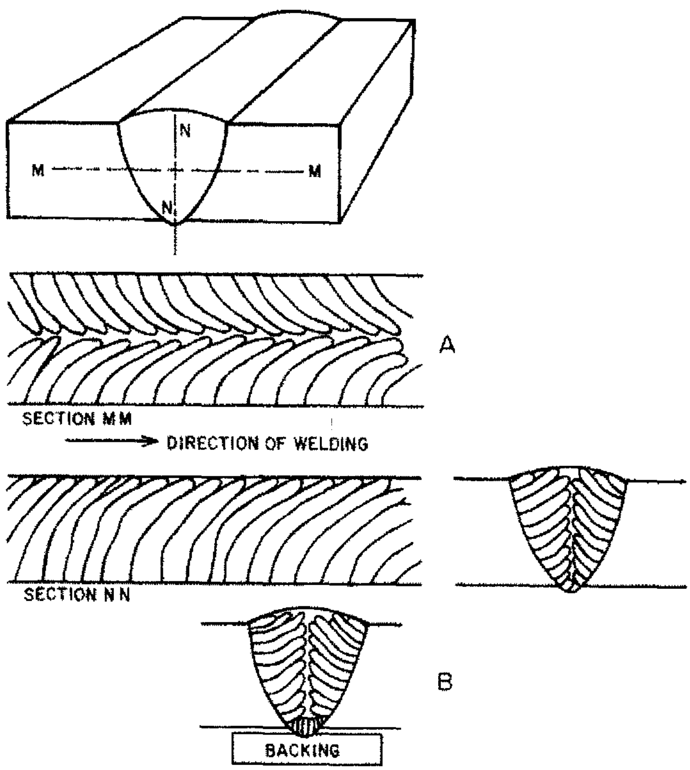
Cold-working imparts stresses in metals that remain after the cold-working operation is finished. These stresses are called residual stresses. When the cold-working is severe the grains are distorted as a result of this operation (see Fig. 11-17). Machining operations also impart residual stresses in metals as a result of the cold-working effect, the severity depending upon the size of the cut, the sharpness of the cutting tool, and the type of machining operation. There are other causes of residual stresses in metals such as grinding stresses caused by the grinding operation and residual stresses in castings resulting from a solidification of the cast metal in the mold. Welding will also impart residual stresses in a metal.

The grains of a bar of cold-drawn or cold-worked steel are distorted in a direction perpendicular to the cold-working operation and this bar will contain severe residual stresses. If this bar is heated to below the lower critical temperature, usually 1000 to 1200F, the distorted grains will recrystallize and the residual stresses will be relieved. A new, and finer, grain structure will result from this operation, and the hardness of the bar will be lower.

This operation is called "stress relieving" or "stress-relief" annealing. When welding a piece of cold-drawn or cold-rolled steel, the metal adjacent to the weld that has been heated to a temperature above 950 to 1000F, but not exceeding 1333F, will also be stress relieved as described and the grain structure will be refined.

Structure of the Weld

When making a butt weld (see Fig. 11-15) to join two mild steel plates, the liquid in the puddle is mostly above the melting point, but



Courtesy of George E. Linnert, "Welding Metallurgy" (New York: American Welding Society, 1965)

Fig. 11-15. Three views of crystals in a single-pass weld. (Top) Single-pass butt weld on a plate. (A) Three views of crystals or grains from top, side, and end, in the single-pass weld shown above. (B) A backing strip may exert a chilling action causing the crystals to grow vertically upward at the root of the bead.

at the boundary of the parent metal it is just at the melting point. The parent metal adjacent to the weld is in a mushy condition.

As the source of heat (the arc) is moved on, the mushy region solidifies and the molten metal in the puddle starts to freeze. The molten metal adjacent to the metal at the sides of the weld and, if present, at the solid weld bead starts to solidify first. Grains start to grow out from these surfaces. These grains have a columnar shape, as shown in Fig. 11-15.

As the metal in the weld continues to cool it solidifies completely. Upon cooling from below the solidification temperature to room temperature it undergoes phase changes (see diagram in Fig. 11-12). The temperatures at which these changes occur are lower than those shown in the iron-carbon diagram because of the relatively fast cooling rate of the weld.

The phase changes would occur exactly as described on pages 165 and 166 in a .2 percent carbon steel if the weld cooled slowly. However, the actual weld puddle cools very rapidly. For this reason a somewhat different microstructure will form. The microstructure in the weld will consist partly of a Widmanstätten structure and partly as minute plates of pearlite.

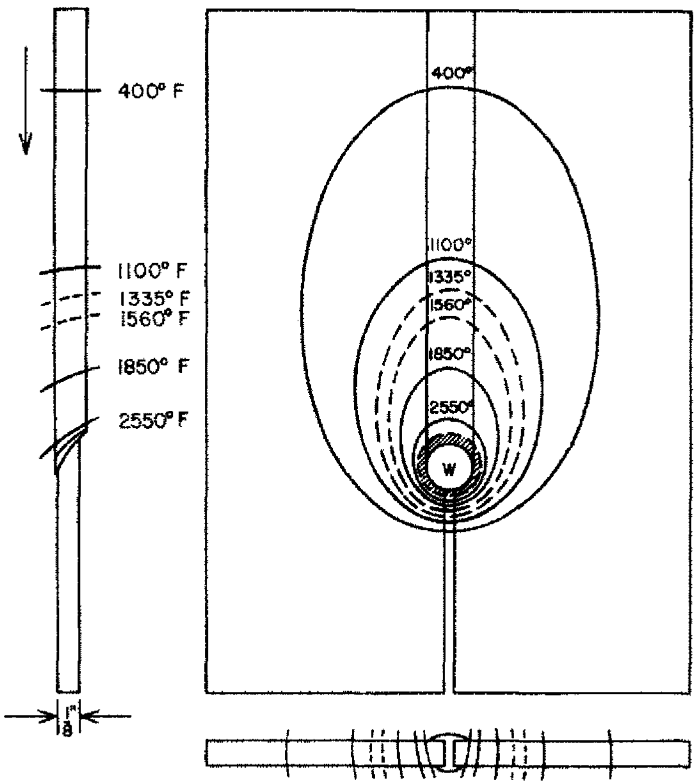
Structure of the Weld and the Weld-Affected Zone

During the welding process, the metal adjacent to the weld is also heated. The temperatures existing in a mild steel plate during welding are given in Fig. 11-16. Since the temperatures adjacent to the weld exceed the critical temperatures, the grain size of the metal in this zone is affected.

The effect of the welding heat on the metal adjacent to the weld is shown in Fig. 11-17. In this case the metal is iron and two welds are shown. The upper weld is made on iron that has not been cold-worked, while the lower weld is on previously cold-worked iron. Observe the difference in the shape of the original grains in these two metals.

In both cases, the metal in the weld has columnar grains. Adjacent to the weld the temperature exceeded the grain-coarsening temperature and, as a result, this region always is characterized by its coarse grains. Further away from this region there is an area where the maximum temperature exceeded the critical temperatures but did not exceed the grain-coarsening temperature. This results in a region of very fine grains that is always present in the case of iron and steel.

Still further away there is a region where the maximum temperature was above 950F but did not exceed the lower critical tempera-

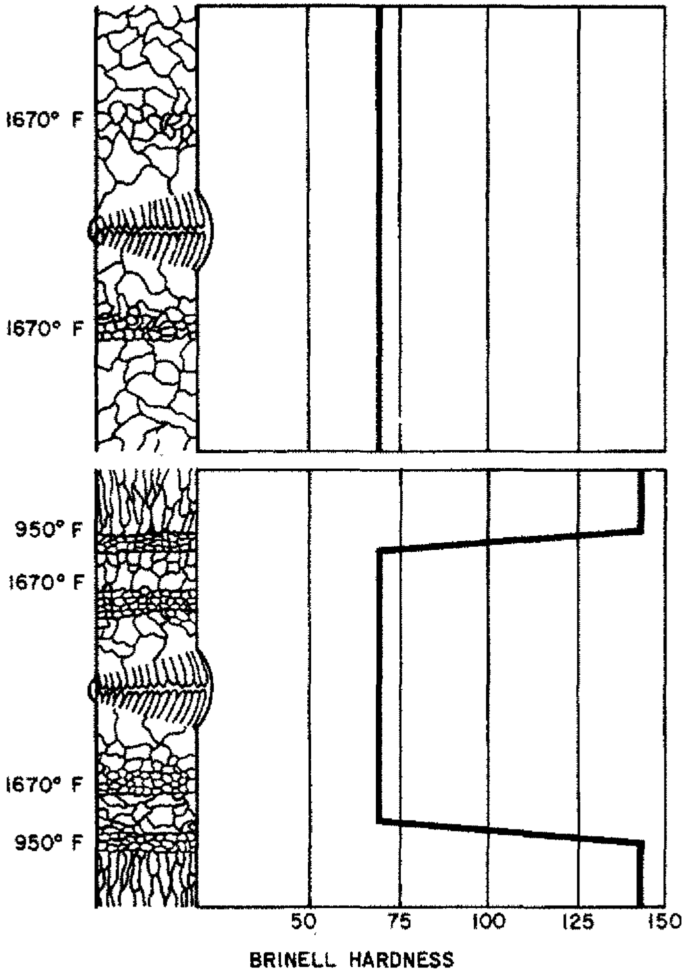


Courtesy of George E. Linnert, "Welding Metallurgy" (New York: American Welding Society, 1965)

Fig. 11-16. The distribution of the temperature in a mild steel plate at an instant during welding. W-Liquid weld metal (puddle). The shaded area is the metal that is in the mushy stage.

ture. The temperature range did not affect the grains in the upper piece (Fig. 11-17), in which the original grains are not cold-worked. However, in the lower piece, which was cold-worked, the grains were refined and the residual stresses relieved. In the lower view the second region of refined grains can be seen. It is interesting to note the coarser-grained region between the two fine-grained regions. This is the result of heating to just below the lower critical temperature. To avoid this coarse-grain structure, the maximum temperature for stress-relief annealing should not exceed 1200F.

In summary, the region adjacent to the weld is always characterized by coarse grains which is followed by a region where the grains are highly refined. Cold-worked steels have a second region where the grain structure has been refined, which does not exist in a steel that has not been cold-worked. The region in which the large grains exist is less ductile than the fine-grain region and the other regions



Courtesy of George E. Linnert, "Welding Metallurgy" (New York: American Welding Society, 1965)

Fig. 11-17. Single pass weld in iron. (Top) Iron annealed before welding. Note grain refinement in the vicinity of the zone that has reached 1670F during welding. Chart at the right shows that welding did not affect hardness. (Bottom) Iron cold-worked (cold-rolled) before welding. Note grain refinement in vicinity of the zones that reached 950F (approximate temperature of recrystallization) and 1670F. Chart at right shows that welding has softened the iron in the zones that were heated above 950F.

where smaller grains exist, unless they are very severely cold-worked.

An advantage of multiple-pass welding is that the following pass refines the grain in the previous pass. The second pass of a two-pass weld in mild steel will, for example, refine the grains in the first bead.

The weld will consist of a fine-grained lower bead and a coarse-grained upper bead; therefore, it will have a better ductility than a single-pass weld.

In the case of mild steel with a .2 percent carbon content, the weld metal will have a Widmanstätten structure at room temperature. All of the metal adjacent to the weld that has been heated above 2000F will also have this structure. The metal that did not reach 2000F, but was heated above 1500F, has a structure consisting of small grains of ferrite among which small grains of pearlite are distributed. This structure is more ductile than the Widmanstätten structure.

The next region is that which has not been heated above 1560F but above the lower critical (1333F) temperature. This region will have some rather large ferrite grains and clusters of finer ferrite and pearlite grains.

The region that did not reach the lower critical temperature remains essentially unchanged although there is some tendency for spheroidite to form. Usually the speed of welding is so high that spheroidization of the cementite in the pearlite rarely occurs. This region will consist of the original ferrite and pearlite grains.

Residual Stresses and Distortion in Welds

Earlier in this chapter stress was likened to an internal load existing inside of the metal. Stresses in metal are a result of external loads and when the external load is removed, the stresses are relieved.

Stresses inside metals can also result from other causes, such as cold working, machining, grinding, heat treating, casting, and welding. Since there are no external loads to remove, these stresses cannot readily be relieved and they remain locked up inside the metal. These stresses are called residual stresses. Residual stresses can be relieved by heat treatment, by physically removing a section of the metal, or by yielding (distortion) of the metal.

Residual stresses always react against other residual stresses inside a metal in order to achieve a balance. No attempt will be made here to show exactly how these stresses are distributed inside the metal, but rather to show their cause and effect.

An edge weld is shown in Fig. 11-18A. Assume that this weld bead could be separated from the base metal while it is still very hot, perhaps just below the solidification temperature. Of course, the metal bar adjacent to the weld bead would also be very hot however, for simplicity, let it be assumed that it is at room temperature. This condition is shown in Fig. 11-18B, where the length of the bead is equal to the length of the block (L_1).

Let the weld bead cool to room temperature. When this happens the weld bead shrinks in length and, as shown in Fig. 11-18C, the length of the weld bead, L_2, is less than the length of the block, L_1.

In order to attach the weld bead to the block so that the ends of the bead are flush with the ends of the block, it is necessary to pull on the bead in order to stretch it, and to push on the block to compress it, Fig. 11-18D. Pulling on the bead results in a tensile stress in the metal inside of the bead. Similarly, a compressive stress is set up inside the block in the region adjacent to the bead.

In Fig. 11-18E, assume that the weld bead and the block are now firmly joined together. The block, having been compressed, wants to stretch out again because of the elasticity of the metal. In doing so it

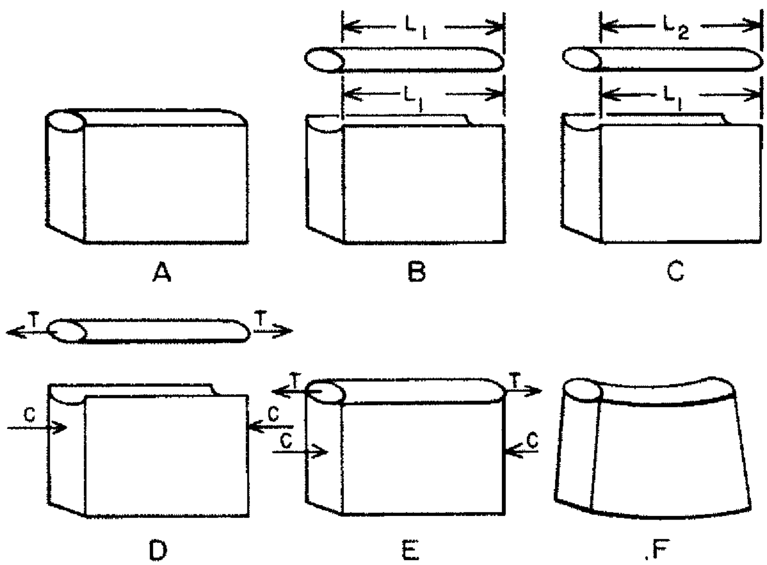


Fig. 11-18. Schematic drawing showing why residual stresses exist in welds and their effect in causing weld distortion.

pulls on the weld bead thereby setting up a permanent residual tensile stress in the metal inside the weld bead. The weld bead, in turn, was stretched in order to join it to the block. The elasticity of the weld metal causes it to want to pull together, thereby exerting a permanent compressive force on the metal in the block that is adjacent to the bead.

The end result is that a permanent residual tensile stress remains in the weld bead and a permanent residual compressive stress remains in the metal in the block that is adjacent to the bead. In actual practice, the situation is much more complex; however, this provides a model for visualization.

The reaction of the weld bead on the block in compressing the metal adjacent to the bead tends to bend the block, as shown in Fig. 11-18F. The degree of actual bending that might occur will depend upon many factors such as the size of the block, the size of the weld, and the restraints upon movement placed on the block by other members to which it may be attached.

Similarly, it can be shown (Fig. 11-19) that a butt weld has residual tensile stresses in the weld bead and residual compressive stresses in the metal within the plates that are adjacent to the weld. In this case, however, the two plates react against each other, if they are of approximately the same width, and they will not bend as shown in Fig. 11-18E.

However, if the plates are unrestrained, as in Fig. 11-20A, the weld will tend to offset them at an angle "X," as shown in Fig. 11-20B. The reason for this is the shrinkage of the metal in the weld bead upon cooling to room temperature. As can be seen, there is

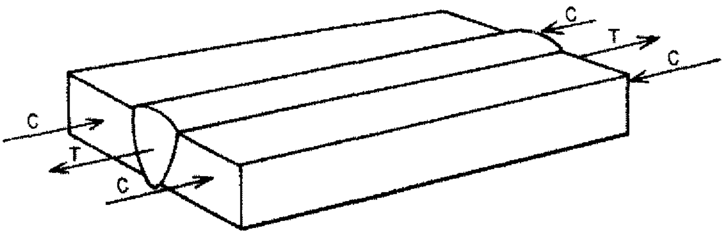


Fig. 11-19. Generalization of the action of residual stresses in the lengthwise direction in a butt weld.

more weld metal at the top of the bead than at the bottom; therefore, the top will shrink a greater distance than the bottom. This action results in the movement of the plates as shown.

If these plates are prevented from moving, as in Fig. 11-20C, the metal in the weld is prevented from shrinking. While the temperature is such that the metal in the weld bead is soft and plastic, it will deform; but when it has cooled down enough to obtain strength it will be stretched elastically, thereby setting up a permanent residual tensile stress in the weld bead.

The residual tensile stress in the weld bead tends to pull on the plates to which it is attached, and in doing this sets up residual

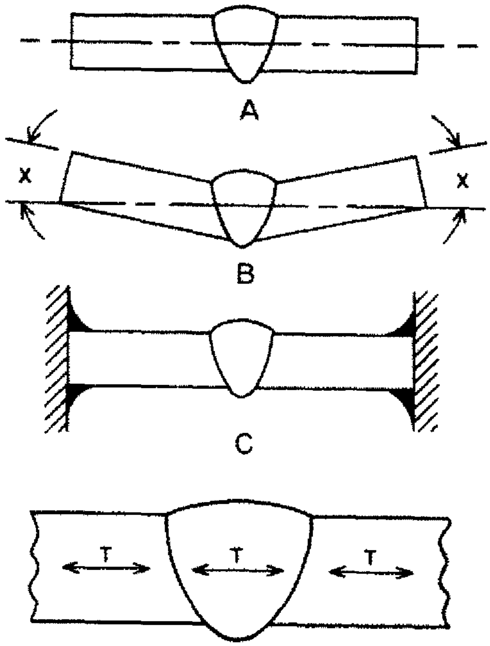


Fig. 11-20. Generalization of the action of residual stresses perpendicular to the lengthwise direction in a butt weld.

tensile stresses in the plates, Fig. 11-20D. Again, the actual stress pattern in the weld is more complicated; however, this example helps to visualize why distortions occur and how residual stresses within the weld occur. Without going into the reasons why at this time, the welded plates in Fig. 11-20C would tend to distort in the general direction of the plates in Fig. 11-20B.

In Fig. 11-21A, the fillet weld causes the plates to move at an angle, in a manner similar to the butt weld in Fig. 11-20. If the plates in Fig. 11-21 are restrained from movement, residual stresses will be set up in the weld bead and in the plates being joined.

When a fillet weld is made on relatively thin plates, where the temperature rises to nearly a red heat at the bottom of the lower plate, the metal may be upset, as shown in Fig. 11-21B and C.

The metal in the lower plate is heated in the region of the weld and wants to expand. However, it is prevented from doing so by the surrounding colder metal and the restraints. As a result, the relatively weak hot metal near the weld is upset by compression and possibly bent. During cooling the plates were not sufficiently rigid to iron out the bend.

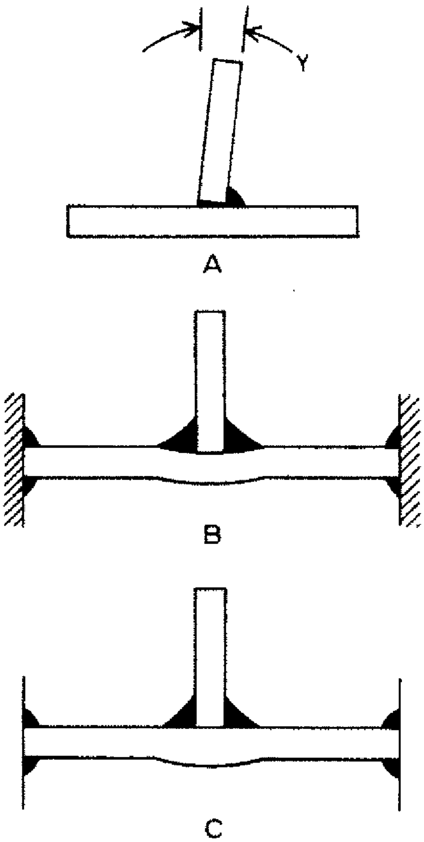


Fig. 11-21. Distortion occurring in fillet welds.

CHAPTER 12

Distortion in Pipe Welding

Distortion caused by welding can seriously affect the alignment and the locational accuracy of a pipe installation unless preventive measures are taken to avoid these problems. While in the last chapter the basic causes of distortion in weld joints were treated, this chapter will show how the distortion in the weld joint can affect the fabrication of the pipe installation and explain the steps necessary to overcome this.

On the job, the pipe welder must always be aware of the distortion and must take those steps required to prevent this from affecting the quality of his work. The amount of distortion cannot be calculated, even by engineers. However, this should not deter the welder from estimating the direction and possible magnitude of the distortion. Having done this, he should plan his work in advance to minimize the effect of the distortion. The following examples will describe how this is done.

Example 1

When cross-country pipelines were discussed in Chapter 1, it was pointed out that line-up clamps are used to hold the pipes in place while welding the root bead. Their primary purpose in pipeline welding is to prevent the root bead from cracking as it is being deposited, but these clamps also serve to align the pipes.

Line-up clamps are also used on other types of pipe-fabricating jobs. Here their main purpose is to align the pipes and to hold them in position. A sufficient amount of the root bead is deposited to assure alignment of the pipes after they are welded and to prevent the root bead from cracking before removing the alignment clamps. These clamps can be obtained in several different styles and sizes (see Fig. 8-5).

When welding longer lengths of pipeline, where several standard lengths of pipe are welded together, the pipes will bend under their own weight. It is important then to provide an adequate means of support under the pipes to prevent them from sagging while they are being welded together.

Example 2

A typical welded-pipe fabrication is shown in Fig. 12-1. Several welds are required to fabricate the installation, which presents some distortion problems that are frequently encountered in pipe welding. The header, Fig. 12-2, has four branch pipes that are welded along the top of the header pipe, as shown. Weld joints, such as made by these branch lines, are sometimes called "weldolets."

Simply welding the branch lines to the header pipe would cause it to bend, as shown in the lower view of Fig. 12-2. To prevent this from occurring, a strongback is attached to the header on the side opposite the branch pipes. The purpose of the strongback is to add to the stiffness of the header pipe, and to resist the tendency of this pipe to bend as a result of heat input, in making the welds.

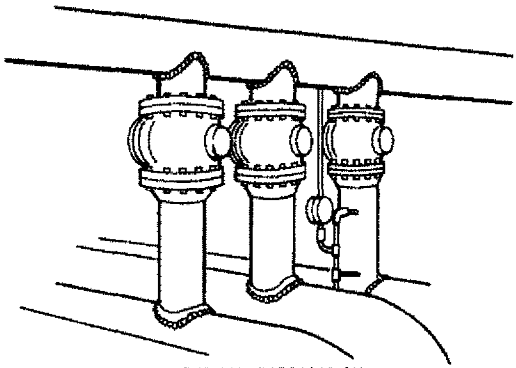


Fig. 12-1. A typical welded-pipe fabrication.

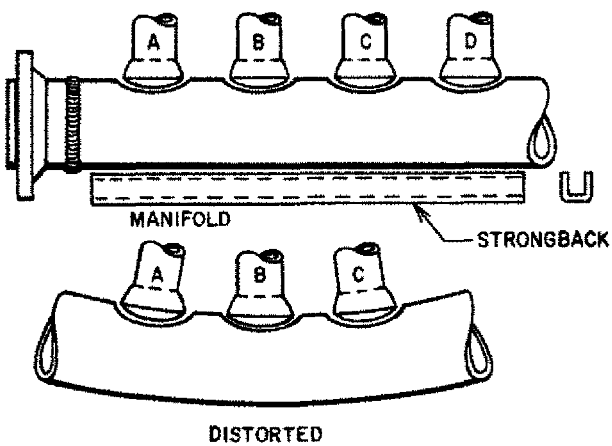


Fig. 12-2. (Top) Use of a strongback to prevent distortion. (Bottom) Pipe distorted (bent) as a result of welding.

A strongback may be a channel section or an I-beam of adequate size in relation to the header pipe. On mild steel pipe it may be attached to the header by a series of tack welds. After the branch pipes have been welded in place, the header is removed with an oxyacetylene cutting torch. On some jobs this procedure for attaching the header is not permissible, especially when the header pipe is made from a higher alloy steel. In this case the strongback is attached by using heavy-duty clamps.

The branch lines should not be welded in the alphabetical order shown in Fig. 12-2. To minimize distortion, they should be welded in the following order: C, A, D, and B. By welding the branch pipes in this sequence, the amount of heat put into the area surrounding a header at one time will be reduced. While the temperature of the weld must be high enough to obtain fusion, the heat will diffuse more rapidly and only a small area will attain a temperature high enough to cause serious distortion. It is the expansion and contraction of the metal surrounding the weld, as well as the weld metal itself, that causes the distortion. The overall effect of using this sequence, together with the strong back, is to reduce the amount of distortion that occurs, or to eliminate it entirely.

To be able to more fully understand how distortion occurs when the metal adjacent to the weld is heated to a high temperature, a schematic example will be given. The bar of steel in Fig. 12-3 is to have a small section heated to a high temperature where plastic flow can readily occur. This can be likened to heating this part of the bar to the forging temperature. Moreover, heating a small section of the bar to this temperature can be compared to the condition of the bar when welding a single bead.

Assume that the section of the bar to be heated can be cut out and that this section will fit tightly into the resulting slot, as in Fig. 12-3A. If the section is removed from the bar and then heated, it will expand and no longer fit into the slot, as in Fig. 12-3B.

In order that it again may fit tightly into the slot, the removed section must be upset by applying a compression force, as shown in Fig. 12-3C. This section is then placed back in the slot, Fig. 12-3D, and allowed to cool to room temperature. When this has occurred, the upset section will shrink and, as shown in Fig. 12-3E, it will fit loosely in the slot.

Two things occur to make the loose section fit tightly in the slot again; these are shown in Fig. 12-3F. The loose section is stretched by pulling on it in tension and the sides of the slot are pulled inward. However, pulling inward on the sides of the slot will tend to cause the large bar of steel to bend. Figure 12-3G shows how the bar of steel may be bent permanently when the loose section is back in the slot, fitting tightly.

Heating a part of the bar of steel or a part of a pipe only will result in a situation that is very similar to the schematic example discussed in the preceding paragraphs. When the small part of the bar or pipe is heated, it will be upset by the unyielding colder metal that surrounds it. As the upset metal cools to room temperature it contracts and, if left by itself, it would be even shorter than before because it was upset while hot. In contracting, the upset metal pulls on the surrounding colder metal while, at the same time, it is being pulled by the colder metal. By pulling on the surrounding colder metal, the heated part of the bar tends to cause the entire bar to bend as it cools.

Actually, the bar may bend very noticeably or very little bending may take place. The amount of permanent bending that occurs will depend on the amount of heat input, the size of the area heated, the size of the bar of steel, and its shape.

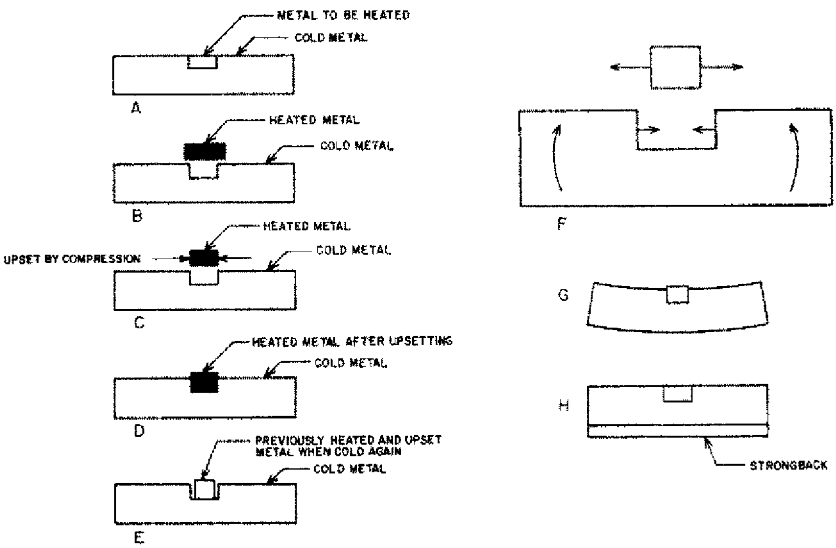


Fig. 12-3. Schematic drawings showing how a bar of metal is bent as a result of heating a small volume of metal on one surface. A. Original bar; B. Small section of bar removed and heated to a forging temperature; C. Heated section upset by compression; D. Upset section placed in notch with a tight fit; E. Upset section after cooling to room temperature; F. Forces on the bar and the upset section required to obtain a tight fit; G. Bar bent to close notch in order to obtain a tight fit of the upset piece; H. Strongback prevents the bar from bending. When upset piece is attached to ends of notch, it will be elongated or "ironed out."

If a strongback is added to the bar of steel to increase its stiffness, Fig. 12-3H, the amount of permanent bending will be reduced or, perhaps, it can be prevented entirely. In this case the bar of steel is stiff enough to resist bending and the tensile forces pulling on the heated section will elongate or "iron out" this section as it cools.

It should be remembered that heating and cooling a small area of the bar will set up residual stresses within the metal. These occur whether or not a strongback is used. When the strongback is removed, the residual stresses will usually cause a slight amount of bending, but often this is a negligible quantity. The residual stresses can be removed only by heating the entire bar of steel to a temperature that is just below the lower critical temperature.

Example 3

When welding branch lines onto a pipe, where the branch lines are not in the same plane, the welder must plan to weld the branches in the correct sequence in order to minimize the effect of distortion. In Fig. 12-4, the branch line *C* is to be welded on the opposite side of *A* and *B*.

Because they are located further from the center of the pipe, the welds at *A* and *B* will cause less distortion and bending than the weld at *C*, which is located near the center of the pipe. For this reason, branches *A* and *B* should be welded first. If the pipe is bent as a result of the welds at *A* and *B*, welding the branch at *C* will tend to straighten the pipe out again because this weld has the greatest bending effect on the pipe.

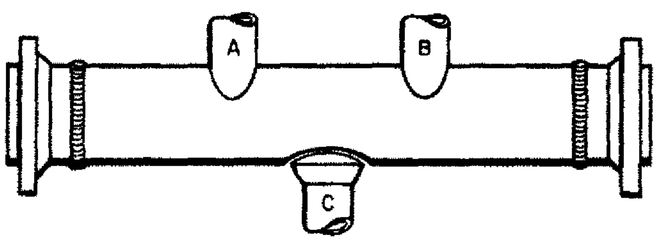


Fig. 12-4. Correct welding sequence for welding branch lines that are in different planes along the header pipe.

Example 4

To maintain alignment when welding and after the completion of a weld, a branch pipe must not be welded by depositing the root bead completely around the circumference of the pipe at one time.

The central axis of the pipe is called the neutral axis. In order to balance the distortion resulting from the shrinkage of the weld metal when it cools (thereby maintaining the alignment of the branch pipe), the welds should be balanced around this neutral axis, as much as possible, as shown in Fig. 12-5.

The procedure to follow is to weld two short tack welds on opposite sides of the branch pipe and two more 90 degrees from the first two. Then weld a short section of the root bead on one side of the pipe as in Fig. 12-5, and another short section of the root bead on the other side. After this the root bead is welded on the remaining sides.

While it is most important to weld the root beads in sequence, it will also help to minimize distortion and to maintain the alignment of the branch pipe if the intermediate layers are welded in the same sequence. The cover layer may be welded by going entirely around the circumference of the pipe.

While the weld must be built up to have enough strength to withstand any load to which it might be subjected, it is a mistake to overweld the joint. This can cause distortion and will reduce the elasticity of the joint. Particularly when the piping system is to contain hot fluids, some elasticity in the piping system is required to allow for the temperature changes that will occur. Elasticity is also required for an outdoor piping system if it is subjected to large seasonal temperature variations.

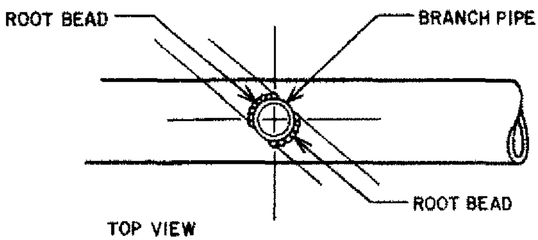


Fig. 12-5. Method of balancing the root beads around the neutral axis of a branch pipe to minimize distortion and maintain alignment.

Example 5

Frequently, short sections of pipe, as in Fig. 12-6, must be welded together so that they will align with two or more pipes. They must be carefully aligned when they are fit-up and they must be welded together in the correct sequence; otherwise distortion can cause the vertical pipe to be misaligned with respect to the pipe to which it is attached.

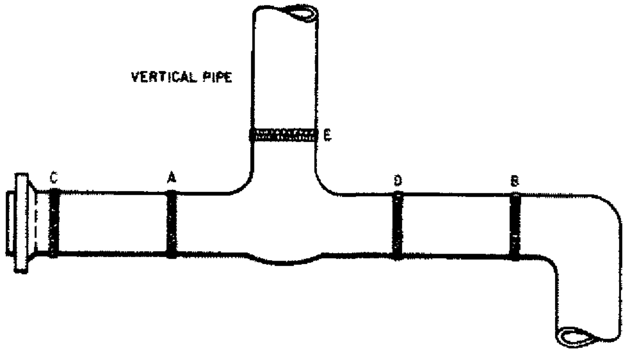


Fig. 12-6. Correct welding sequence for welding the root beads of the pipe assembly.

Hot metal deposited in the weld joint will shrink as it cools to room temperature. For a given metal, such as steel, the amount of shrinkage will depend upon the size of the deposit of weld metal and the freedom of the pipes to move. After the tack welds have been made to hold the pipes in place, the root bead should be welded in place on all of the joints in Fig. 12-6 before the remaining beads are deposited. The root beads are relatively narrow and cause less distortion than the wider intermediate and cover beads. Moreover, they stiffen the entire assembly, thereby reducing the distortion resulting from the shrinkage of the wider beads.

It is equally important to weld the root beads in the correct order. The last root bead should always be welded in the joint at *E* and the other root beads should be welded in a balanced sequence on either side of *E*. In this way, a misalignment of the vertical pipe can be corrected by heating the tack welds at *E* and drawing the misaligned pipe into position before the root bead is deposited in this joint.

The first step in fabricating the pipe assembly is to fit-up the pipes. Since this subject is treated in detail in Chapter 14, it will only be necessary to mention here that the pipes must be aligned in the specified position and tack welded in place. Then the root beads are welded in all pipe joints and in the correct sequence. The correct sequence is the alphabetical order given in Fig. 12-6, i.e., joints *A*, *B*, *C*, *D*, and *E*. By following this procedure, the root beads are alternately welded in joints on one side and then on the other side of *E*, and joint *E* is welded last. The remaining beads should also be welded by welding the joints in this sequence.

Example 6

Right-angle pipe joints, Fig. 12-7, are frequently encountered in pipe welding. The 90-degree turn is made by welding a pipe elbow in place as shown. As always, the pipes must be fit-up correctly; however, a good fit-up job can be spoiled by using an incorrect welding procedure. As shown in Fig. 12-7B, distortion caused by welding can cause the pipes to move so that they no longer are at right angles after they are welded together.

To prevent this from happening, the elbow should first be tack welded to the pipe that is in the fixed location, which, in this case, is the horizontal pipe. If the vertical pipe is in a fixed location, the

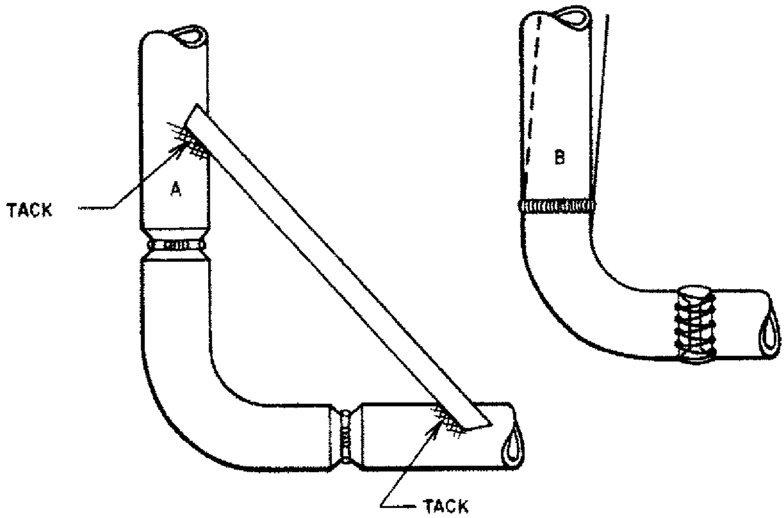


Fig. 12-7. A. Using a support to maintain the correct alignment of a right-angle pipe joint; B. Distortion of a right-angle pipe joint caused by welding.

elbow should first be tacked to this pipe. After the elbow has been tack welded to the horizontal pipe, the angularity of the pipe should be checked by placing a level across the unwelded face of the elbow. If necessary, the elbow can be aligned by heating the tack welds and bending it slightly.

The vertical pipe is then placed in position and aligned with the elbow. The correct spacing of the root opening can be obtained with a bent piece of wire. Four tack welds are then deposited around this joint in the usual manner and the alignment of the assembly is checked.

Before welding the remainder of the root bead, a support is added to hold the pipes in position. This can be in the form of an "angle iron" (correctly called a "steel angle") which is tack welded to the two pipes to which the elbow is attached. The angle iron should be welded at approximately 45 degrees, with respect to the elbow, to form a right triangle (disregarding the curvature of the elbow). This will provide the maximum stiffness to the joint for holding the pipes in place while welding.

With the pipes held in the correct angular relationship to each other, the root beads are deposited in both weld joints, after which the intermediate and cover beads are welded. When the welds in both joints are finished, the angle iron is removed with an oxyacetylene cutting torch. It is easy to visualize how joints can be welded at other angles, as in Fig. 12-8, by using this procedure.

In summary, while pipe welds tend to distort, errors caused by distortion can be avoided by planning ahead and by using the

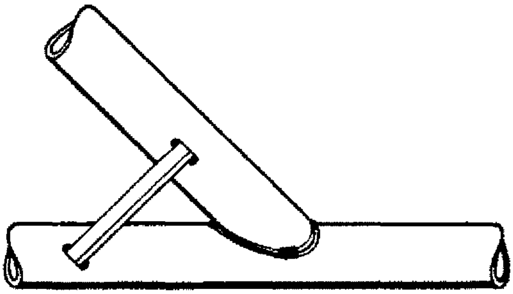


Fig. 12-8. Using a support to maintain the correct angular alignment when welding a pipe joint.

correct welding procedures. The real craftsman not only can make good welds, he can fabricate pipe installations that meet all of the dimensional requirements.

Following are some suggestions that will help to prevent distortion:

1. Plan how each job is to be done before starting. Determine the best sequence in which the pipe joints are to be welded.
2. Check the position and the alignment of each joint before the filler layers are deposited. Usually, this should be done after tack welding.
3. Balance the welds, especially the tack welds, about the neutral axis of the pipe. Weld short root beads opposite each other.
4. Keep to a minimum the heat input in any section along the pipe. Do not allow the heat to build up but distribute it as evenly as possible.
5. Clamp or weld temporary supports to the pipes in order to maintain the alignment while welding.
6. Make allowances for the contraction of the weld when lengths of pipe are welded together.
7. Never weld the pipe joint to completion unless the pipes are known to be in correct alignment and in the correct position. Before starting to weld, make sure that the job will be right when it is finished.

CHAPTER 13

Pipe Welding Defects

Many of the defects that occur in pipe welding have, of necessity, already been discussed in previous chapters. In this chapter additional information will be given on the causes of these defects and preventive measures required to avoid their occurrence. The subject will be covered from the point of view of the welder, rather than that of the engineer.

Arc Strike Cracking

There are many reasons why cracking occurs in the weld and in the adjacent weld-affected zone. One cause of cracking is carelessly striking the arc outside of the weld groove, or in the area in which the weld deposit is to be made, Fig. 13-1.

When the arc is struck, the metal with which it is in contact is very rapidly heated. Then when the arc is moved on it is very rapidly cooled again; in effect, it is quenched. This affects only a relatively small volume of metal, the remainder not being heated appreciably.

As explained in Chapter 11, when the carbon content in steel is high enough, heating it to above the upper critical temperature and quenching it results in the formation of martensite. Low-carbon martensite can even form in low-carbon steel if the quench is drastic enough. With the addition of alloying elements, martensite will form at a lower carbon content and at a slower cooling rate. The martensite forms while the metal is cooling at some temperature below 700F and metal that has formed into martensite expands. This expansion of the metal results in internal stresses that may cause small micro-cracks to occur on, or just below, the surface.

If the arc is struck in the area over which the bead is to be deposited, the metal that is stressed or possibly cracked is melted a short time later as the bead is deposited, which eliminates the problem. On the other hand, if the arc is struck outside of the weld zone, the stresses and the cracks remain.

If cracks resulting from the arc strike appear on the surface, a weld bead must be deposited over them. The bead should be made reasonably long and wide in order to increase the amount of heat input to the defective area, thereby reducing the cooling rate. Inter-

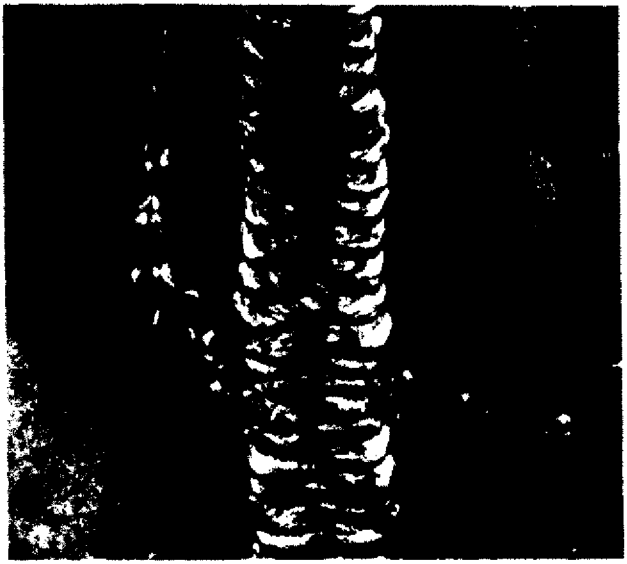


Fig. 13-1. Deposits caused by striking the arc outside of the weld joint.

nal stresses can be corrected by postheating; i.e., by heating the affected area with an oxyacetylene torch allowing the metal to cool slowly. A most effective way to prevent the occurrence of these stresses and cracks is to preheat the weld-affected area so that the cooling rate is slowed down. Of course, the cardinal rule to follow is never to strike the arc outside of the weld joint.

Underbead Cracking

This form of cracking occurs within the base metal at a very short distance away from the fusion line. It occurs in low-alloy and high-alloy steels. The factors responsible for this form of cracking are not, as yet, completely understood. It is known that dissolved hydrogen gas must be present; otherwise underbead cracking does not occur. It is believed to be caused by stresses within the metal that are the result of:

1. The unequal contraction of the base metal and the weld metal
2. The restraint of the cooler base metal
3. Stresses caused by the expansion of the metal when martensite is formed
4. Stresses set up by the precipitation of hydrogen out of the metal to form molecular hydrogen.

The presence of hydrogen seems to act as a trigger to start the formation of these cracks.

The cracks occur below the surface of the metal and when a pipe is subjected to a load, they spread very rapidly, causing the joint to fail.

Since the presence of hydrogen is the primary cause of underbead cracking, everything possible should be done to prevent hydrogen from entering the molten metal. It can enter this molten metal from the atmosphere, from ingredients in electrode coatings, and from moisture.

To prevent hydrogen from entering from the atmosphere, the molten metal should always be blanketed with the gaseous shield formed by the electrode coating or, in the case of GTAW welding, by the inert gas. Low-hydrogen electrodes are so designed that the coating contains only the smallest trace of hydrogen. While these electrodes eliminate underbead cracking, they are difficult to use in some pipe-welding applications and, in the case of downhill welding, they cannot be used at all.

A primary source of hydrogen in welding is moisture. Some welders like to soak their electrodes in water in order to obtain a better arc characteristic. This practice should be discouraged. The electrode coating should be protected from any form of dampness. Before attempting to weld, the weld joint should be dry and welding should never be attempted in rain or snow.

If the weld metal cools more slowly, some of the hydrogen gas that has been dissolved will have an opportunity to escape from the weld by precipitating out. For this reason, preheating the metal before welding helps to prevent underbead cracking. Preheating will also prevent the formation of martensite, as explained before, thereby eliminating one of the factors contributing to underbead cracking. While postheating will help to relieve locked-up stresses in the metal, it is seldom effective in preventing underbead cracking.

Restraint Cracking

Restraint cracking is usually associated with small welds made on thick metal sections. This form of cracking occurs in the weld bead and it is caused in part by the solidification and cooling pattern of the weld. Because the parent, or base, metal is much cooler than the weld metal, solidification progresses from the fusion line inward. For this reason the center of the weld is at a higher temperature than the remainder of the weld while it cools.

The mechanism of restraint cracking can be illustrated by again resorting to an imaginary situation, as seen in Fig. 13-2. Cross sections through an imaginary weld are indicated. For simplicity, a square butt joint is shown. Above each joint a small graph indicates the distribution of the temperature across the joint.

Shown on the graph are the solidification temperature and the strengthening temperature of the weld metal. Actually, there is no fixed strengthening temperature, although each metal does have a temperature range below which it attains a reasonable amount of strength and above which it is very weak when slowly cooled.

In Fig. 13-2A, the weld metal has just solidified and, as can be seen in the graph above the weld, the temperature drops off very rapidly at the fusion line because of the chilling effect of the heavy plate. In Fig. 13-2B, C, D and E, the temperature is assumed to have

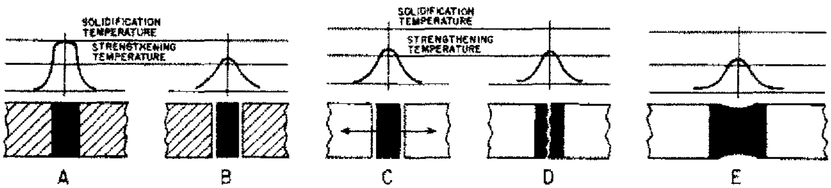


Fig. 13-2. Mechanism of restraint cracking. A. Temperature distribution across butt joint just after all of the metal has solidified; B. Assumed shrinkage of weld metal if separated from wall after the weld has cooled to temperature shown; C. Weld metal must be pulled to rejoin base metal, thereby setting up tensile stresses; D. Weaker metal in center of weld will crack as a result of the tensile stresses; E. Thicker weld joint may yield instead of cracking.

dropped an equal amount; i.e., they represent the same instant during the cooling cycle.

For a moment, let it be assumed again that the weld metal could be separated from the sides of the weld as it cools from the solidification temperature shown in Fig. 13-2A to the temperature shown in the other diagrams. In this case the weld metal would separate completely from the sides because it would have to shrink as it cools, as shown in Fig. 13-2B.

In order to attach the weld metal to the sides while at this temperature, it would be necessary to pull on the weld in order to stretch it as shown in Fig. 13-2C. When this is done, the weld metal is in tension and tensile stresses exist within it.

Most of the weld metal is strong enough at this temperature to resist the tensile stresses; however, as shown in Fig. 13-2D, the metal in the center of the weld, which is at the highest temperature, is still very weak. The weak metal in the center will crack when subjected to internal stresses. Of course, the weld metal does not actually separate from the wall, but in shrinking as it cools, stresses are set up within the metal that can cause the weaker metal in the center of the weld to crack.

As the weld shrinks upon cooling it must deform if it remains attached to the sides of the weld. The amount of deformation that can take place before cracking occurs depends upon the amount of metal that is available. A thick weld, having a larger volume of metal, will accommodate more deformation without cracking than will a thin weld. Therefore, as shown in Fig. 13-2E, a heavy weld is less likely to crack than a small weld, when they are on thick metal sections.

Welding Faults and Their Prevention

Undercutting. When the base metal along the edge of the weld is reduced from its original thickness, as shown in Fig. 13-3, the weld is said to be undercut. There are several reasons why undercutting occurs.

Excessive current can cause the edge of the joint to melt and the molten metal will wash into the weld, leaving a drain-like impression at the edges of the weld. This can occur in varying degrees; even with a normal arc length, undercutting can occur if the electrode is not manipulated in such a manner as to supply an adequate amount of filler metal to the molten edge of the weld. Because the edge of the weld cools more rapidly than the center of the weld, the arc should pause at the edges, when weaving, in order to deposit filler metal and to supply additional heat to the area.

Pausing at the edge also has the effect of churning the metal in this region, thereby obtaining a better mixture of the base metal and

Fig. 13-3. Undercut.

the filler metal. If the composition of the weld metal varies greatly from the edge to the center, it will solidify at a different temperature, and for this reason, the correct composition of filler metal should always be used. Using incorrect filler metal can also contribute to undercutting.

If the electrode angle is too small, the arc force will tend to wash away the molten metal at the edges of the joint to cause undercutting. To avoid this cause of undercutting, it is important to maintain the correct electrode angle while welding. Other causes of undercutting are dampened electrodes, using an excessive arc length, and a welding speed that is too slow.

In summary, undercutting is caused by any one or a combination of the following factors:

1. Excessive welding current
2. Incorrect electrode manipulation
3. Using an incorrect welding rod which provides filler metal of the wrong composition
4. Electrode angle too small
5. Arc length too long
6. Welding speed too slow
7. Using dampened electrode.

Slag Inclusions. Slag inclusions (nonmetallic particles of slag embedded in the weld) can have a serious, adverse effect on the quality of a weld. Usually the slag is from the electrode coating, although, in some instances, particles of slag (slag inclusions) appear in the base metal and they can be retained in the weld. Figure 13-4 illustrates a weld in which a large amount of slag inclusions appear.

These slag inclusions frequently appear at the edges of a weld if the correct welding procedure is not used. The molten slag, being lighter than the weld metal, rises to the surface of the liquid pool, rapidly forming a blanket that covers the metal. Furthermore, the slag solidifies at a lower temperature than the metal. Thus, when an edge is not completely filled with metal and has a drooping contour, the slag blanket slips around this contour and settles in the corner. When the metal solidifies, more slag will settle in the edge to form a tightly adhering inclusion.

During weaving, the arc should pause at the edge of the joint to provide sufficient heat in this area so that it will not cool too rapidly and will deposit additional filler metal to join the surfaces of the solid and liquid metal without an undercut appearing. By pausing, any previously trapped slag in this area will also be remelted and will have time to rise to the surface of the weld metal.

Fig. 13-4. Inclusions in weld metal.

The arc force churns the metal and forces some of the slag into the body of molten metal. Under certain conditions, some of this slag can become entrapped below the surface of the metal by other metal that is solidifying from the walls of the joint and up from the bottom of the weld as well. This can result from erratic electrode manipulation. Most frequently, however, it is caused by maintaining a pool of molten metal that is too large in relation to the electrode diameter.

If the body of liquid metal is too large it will have a tendency to roll, especially if it is also excessively hot and very fluid. As shown in Fig. 13-5, the layers of liquid metal above the fusion line will move

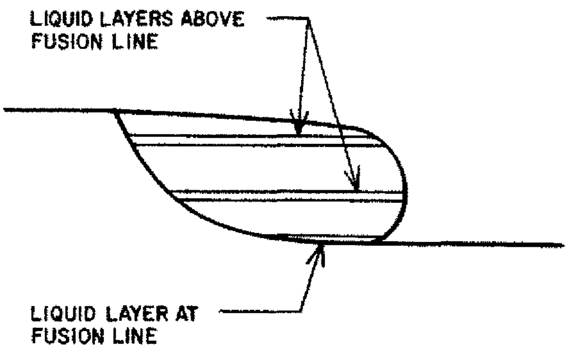


Fig. 13-5. Liquid layers above the fusion line will move out further than liquid layer at fusion line.

out further than those close to the fusion line. The liquid slag which blankets the molten metal will be rolled over toward the fusion line where it will be trapped as the metal solidifies. To prevent slag inclusions from this cause, the puddle must not be allowed to become too large in relation to the electrode size and an excessively high current setting should not be used.

Another frequent cause of slag inclusions is carelessness in deslagging a previous layer of weld metal. Proper cleaning and deslagging is essential prior to welding any additional beads. If this has not been done, some of the particles of the slag coating may not have enough time to rise to the surface when the weld is restarted, thereby becoming entrapped. At all times, the solidified slag coating of a previously deposited bead must be chipped off and this should be followed by a vigorous application with a wire brush to remove any remaining particles. When restarting the weld to continue a bead, this should only be done for a distance of one or two inches behind the crater and in the crater, in order to retain as much heat as possible in the bead. However, before another bead is deposited over this bead, all of the slag coating must be removed.

Inclusions can also be caused by heavy oxides such as rust and surface scale. These oxides remain undissolved in the molten metal and do not readily rise to the surface. When the weld metal freezes, the oxide inclusions remain entrapped in the weld.

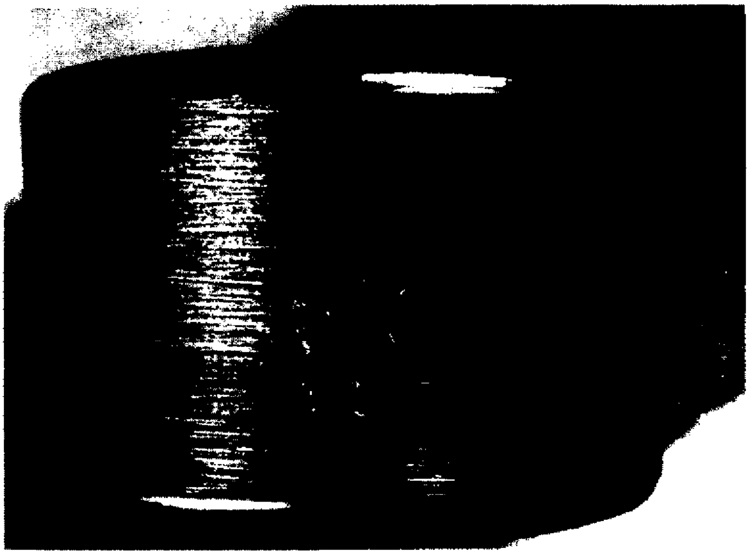


Fig. 13-6. Porosity below the surface of the weld bead. Part ground to expose porosity.

Porosity. Porosity is caused by oil, grease, or moisture entering the weld metal to form gas bubbles which become trapped in the freezing metal. Porosity can appear in the form of large blow holes or in the form of small pinholes. In Fig. 13-6, the weld bead has been ground down slightly below the surface to show porosity in the form of small blow holes. It is possible that there are additional blow holes or pinholes below those shown.

Moisture is, perhaps, the principal cause of porosity. When moisture enters the molten metal it forms a vapor, and at the temperature of the melt, the water vapor (H_2O) quickly disassociates into hydrogen and oxygen gas. A part of these gases rises to the surface and escapes to the atmosphere. However, a part of these gases is dissolved by the molten metal.

The amount of gas that a metal can hold in solution is dependent upon the temperature of the melt. Less gas can be held in solution as the temperature decreases. When the temperature of the molten metal drops, it must precipitate out some of the gas that was in solution. The precipitated gas forms a bubble which grows in size as it rises to the surface of the puddle.

When the temperature of the molten metal drops, the liquid metal also becomes less fluid. Ultimately, as the temperature continues to drop, the metal becomes mushy. When the mushy stage has been reached, gas bubbles rise very slowly and it is easy for them to be trapped in the weld metal upon further cooling and solidification of the melt.

Not all of the porosity is caused by the gases that were precipitated from the molten metal. If the speed of welding is very fast, the molten metal will freeze so rapidly that bubbles of undissolved gas are trapped. Also, excessively long whipping or weaving strokes can cause the molten metal to periodically freeze very rapidly thereby entrapping the bubbles. Moreover, by exposing the surface of the puddle to the atmosphere, additional gases will be dissolved by the molten metal when weaving or whipping excessively.

To prevent porosity, excessive whipping and weaving must be avoided and the speed of welding must not be too fast. All oil and grease must be removed from the weld joint prior to welding. Handling the electrodes with oily, greasy, or damp gloves is an all-too-common cause of porosity, something of which many welders are not aware. Oil, grease, and moisture can be soaked up by the electrode coating and passed on into the weld metal. Electrodes should not be soaked in water and whenever rain or snow can reach the weld joint, welding should be stopped. The weld joint must be free of any moisture; if necessary, the joint should be dried with an oxyacetylene torch. When they can be used, low-hydrogen electrodes reduce porosity to a significant extent.

Lack of Fusion and Incomplete Penetration. Lack of fusion and incomplete penetration are unacceptable in many industrial piping systems, particularly in systems subjected to high pressures. When these defects are present in root beads they are in the form of small channels and crevices in which corrosive compounds can settle, as shown in Fig. 13-7. These small defects can enlarge into more serious defects, especially when the pipes contain corrosive substances such as acids, liquefied gases, and sulfur compounds.

Primarily, lack of fusion and incomplete penetration occur when the welding procedures described in the previous chapters have not been followed or when the welder is careless in depositing the weld. In any particular case, the reader must refer back to the pertinent chapters when seeking measures to prevent a particular kind of defect. All that can be said in a general way is that all facets of the welding procedures must be given the most careful attention. This would include the current setting, arc length, electrode angle, electrode manipulation (weave or whipping), the keyhole in the case of root beads, and always the pool of molten metal.

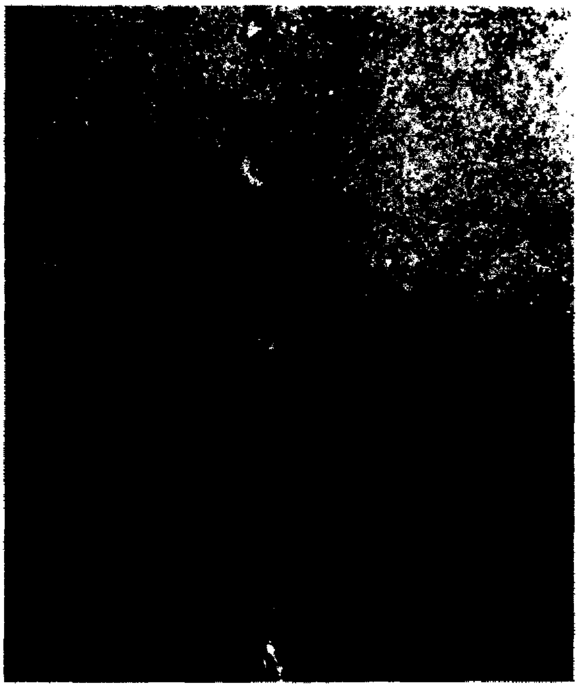


Fig. 13-7. Incomplete penetration at the bottom of a root bead.

WELD REPAIR

This section discusses some of the proper methods for evaluating and repairing defective welds. The defects covered here are those created during and after welding, such as those caused by improper manipulation, insufficient protection of the weld metal pool, oxidation and impurities, and willful neglect to procedures such as proper cleaning, edge preparation and spacing of the joint to be welded. Within the industry, some supervisors themselves ignore these procedures for the sake of productivity. Although avoiding defects has its cost, repairs can be even costlier, even more so when the repairs are not handled in a systematic way.

The repairs to be covered here are based on the following defects, which have been discovered by nondestructive testing: 1) porosity, 2) lack of fusion, 3) lack of penetration, 4) Wagon track, and 5) root bead cracking, excessive penetration, and cold lap.

First Step in Repair

The first step in any report is to locate the defect and establish its size. Even those defects that are visible to the eye must be evaluated for size in order to avoid excessive removal of the base and weld metal.

Second Step in Repair

If a welding procedure already exists for the weld being made, then it should be reviewed in terms of the following:

— Material composition
— Electrode classification
— Joint preparation
— Interpass temperature
— Preheating temperature.

This procedural review helps establish those items that will be used as part of the welding repair. It may not be necessary to undertake an elaborate study if other welds in the piping system are satisfactory,. The failure of the weld may be due to any one of the conditions mentioned above. However, it is important to realize that the weld has gone through a cycle of intense heating and cooling; the internal or shrinkage stress can be quite high. If the pipe material is of medium alloy, or heat resistant steel, then a repair procedure should be prepared to verify the steps needed for the repair. This procedure will include the following steps:

- Method of exploring the defect
- Method of removing metal in and around the crack
- Explanation of the applications of preheating and inter pass temperature, both before and during welding
- Postweld heat treatment
- Electrode classification to be used in making the repair
- Whether the weld will be supervised by anyone experi enced in repairs
- Use of qualified welders
- Sketches showing the final shape and detail of the pre pared area to be repaired

On most repair jobs, metal must be removed so that there is no evidence of discontinuity, creating, a sound base upon which to make weld metal deposit. The following factors must be established:

a. the type of alloy
b. the location, size, and depth
c. wall thickness
d. the propensity to harden
e. probing method

The question at this point might well be: Why is there so much fuss over the repair of a simple weld? If the defect is discovered in a medium carbon steel pipe system, the repairs will not need the precaution used with those materials alloyed for services such as high temperature and high pressure services. At the same time, preparation of a defect, regardless of the material involved, is similar in many respects. The repair procedure document has important reference information about similar situations in which repairs were successful.

When repairing a defective root bead, one with cracking, the procedure will be to remove metal. It is important to establish whether the crack was propagated into the second and third passes. If it did, then the defect is more complicated. In this case, it is possible that that crack was caused by shrinkage stress, complemented by part of the root bead being too weak to withstand or accommodate the stress during cooling. However, there are still other reasons which could be associated with such a defect.

For instance, the preheating temperature may have dropped lower than that specified while initially welding the joint. If the alloy material is of the high hardenable type, the weld may crack. If there were just a few passes, the cracks may not be visible to the naked eye because the area is still at a high temperature and has not experienced full contraction. Furthermore, cracks do not always develop instantly. However, when the temperature falls, the microstructure of the hardened type develops and can lead to cracking.

When developing a welding procedure for weld repairs, the following factors must be considered:

- The type of micro structure
- Heat treatment prior to attempting removal of weld metal for repair
- Exploratory method for removing defective metal, with the hope of not encountering transverse cracking

A crack that is restricted to the root bead can be looked at differently. Here, the shrinkage stress is the cause, perhaps complemented by other factors such as stress risers, inadequate root opening that led to lack of penetration, or poor restart when depositing the root bead.

In other instances, where the material on which the repair is to be made is of a medium-alloy type, the procedure becomes more challenging. The welding procedure in the first instance (making the weld initially) requires preheating and interpass temperature as well as a normalizing or stress relieving postweld heat treatment. After welding, if the postweld heat treatment was not already performed, then it will be required before the repair exercise begins, and to be normalized when the weld (repair) is completed.

In some cases involving a weld on a pipe with a heavy-wall thickness, even if preheating and interpass temperature were part of the initial welding procedure, both would be applied in repairing the weld. In that case, the sequence will be changed because of the variables involved.

Removing the metal by the carbon process (gouging) requires that preheating should be conducted the same way it was during the initial welding, due to terminal shock of the base metal. Gouging on cold metal that has the potential to harden can create microcracks. This effect is not different from that of welding an alloy that will harden when cooling exceeds the critical rate.

If the mass is great and the joint is complicated, then there is a possibility of multiaxial stress. In this case, surface heating is not an accepted part of the procedure. Heating should be slow so that the full thickness of the section as well as a short distance surrounding the area is uniformly brought to the required temperature.

Repairs

Welding has been ignored in many ways and has often had to overcome a bad reputation. Too often a welder is requested to run a pass over a surface crack which is not properly prepared or badly prepared, yet is still expected to produce a sound weld. If the weld turns out to be sound, it is because of sheer luck and the welder's ingenuity. In general, either the process or the electrode are to blame for such unsatisfactory workmanship. Often, it is not sufficiently considered that the defective area was not prepared properly, that all the scale and oxide were not properly removed, or that the welder was not instructed to use preheating and interpass temperature.

To produce a good repair weld, one must follow a set of instructions that are stipulated in the procedure, as follows

1. cleaning
2. preparation of the joint to be repaired
3. selection of the welding process and electrode
4. execution of proper preheating and interpass temperatures

Carbon arc gouging is actually part of the method used for removing metal when repairing a weld. Therefore, care should be taken to ensure that the temperature of the weld is held at the required level in order to prevent cracking. This type of cracking is known as terminal shock cracking. It is caused when the surface is heated at a rapid rate and then allowed to cool at a rapid rate. In fact, pipes with greater mass (wall thickness) actually quench the surface, which is expanded on heating. The cooling at a rate of quenching can be so fast that the surface actually shrinks beyond the greater mass of the weld. The surface will develop stress.

Removal of Defects

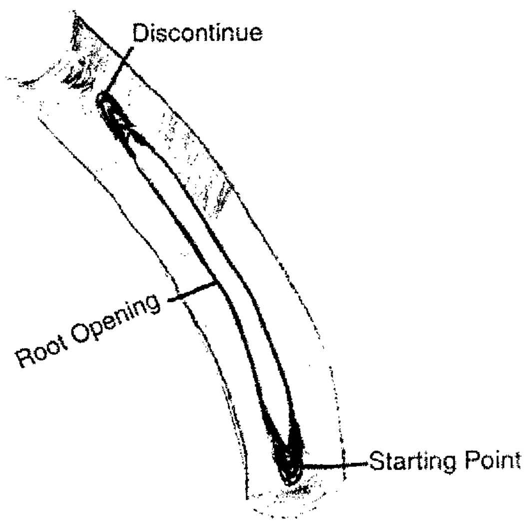
A defect should be clearly marked by the inspector or supervisor so that the metal can be excised with a minimum of material loss. Normally surface defects and those of reasonable depth can be removed by grinding or gouging. Defects that go into the weld are removed by the gouging method; the weld must be preheated to the required temperature and maintained as such. The preheating temperature is the same as that used for making the weld.

There are two stages of repair: (a) removal of defects and (b) preparation of the defective area for welding. The cavity, which has been prepared by gouging, must now be dressed by a grinder or a burring tool that can effectively remove the rough surface in the cavity. The repair cavity must be wide enough so that electrode can fully access the defective area.

A weld that is fully prepared should be as follows:

1. The prepared cavity surface must be smooth without peaks and valleys.
2. All traces of oxide must be removed.
3. All spatter and globular deposits in the groove during each welding pass should be removed repeatedly.

As shown in the figure below, the root opening is reestablished. This part of the root bead must first be deposited, because the base metal is that of a medium alloy composition. If the root pass was originally deposited by the gas tungsten arc welding process, it should again be applied here. However, if the machine to be used for welding has an attachment for pulse arc, then it should be used instead to control burn through. The second pass should be slightly wider than the first, using the pulse arc. From there on, the shielded metal arc process can be used to deposit stringer beads of a limited size. All slag particles and dust should be removed from the cavity after each deposit. As shown in Fig the figure below, the starting point should be approximately 3/16 of an inch on the base metal. It should then be either ended or discontinued the same distance on the base metal. Stringer beads should be used until it is filled, and then two weave passes or a single, wider weave can complete the weld.



Preperation of weld repair

CHAPTER 14

Fitting-Up Pipe

Fitting-up pipe is one of the basic skills of pipe welding. In simple terms, fitting-up means to position the pipes in the correct location as specified by the blueprint. The general procedure used to fit-up pipes is basically as follows:

1. Align the pipe or pipe fitting as closely as possible and hold it in this position
2. Weld a single tack weld in place
3. Measure the location of the pipe or pipe fitting
4. If necessary, adjust the position of the pipe or pipe fitting until it is in the specified location
5. Weld a second tack weld opposite the first tack
6. Check the location of the pipe or the fitting again and, if necessary, adjust the position
7. Weld the two remaining tack welds in place.

Usually all or a number of joints are fitted-up as described above, before the complete root bead is welded, in order to keep the joints flexible so that adjustments can be made in the positions of the pipes. Each joint is held together by the four tack welds, unless it is necessary to weld the entire root bead to enable the joint to carry the weight to which it is subjected. Braces may also be used to support the load.

While the general procedure for fitting-up is the same, regardless of where the job is done, variations in which the details are performed are to be expected. For example, very heavy pipes and fittings have to be lifted by cranes or by chain hoists, using chains or steel cables to hold the pipes or the fittings. On the other hand, smaller pipes can usually be held more conveniently by a helper while the welder welds the first tack weld.

The pipe welder should know the basic methods of fitting-up and should be skilled in their application. He should plan each job in advance. By doing this he can avoid costly errors. Fitting-up is interesting work because it requires thought, planning, and often a considerable degree of ingenuity, since it is seldom that two jobs are the same.

Tools Required

For very heavy pipes and fittings, tackle is required for lifting and holding them. Chains, steel cable, heavy-duty C-clamps, chain hoists, and cranes are used, if available. Hammers of various sizes, crowbars, and pinch bars are needed occasionally to bend the pipe joints in order to align them. These tools should always be used carefully so that they will not damage the pipe or the pipe joint.

Steel rules, steel tapes, spirit levels, protractors, and rafter squares are indispensable tools for fitting-up pipe. Careless usage of these tools must be avoided as it may impair their accuracy. A level that does not read correctly or a square that is "out-of-square" can cause serious errors. For this reason, levels and squares should be checked occasionally.

A level is checked by placing it on a plane surface that is horizontal, or nearly so. In Fig. 14-1, this is called POSITION 1 and the encircled numbers identify the ends of the level. When in POSITION 1, carefully read the position of the bubble in the glass. Then turn the level around to POSITION 2, Fig. 14-1. If the level is

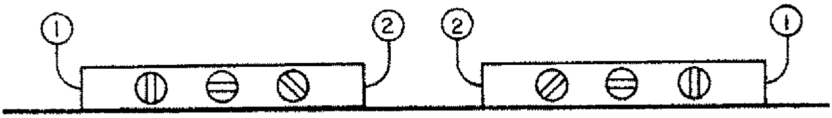


Fig. 14-1. Method of checking a level. The bubble should read the same when the level is in either position shown.

reading correctly, the bubble will be in the same place but on the opposite side of the glass in relation to the ends of the level. The vertical and 45-degree glasses can only be checked by placing the level on surfaces that are known to be vertical or 45 degrees. Most levels have provision for adjusting the glass so that it will read correctly.

The best method of checking a square is to hold it against a square that is known to be true. Both squares should be placed on a perfectly flat surface, as shown in Fig. 14-2A. Another method, shown in Fig. 14-2B, is to set the square on a flat surface and against another, smooth surface on which a line can be scribed. Scribe a line using the square and then turn it around and scribe another line in the same place. If the two scribed lines coincide, the square is true.

A square that is not true can only be corrected in a precision machine shop. Usually it is less expensive to purchase a new square.

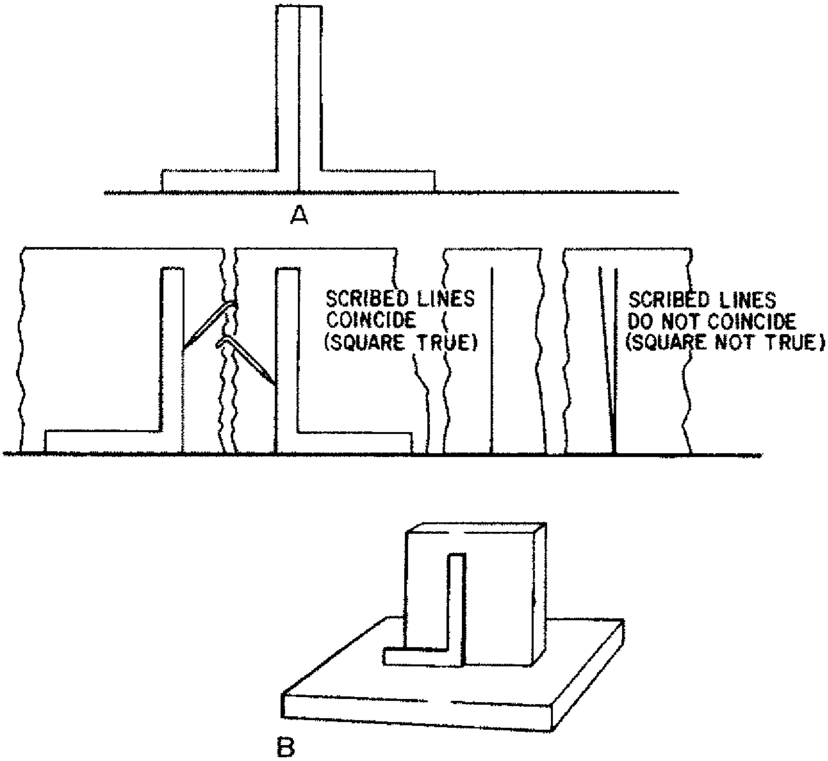


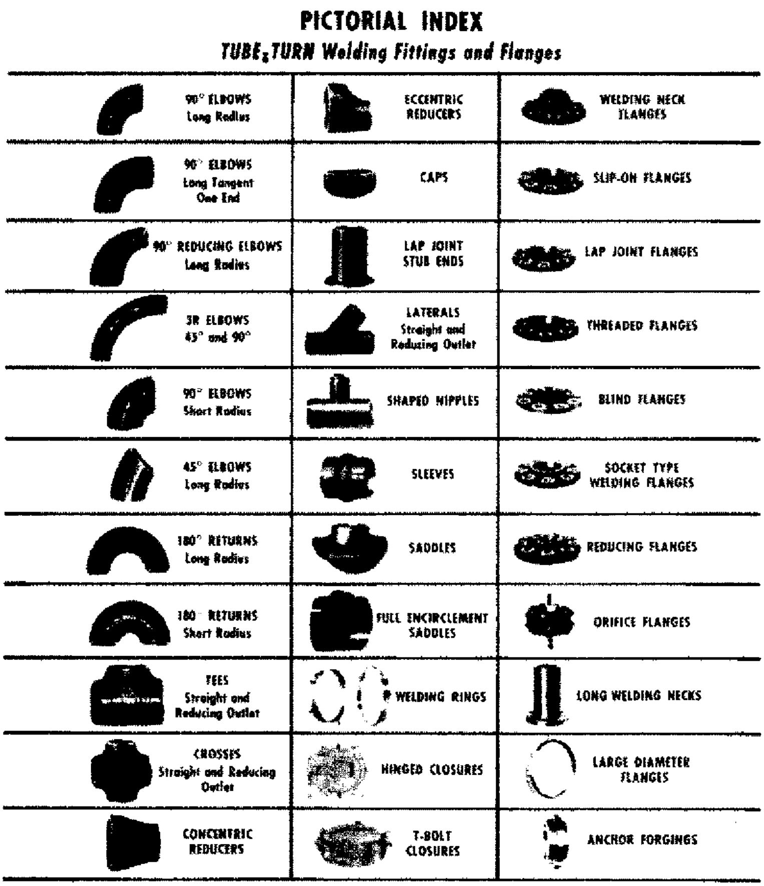
Fig. 14-2. Methods of checking a square. A. Comparing a square to another square that is known to be true; B. Scribing two lines with square blades resting on table in opposite directions.

Pipe Fittings. A wide variety of standard pipe fittings is shown in Fig. 14-3. These fittings are produced especially for welded pipe and they are purchased with the ends beveled correctly in preparation for welding.

Pipe-to-Pipe Fit-Up

When there are two lengths of pipe that must be fitted-up together, they can be aligned by the methods shown in Fig. 14-4A and B. A very effective method is illustrated in Fig. 14-4A, where an ordinary piece of straight angle (or steel angle) is used as a gage to check the alignment. The angle iron must be straight and the burrs on the ends, caused by the saw cuts, must be removed.

The angle iron is first placed on one side of the two pipes, bridging the joint, and then it is placed against the opposite side of



Courtesy of the Tube Turns Div., Chemetron Corp.

Fig. 14-3. Standard pipe fittings used for welded pipe.

the pipe. In each position an attempt is made to rock the angle iron. When it will not rock in either position, the pipes are aligned. Sometimes, the angle iron is held over the pipes while the tack weld is deposited on the other side.

The second method, shown in Fig. 14-4B, is simply to bridge the joint with a straightedge or with a blade of a rafter square. At least two positions on the pipe, 90 degrees apart, should be checked in this manner. While aligning the pipes in preparation for the first tack weld, the correct root opening must be maintained. This can be done by placing a piece of bent wire between the pipes as shown in Fig. 14-4C. Of course, the diameter of the wire must be equal to the root opening.

The procedure for fitting-up two pipes is illustrated in a step-by-step manner in Fig. 14-5. This general procedure is also used to

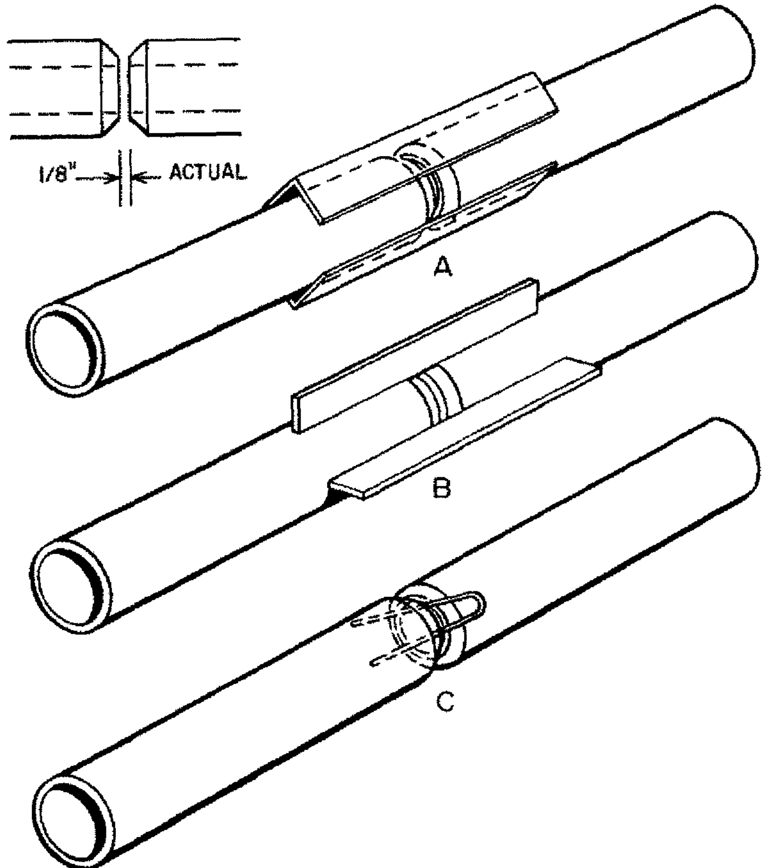


Fig. 14-4. Method of aligning two pipes. A. Using angle iron to align the pipes; B. Straightedge used to align the pipes; C. Using a piece of bent wire to obtain the correct root opening.

align the fittings, with appropriate variations, as will be explained further on.

Welding Pipe Parts to Pipe

Flanges. Frequently, a flange must be welded to the end of a pipe, as shown in Fig. 14-6. It must be centered with respect to the axis of the pipe and the face of the flange must be perpendicular to the axis. The bolt holes in the flange are usually in multiples of four and it is common practice to weld the flange so that two bolt holes share the uppermost position on the flange.

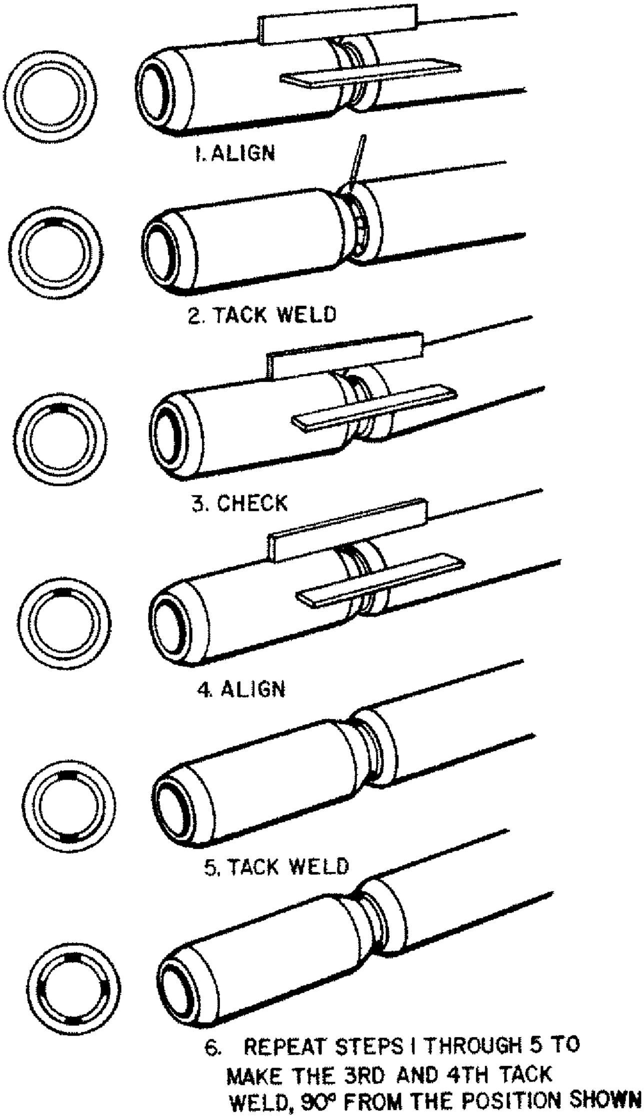


Fig. 14-5. Step-by-step procedures for fitting-up two pipes.

The first step in fitting-up the pipe is to hold it in place as shown in Fig. 14-6A. Two bolts are inserted in the bolt holes and a spirit level is placed so that it rests on the bolts. A helper holds the flange in the center of the pipe so that the bubble of the spirit level is centered. While the helper holds the flange in this position, the welder deposits the first tack weld in place. If bolts are not available, the level can be held as shown in Fig. 14-6B, with the top of the level tangent to the two bolt holes.

After the first tack weld has been deposited, the flange is carefully aligned. It is aligned centrally with respect to the axis of the pipe by checking the internal and external surfaces of the flange and the pipe. If the pipe is known to be in a horizontal position, the flange may be positioned perpendicularly to the pipe axis, in one plane, by placing a spirit level against the face, as in Fig. 14-7. The flange is aligned by tapping it with a hammer until the bubble in the vertical glass on the level reads zero; however, it is necessary to protect the flange against dents by placing a piece of soft metal or wood where the hammer blow is struck. When the flange is aligned, the second tack weld can be deposited.

Another method of aligning the face of the flange is illustrated in Fig. 14-8. One blade of a square is placed against the face while the

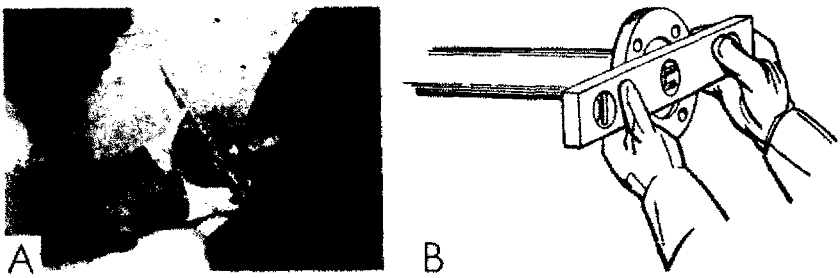


Fig. 14-6. A. Aligning bolt holes on flange by placing the level on two bolts inserted in bolt holes; B. Aligning bolt holes on flange with a level.

Fig. 14-7. Aligning a flange using a level, when the pipe is known to be in a horizontal position.

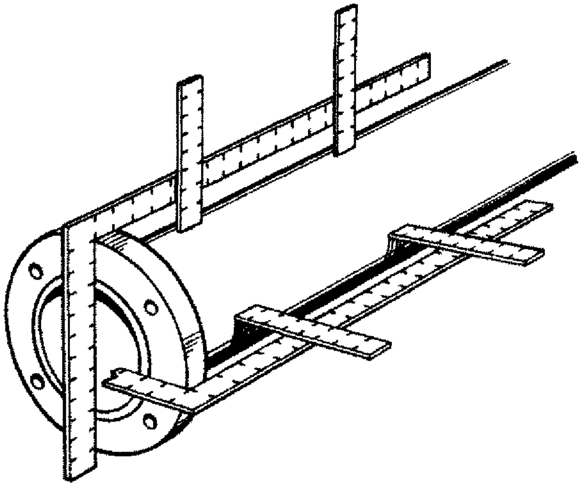


Fig. 14-8. Method of aligning a flange perpendicular to the axis of the pipe to which it is to be welded.

other blade rests on the side of the flange. With the square in the center of the pipe, two measurements are made between the surface of the pipe and the blade of the square. When both measurements are equal, the second tack weld can be made.

Before the two final tack welds are deposited the flange must be aligned again, this time 90 degrees from where it was first aligned. If the pipe is horizontal, a level cannot be used to check this alignment. A square and a rule must be used, as shown in Fig. 14-8. The last two tack welds can be deposited when both measurements are equal.

If the flange is to be attached to a pipe that extends out from a vessel, as in Fig. 14-9, it must be welded in place a certain distance from the vessel. To obtain this distance is largely a matter of welding the pipe to the vessel correctly; however, the location of the flange should be checked. This can be done by drawing a horizontal chalk line along the side of the vessel that is the same height as the center of the pipe, as shown in Fig. 14-9. The measurement is made by placing a straightedge or the blade of a rafter square against the face of the pipe and measuring between it and the chalk line.

The flange is held in the correct position by a helper while the welder deposits the first tack weld. When this has been done the flange must be checked and aligned before the second tack is deposited by placing a level against the face of the flange, as was shown in Fig. 14-7. After the second tack weld has been deposited the straightedge, or square, is again placed against the face of the flange and two measurements that are a distance apart are made

Fig. 14-9. Aligning the flange and measuring the distance from the face of the flange to the vessel.

between the straightedge and the chalk line. When the flange has been adjusted so that both measurements are equal, the remaining tack welds can be deposited.

90-Degree Elbows. If the pipe to which the elbow is attached is horizontal, the most convenient method of alignment is by using a spirit level, as shown in Fig. 14-10. By placing the spirit level on the face of the elbow, as shown in Fig. 14-10A, the elbow is leveled before the first tack is welded. After this tack weld has been made, it is again checked with the elbow in this position and adjusted until the bubble is centered. The spirit level then is placed in the position

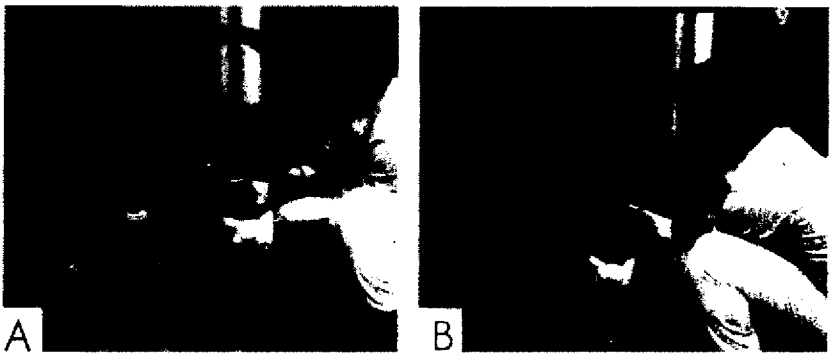


Fig. 14-10. A. Aligning a 90-degree elbow, using a spirit level, prior to depositing the first tack weld. B. Aligning a 90-degree elbow prior to depositing the second tack weld.

shown in Fig. 14-10B and the elbow is aligned until the bubble on the level is centered. The bottom tack is then deposited. The elbow should be checked in both directions again and realigned, if necessary, before the two remaining tacks are deposited.

If the pipe is not exactly horizontal, the elbow can be checked for crosswise alignment as shown in Fig. 14-10A. For lengthwise alignment, a straightedge or the blade of a rafter square is used, as in Fig. 14-11. When two measurements between the straightedge and the center of the pipe, taken a distance apart, are equal, the elbow is aligned. The checking, aligning, and welding are done as before.

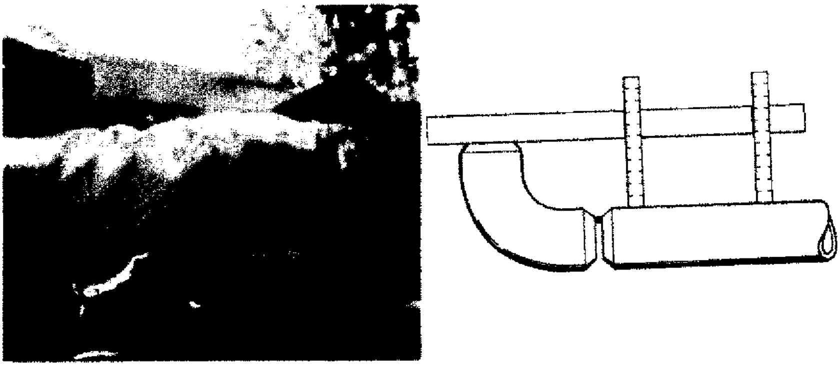


Fig. 14-11. Method of aligning a 90-degree elbow using a straightedge or rafter square.

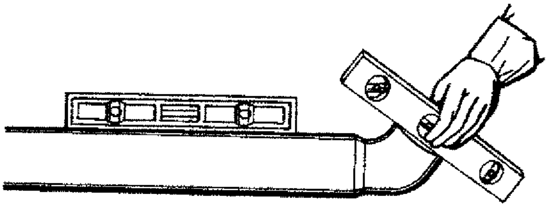


Fig. 14-12. Checking the alignment of a 45-degree elbow with a spirit level when the pipe to which it is to be attached is horizontal.

45-Degree Elbows. When the pipe to which the 45-degree elbow is attached is horizontal, the most convenient method of aligning the elbow in the direction parallel to the pipe is to use a spirit level, as shown in Fig. 14-12. The elbow is aligned when the bubble in the 45-degree glass on the level is centered.

If the pipe is not horizontal, as in Fig. 14-13, a protractor level can be used. The bubble in the glass is centered when the protractor is resting on top of the pipe and the reading, in degrees, is obtained.

Forty-five degrees are added to this reading and the protractor is adjusted to this position. For example, if the reading on the pipe is 12 degrees, the protractor is adjusted to read 57 degrees (12° + 45° = 57°). Adjusted to this setting, the protractor level is placed on the face of the elbow, as shown, and the elbow is aligned when the bubble is centered. Sometimes a flat piece of steel must be placed across the elbow, on which the protractor can rest.

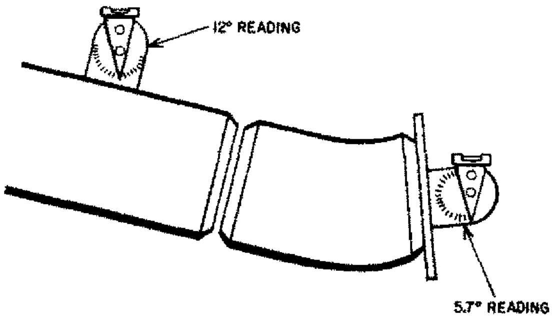


Fig. 14-13. Method of checking the alignment of a 45-degree elbow with a protractor level when the pipe is not perfectly level.

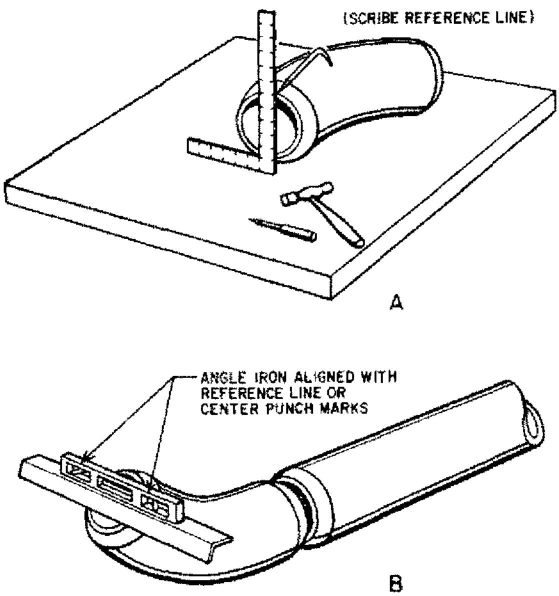


Fig. 14-14. Method of checking the crosswise alignment of a 45-degree elbow. A. Laying out the reference line; B. Method of supporting the level to align the elbow.

Frequently, the 45-degree elbow is aligned crosswise, with respect to the axis of the pipes, by visual estimation. A method that can be used is shown in Fig. 14-14. The pipe is shown lying on a flat surface in Fig. 14-14A, with a square positioned against the face. Chalk is rubbed on the face and a reference line then is scribed across the face, using the blade of the square as a guide. The chalk makes the scribed line more visible. Two shallow center-punch marks are often punched at each end of the reference line and the angle iron is aligned with respect to these marks.

When the elbow is to be aligned against the pipe, the spirit level is placed on an equal-legged angle iron (3 x 3 x ¼ in. or 1½ x 1½ x ⅛ in.) and the angle iron is positioned parallel to the reference line or the center-punch marks on the face of the elbow, as shown in Fig. 14-14B. With the level in this position, the elbow is aligned when the bubble is centered.

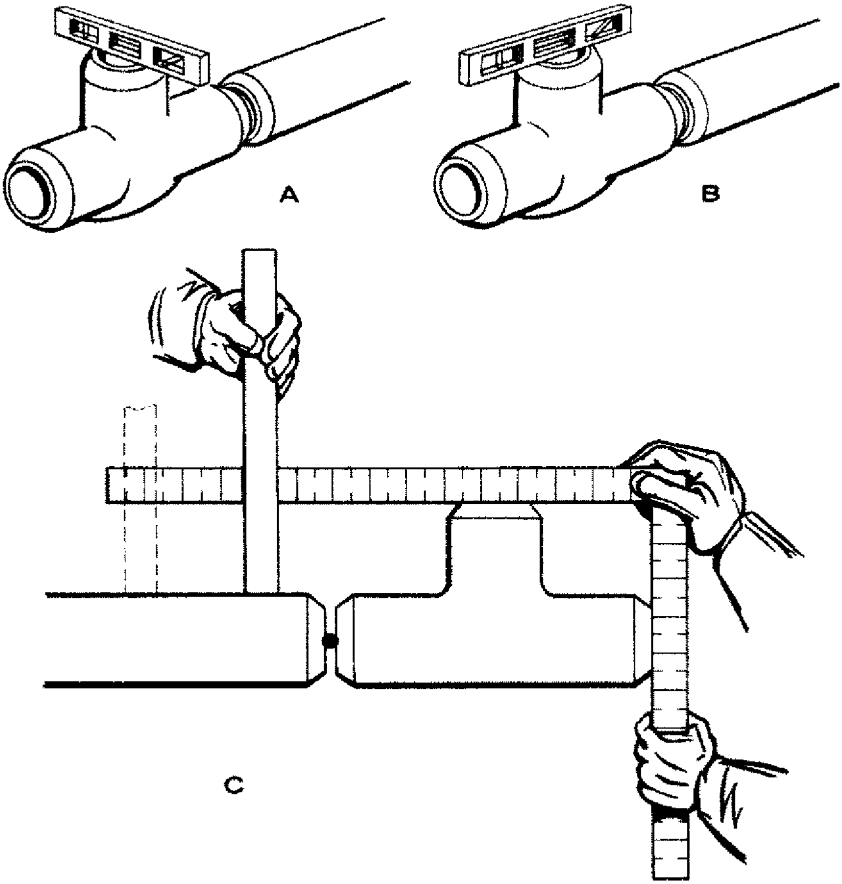


Fig. 14-15. A. Aligning a tee prior to depositing the first tack weld; B. Aligning the tee prior to depositing the second tack weld; and C. Alternate method of aligning the tee.

Tees. A spirit level can be used to align a tee when the pipe is horizontal. As shown in Fig. 14-15, the level is placed crosswise and lengthwise on the upper face of the tee to align it in these two directions.

When the pipe is not exactly horizontal, the crosswise alignment is obtained by using the level as shown in Fig. 14-15A. Lengthwise alignment is obtained by using a rafter square, as in Fig. 14-15C. A blade of the square may be held firmly to the end face or to the top face of the tee, and two measurements are made between the top of the pipe and the square. When the two measurements are equal, the tee is aligned in the lengthwise direction.

When the branch pipe to which the tee is to be connected is horizontal, the tee must be positioned as shown in Fig. 14-16. In this case, the tee can be aligned by placing the spirit level against one face and then the other face of the tee, as shown.

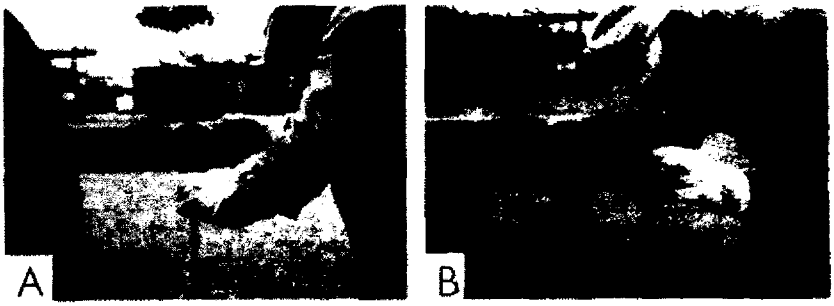


Fig. 14-16. A. Aligning a tee with a spirit level prior to depositing the first tack weld; B. Aligning the tee prior to depositing the second tack weld.

Vertical Pipe Alignment. The procedures for aligning vertical pipes are shown in Fig. 14-17. Short runs of vertical pipe can be aligned by using a level, as shown in Fig. 14-17A. Two positions on the pipe that are 90 degrees apart should be checked in this manner to make certain that the pipe is truly vertical. The pipe should be checked in this manner before depositing each tack weld. A piece of bent wire can be used to obtain the root opening when the pipe is in this position.

Longer lengths of vertical pipe can also be checked with a level. The pipe should be checked in two places around the pipe as before, but this must be done in several locations along the length of the pipe. A procedure that is frequently used to check long runs of vertical pipe is shown in Fig. 14-17B. A plumb bob is attached to the end of a line hanging from a convenient place near the top of the pipe. The distance between the wall of the pipe and the line is

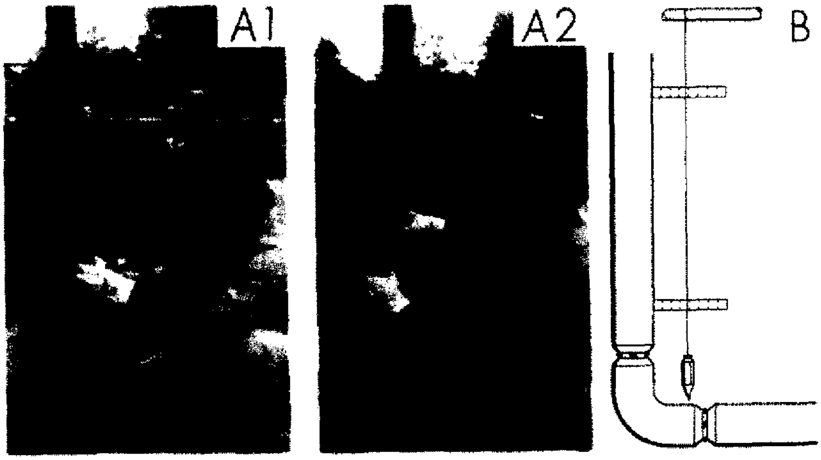


Fig. 14-17. A-1 and A-2. Aligning a vertical pipe with a spirit level; B. Aligning a vertical pipe with a plumb bob.

measured in several places. When these measurements are all equal, the pipe is vertical in the direction shown.

Perpendicular Pipe Alignment. Frequently, a pipe must be welded perpendicular to another pipe. The elbow alone cannot be depended upon to provide the necessary alignment. A typical example of the method of aligning the pipe after the first tack weld has been made is shown in Fig. 14-18. The rafter square is held firmly against the

Fig. 14-18. Method of aligning two pipes perpendicular to each other.

Fig. 14-19. Another method of aligning two pipes perpendicular to each other.

horizontal pipe and several measurements are made between the blade of the square and the surface of the pipe. By lifting the end of the horizontal pipe, it is adjusted until the measurements are all equal, after which the second tack is welded in place.

As shown in Fig. 14-19, the measuring procedure could have been reversed, with the square held against the vertical pipe and the measurements taken between the blade of the square and the horizontal pipe. However, in this illustration the other end of the horizontal pipe is tack welded in place before the second tack weld is deposited on the elbow. Before the other end of the pipe is tack welded in place, the square is used, as shown, to make certain that the pipes attached to the elbow are 90 degrees apart. By this procedure, the horizontal pipe is held firmly in the correct position before the remaining tack welds are deposited on the joint at the elbow.

CHAPTER 15

Qualification of the Welding Procedure and the Welder

On many welding jobs, the fabricator is required to separately qualify the welding procedure to be used and the welder who is actually to weld the pipe. How this is done is specified by a code. One code frequently encountered in pipe welding is the ASME Boiler and Pressure Vessel Code, Section IX. While this code is not reproduced here in detail, the discussion in this chapter is based largely on the code.

Qualifying a Procedure

To qualify a procedure, the fabricator must prove the adequacy of his procedure with consideration given to the service conditions, particularly to the consequences should the piping system fail. A pipe weld is made according to the procedure to be qualified. Samples are cut from the weld; the positions from which they are cut are shown in Fig. 15-1. Figure 15-1 also specifies the dimensions of the test samples and the type of test to which they are to be subjected. After the weld specimens have proven to be acceptable, the procedure is considered to be valid.

Qualifying the Welder

In order to qualify the welder, the fabricator must have him weld a pipe joint in both the horizontal (2G), and the vertical (5G), positions, using the procedure that has been qualified for doing the job. Four samples, Fig. 15-2, are cut from each of the welds and bend test samples are prepared. As shown in Fig. 15-2, two face-bend tests and two root-bend tests are made from each weld.

The fabricator must maintain a record of the tests made by each welder, who is assigned an identification number for use as a reference. No welder is allowed to perform on the job unless he has been successfully qualified by passing the bend tests.

Passing one particular procedure will not qualify the welder for welding all different pipe sizes and wall thicknesses, but will restrict the operator to welding within a specific range of wall thickness. If

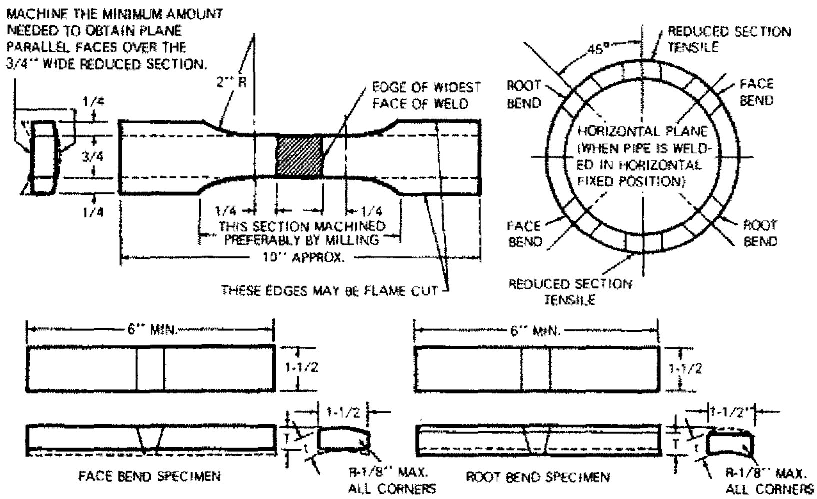


Fig. 15-1. Specification of test specimens for qualifying the pipe welding procedure.

tests are conducted on pipe with ⅜-inch wall thickness, the operator is then qualified to weld wall thicknesses one-half the size of the sample, or twice the sample size. Therefore, before attempting to weld heavier wall pipe, the welder, and procedure, must have new qualification.

A welder shall be requalified when there are one or more changes made, which differ from that of the already established procedure. The following changes are responsible for new qualifications:

A. A change from a base metal listed under one letter subgroup to one listed under another subgroup.

B. A change from one diameter wall-thickness range to another.

C. The addition of any welding position in which a large number of welds is made.

D. If the direction of welding is changed from bottom to top, or top to bottom.

There are other changes which are not quite related to this process:

E. An operator who is qualified with an E-6010 is not necessarily permitted to use a low-hydrogen electrode. If he is qualified with a low-hydrogen electrode, it is possible for him to use an E-6010 if the job permits.

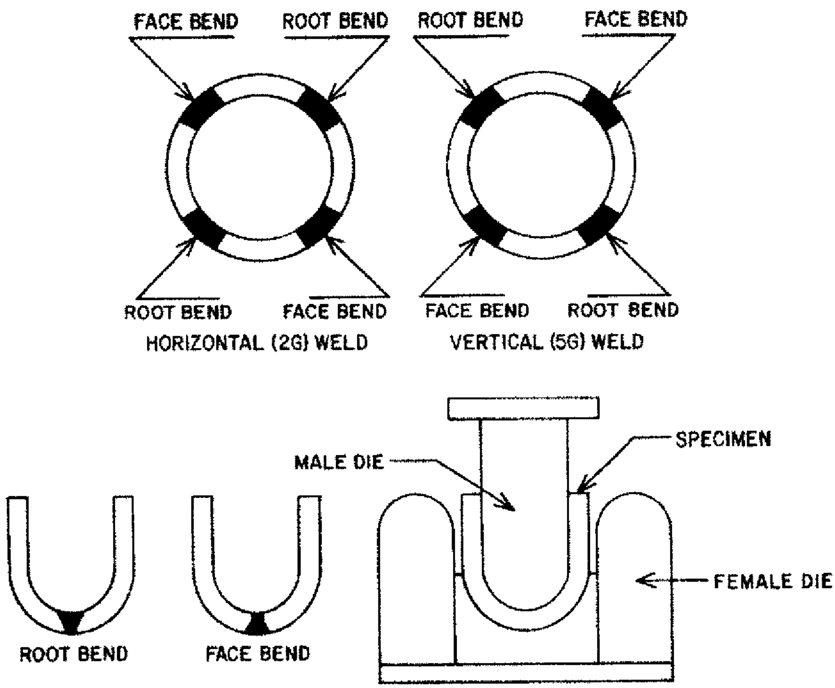


Fig. 15-2. Bend test specimens for qualifying the pipe welder. The weld must bend 180 degrees without breaking.

Qualifying welders according to a procedure is the responsibility of a qualified inspector. An inspector not only inspects the completed weld samples, but also conducts this test in a systematic manner. There are three basic steps in testing:

1. Visual inspection
2. Acceptance quality
3. Final result.

Perfect Weld Requirements

A. The pipe nipples and the edges to be welded should be free from oil, grease, etc.; after they are tacked together, the root openings are inspected. During the course of welding, each layer of welded metal is checked for porosity, undercut, slag inclusion, and surface roughness. An inspector has the responsibility of terminating any particular test at any time if he finds that the operator does not have the skill required to produce satisfactory welds.

B. When a test weld is completed, further visual inspection is conducted to see that the weld is free from cracks, that there are no arc strikes on the pipe surface, that the melt-through does not exceed ⅛ inch, that concavity of the root bead does not exceed $1/16$ inch, that incomplete fusion is not present, that restarts and tie-ins do not exceed $1/16$ to $1/64$ inch in cavity, and that the cover pass is uniform and smooth.

C. Having passed the visual inspection, four specimens are extracted from the welded pipe as shown on page 227, comprising two face bends and two root bends. Those bends must be inspected for the following:

A. Slag inclusion
B. Cracks
C. Incomplete fusion between the welded metal and the base metal, and between any of the weld passes.

Bend Tests

If the welder is to pass the guided bend test, the specimen shall have no cracks or other defects exceeding ⅛ inch in any direction, with the exception of corner cracks. However, if corner cracks are caused by lack of fusion, slag inclusion, or other defects, the welded specimen can be rejected.

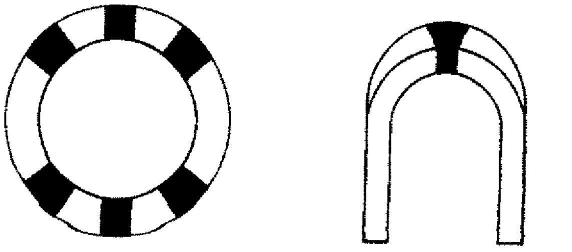
A complete record is kept on each welder if the specimens have passed the described test. Procedure and qualification tests for each specimen, including tensile and bend tests, are recorded in detail.

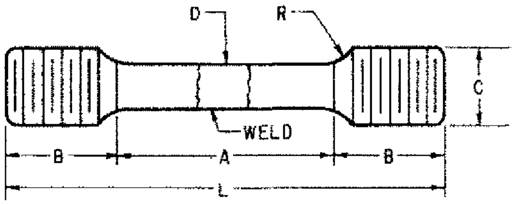
In addition, a written document is kept, showing:

A. Specification of material being welded
B. Specification of filler metal
C. Edge preparation
D. Preheat and postheat, if being used
E. Volts and amps
F. Spacing or root opening
G. Number of passes
H. Size of electrode and classification
I. Wall thickness and diameter of pipe being tested
J. The test conditions, open air or closed shop.

All this and other important information is documented and made available to supervisors and inspectors.

It is important to note that when tests are conducted on pipe with wall thickness exceeding ¾ inch, the test specimen is sectioned out differently from those in Fig. 15-2. Bend specimens are prepared





	Standard Dimensions, Inc.			
	(a) 0.505 Specimen	(b) 0.353 Specimen	(c) 0.252 Specimen	(d) 0.188 Specimen
A-Length of reduced section	See Note 4	See Note 4	See Note 4	See Note 4
D-Diameter	0.500±0.010	0.350±0.007	0.250±0.005	0.188±0.003
R-Radius of fillet	3/8, min	1/4, min	3/16, min	1/8, min
B-Length of end section	1 3/8, approx	1 1/8, approx	7/8, approx	1/2, approx
C-Diameter of end section	3/4	1/2	3/8	1/4

NOTES:
(1) Use maximum diameter specimen (a), (b), (c), or (d) that can be cut from the section.
(2) Weld should be in center of reduced section.
(3) Where only a single specimen is required the center of the specimen should be midway between the surfaces.
(4) Reduced Section "A" should not be less than width of weld plus two "D."
(5) The ends may be of any shape to fit the holders of the Testing Machine in such a way that the Load is Applied Axially.

Fig. 15-3. Test specimens for thick-wall pipe.

in a way which allows them to be bent sideways. The tensile specimen is also prepared differently for thick-wall pipe (Fig. 15-3).

It is also important to note that when welded specimens are being prepared for bend tests, the surface is smoothed by grinding which should be done in the direction shown in Fig. 15-4.

For information concerning The American Petroleum Institute Butt Weld Procedure Qualification Test (API) 1104 see the latest edition of the API Standard 1104, for sale by

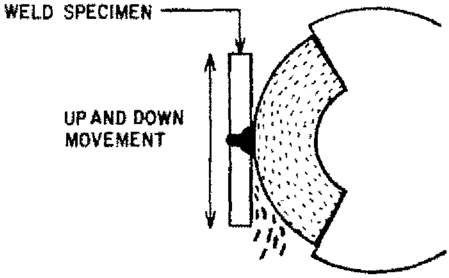


Fig. 15-4. Method of grinding the weld of the test specimen.

the American Petroleum Institute, 1271 Avenue of the Americas, New York, N.Y. 10020.

The points covered in this limited discussion on Inspection and Qualification Procedures will vary over a period of time. Inspections and qualifications are changeable and kept up-to-date. Therefore, it is always necessary to consult the appropriate code (ASME BOILER AND PRESSURE VESSEL CODE, SECTION IX).

CHAPTER 16

General Welding Safety

After a half century, commercial welding has proved itself not to be injurious to health. However, as in most trades, if a welder is careless, some features of the welding process can cause discomfort and actual danger.

Essentially, welding is not a hazardous occupation if proper precautionary measures are always observed. This requires continuous awareness of the possibilities of danger and habitual safety precautions taken by the welder. In addition, it requires that the supervisor be alert, responsible, and stringent in enforcing safety regulations.

SAFETY MEASURES

1. Always wear dry, protective, fire-resistant clothing, cuffless trousers covering the shoe tops, leather gloves, jacket, apron, and proper dark lenses.
2. Always keep a safe, clean work area.
3. Make sure there are no flammable materials nearby.
4. Do not weld in the vicinity of explosive materials or carbon tetrachloride.
5. Always make sure there is enough ventilation to give three or four complete changes of air per hour.
6. Use air exhaust at the weld whenever welding lead, cadmium, chromium, manganese, brass, bronze, zinc, or galvanized metals.
7. Never weld or cut in a confined area without ventilation.
8. Keep all welding equipment in good condition.
9. If it is necessary to couple lengths of cable, make sure joints are insulated and all electrical connections are tight. Use no cable with frayed, cracked, or bared spots.
10. When electrode holder is not in use, hang it on welding machine or special holder. *Never let it touch a gas cylinder.*
11. Always have welding machine properly grounded, usually to cold-water pipe.
12. Make sure pedal controls are guarded to prevent accidental starts.

13. If need arises to weld in damp or wet conditions, wear rubber boots and/or stand on dry cardboard or wood.
14. Stand only on solid items, floor, or ground.
15. When welding in high places without railing, use safety belt or lifeline.
16. Always wear proper eye protection, especially when grinding or cutting.
17. Keep booth curtains closed to protect the eyes of others.
18. Never weld or cut directly on a concrete floor.
19. When using a water-cooled torch, check for water leakage.

SAFE HANDLING OF GAS CYLINDERS

1. Be very careful when moving any gas cylinder — never handle roughly. Always have cylinders capped when moving. Never roll cylinders horizontally.
2. Never use welding gas as compressed air for blowing away dirt or debris.
3. Before attaching a regulator to a cylinder, open and close the valve quickly. This is commonly called "cracking" the cylinder.
4. Open valve on cylinder slowly after regulator is attached.
5. Be sure all connections are clean and gas-tight. Check with saliva or soapy water.
6. When the regulator is not in use, the adjusting screw should be screwed out until diaphragm is free.
7. Always protect the hose from rupture or mechanical damage.
8. Always close the cylinder and release the pressure from the regulator and hose when work is done.
9. Always leave safety plugs alone.
10. Always keep the cylinders in an upright position.
11. Always mark the cylinders that have been used "Empty," or "MT."
12. Never open tank valves until you are certain that regulator valves are closed finger-tight.
13. Never open the valves on the cylinders with a hammer.
14. Never screw the regulator screw in tightly against the regulator.
15. Never use a cylinder, even when empty, as a roller.
16. Do not store cylinders in a room where the temperature is higher than 80 degrees F.

SAFETY REGULATIONS FOR OXYACETYLENE WELDING

1. Check all connections before lighting the torch.
2. When the torch flashes back, or is burning on the inside, turn both cylinders off immediately — first the oxygen and then the acetylene.
3. Extra tips should be put away when not in use. Never put them in a drawer with other tools; this may damage the seat of the tip.
4. Always use the right-size tip for cutting and welding.
5. Always turn the oxygen cylinder valve all the way open. Open the acetylene cylinder valve no more than one turn. One-half turn is preferred.
6. Always place the welding tip so that it points to the side of the torch to which the acetylene hose is attached.
7. Always weld at least 5 feet away from the cylinders.
8. Do not use any oil or grease on any oxygen or acetylene connections.
9. Never hammer on oxygen or acetylene regulators.
10. Do not light a torch with a match or an open flame. Use a striker.
11. Before lighting torch, be positive that hose, tanks, or any inflammable material will not be exposed to heat, flame, or sparks.
12. Beware of high acetylene pressure. Never use acetylene gas when the pressure is greater than 15 pounds per sq in. (acetylene gas, when compressed to more than 15 pounds per sq in., becomes a very high explosive).
13. Do not hold welding or cutting tip too close to the work.
14. Never use a tip that gets too hot.
15. Never use a torch that leaks.
16. Never leave the torch burning and go away from it.
17. Never leave torch valve open.
18. Do not adjust, alter, change, build, or do any experimental work on cylinders, regulators, torches, or any other gas equipment.
19. Never weld a closed or jacketed vessel without an air vent. Also, never weld a vessel which has contained any explosive or flammable material until you are positive that it has been thoroughly emptied and purged, then use extreme care.
20. Always write the word "HOT" on workpieces that are very hot, especially when they are located in work areas frequented by other workers.
21. Always coordinate movement, when shifting large sections of fabricated pipe, if two or three people are working together.

22. Never congest work area with completed jobs, so that evacuation can be quick in case of extreme danger.

23. Always secure pipe from rolling during fabrication and storing.

24. When fabricated sections are in their working position, they should be secured by tacking or bracing properly before the load is released.

25. When removing a single link of pipe from a pile or pipe rack, always start from the very top to avoid the cluster of pipe link from rolling off.

26. Avoid resting tools (hammer, chisel, small pieces of metal, etc.) on pipe, and when working above ground level, to avoid injury to those working on a lower level by falling metal or tools.

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