ISSN 1067-8212, Russian Journal of Non-Ferrous Metals, 2015, Vol. 56, No. 2, pp. 217–221. © Allerton Press, Inc., 2015.

PHYSICAL METALLURGY AND HEAT TREATMENT

Effect of Vibration during GTAW Welding on Microstructure and Mechanical Properties of Ti6Al4V[1]

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Abstract—Grain growth in Ti6Al4V alloy during fusion welding decreases yield stress and tensile strength. This study examined the effect of mechanical vibration of the work piece during GTAW welding on the mechanical and metallurgical properties of Ti6Al4V. The structures of all welded specimens at different levels of vibration was examined and it was found that, during 330 Hz vibration, grain size in the welded metal zone decreased significantly over that of pieces welded without vibration. GTAW at 330 Hz significantly increased the mechanical properties and produced the highest yield strength, tensile strength and percentage of elongation. The highest level of hardness in the welded metal zone was achieved under this condition.

Keywords: Ti6Al4V, GTAW, vibration, mechanical properties

DOI: 10.3103/S1067821215020182

1. INTRODUCTION

The drive to improve weld quality and process parameters demands the use of improved welding techniques and materials [1]. Titanium and its alloys are considered to be the best engineering metals for industrial applications because of their excellent strength-to-weight ratio, high fatigue life, toughness, resistance to corrosion and good fatigue strength [2, 3].

Welding methods such as gas tungsten arc, resistance, and diffusion welding have been developed in response to the expansion of the titanium industry.

Titanium alloys easily absorb harmful gases because of their high chemical activity, resulting in poor mechanical properties and unstable structure [4, 5]. Gas tungsten arc welding is the preferred method for avoiding these deficiencies [6]. The welding of titanium alloys often increases grain size in the welded metal and heat affected zones [7]. Fusion zones typically exhibit coarse columnar grains in response to prevailing thermal conditions during welded metal solidification [6]. These columnar grains produce inferior mechanical properties in the welds [1]. Methods of weld grain refinement include inoculation with heterogeneous nucleants, surface nucleation induced by gas impingement, introduction of physical disturbance through techniques such as electromagnetic stirring [4]. Vibratory techniques, and pulsed current welding techniques [8].

When vibration is applied during welding, the weld pool solidifies and the dendrites can be broken up before they become too large. This limits grains size and curbs the growth of dendrites perpendicular to the fusion line. The effect of these phenomena is to partially randomize the direction of grain growth and inhibit segregation in the weld path. The resulting finer microstructure provides better mechanical properties [9].

The present study examined the effect of mechanical vibration of the work piece during gas tungsten arc welding (GTAW) on the tensile strength, yield strength, grain size and structure of solidification.

2. EXPERIMENTAL

The Ti6Al4V sheets used for welding had a yield strength of 939 MPa, tensile strength of 1018 MPa and elongation of 14%. The chemical composition of Ti6A14v alloy is shown in Table 1.

The Ti6Al4V sheet was wire cut into sections 3 mm × 60 mm × 130 mm in size. The pieces were immersed in an aqueous solution of 5% hydrofluoric acid, 35% nitric acid, and 60% water to deoxidize.

The selected welding method was GTAW direct current electrode negative (DCEN) butt welding without filler metal using a thorium electrode 2.4 mm in diameter and a vertex angle of 60°. The welding

Table 1. Chemical composition of Ti6A14V (wt %)

Ti	V	Cr	Cu	Fe	Mn	Mo	Nb	Sn	Zr	Al
Base metal	4.0	0.01	0.02	0.03	0.03	0.03	0.02	0.05	0.02	6.55

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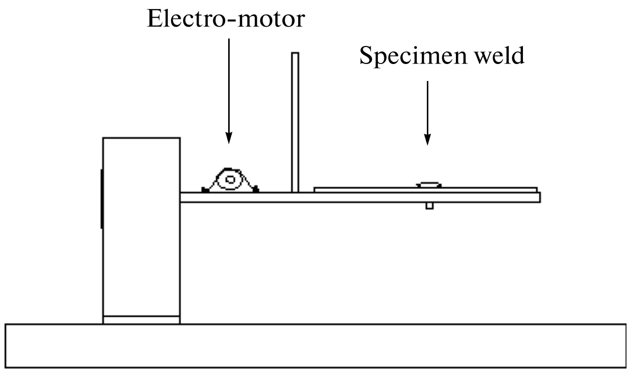

Fig. 1. Schematic vibration machine.

Fig. 2. Tension Test Specimens.

machine was employed at a constant speed of 3 mm/s and 180 A. Figure 1 shows the vibration machine used in this study.

The mechanism converts electrical energy into rotational mechanical energy and mechanical rotational energy into mechanical vibration. The electronic circuit digitally adjusted the electromotor revolutions. The electromotor had an aluminum crankcase and operated at a maximum of 20000 rpm.

High purity argon gas was used during welding. The nozzle was 16 mm in diameter and the gas discharge was constant at 10 L/min. Shower gas was applied for secondary protection of the solidified weld metal and its surrounding zone. The shower gas discharge rate was constant at 25 L/min. Back shielding gas was used at a 5 L/min discharge rate to protect the weld root and the adjacent base metal from contamination by the atmosphere during welding. This was done by passing the gas through a copper tube rib. The different levels

Table 2. Various vibration used in this study

Sample	1	2	3	4
Vibration, Hz	Without vibration (0)	100	200	330

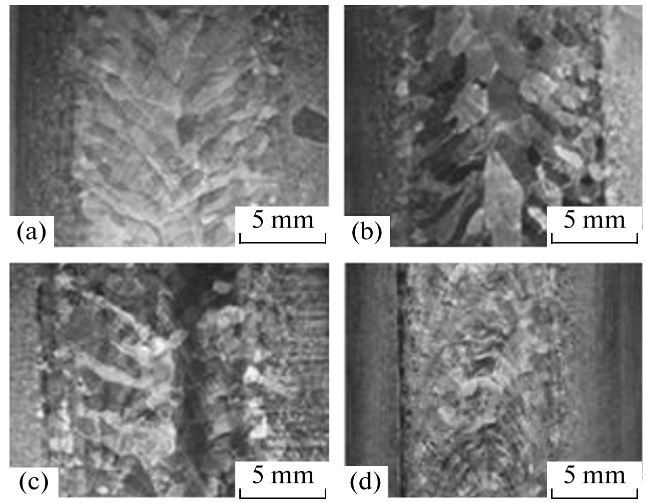

Fig. 3. Fusion zone solidification structures(macro structure) of Ti6Al4V. (a) without vibration, (b) 100 Hz, (c) 200 Hz, (d) 330 Hz.

of vibration under which the specimens were welded are shown in Table 2.

To study the effect of vibration on the macro- and microstructure, welded specimens were cut in cross-sections showing all regions of welding, including the weld metal, heat affected zone (HAZ), and base metal and were mount-heated. The specimens were then micro-etched with a solution of 95 ml water, 2 mL hydrofluoric acid and 3 mL nitric acid and examined using a 60 BX optical microscope. The specimens were macro-etched using a solution of 5% hydrofluoric acid, 35% nitric acid and 60% water and the solidification structure of the weld line was examined. The line intercept method was used for measurement of quantitative grain size. The Vickers micro-hardness method was used at 100 g force for 10 s to examine the hardness of different regions of the weld joints. Tensile testing was performed using an Instron500R testing machine. The dimensions of the tensile specimens were a sub-size length of 23.9 mm and a nominal width of 6 mm in accordance with ASTME standards [10]. Figure 2 shows the tensile test specimens.

3. RESULTS AND DISCUSSION

3.1. Evaluation of Weld Metal Solidification Structure (Macrostructure)

Figure 3a shows the solidification structure of the welding zone without vibration. As seen, the solidification has coarse columnar grain growth from the HAZ to the weld center in the direction of heat transfer. The grains of the metal acted as a base for germination at the weld line. The molten metal in the weld pool was in direct contact with these grains, thoroughly wetting them so that the crystals easily germinated from the molten metal and on the grains. During weld metal solidification, the grains tended to grow perpendicular to the pool boundary because it is the direction of the maximum temperature gradient and, hence, maximum heat extraction. Columnar dendrites or cells within each grain tended to grow in the direction of easiest growth. During solidification, grains that were essentially perpendicular to the pool boundary grew more easily and crowded out those that were less-favorably oriented [11]. Figure 3b shows that the specimens welded at vibrations of 100 Hz had a solidification structure similar to those welded without vibration. This indicates that low vibrations had no effect on the solidification structure. Figure 3c indicates that, when vibrations increased to 200 Hz, solidification developed an equiaxed structure and that the equiaxedgrains blocked the columnar grains growing inward from the fusion line. A mixture of columnar and equiaxed grains with random orientations are evident in the figure. Figure 3d shows the specimens welded at vibrations of 330 Hz and shows that solidification had a completely equiaxed structure and the grain orientation was random. The random variation of grain orientation decreased solidification cracks and prevented crack growth, improving the strength and ductility of the metal weld.

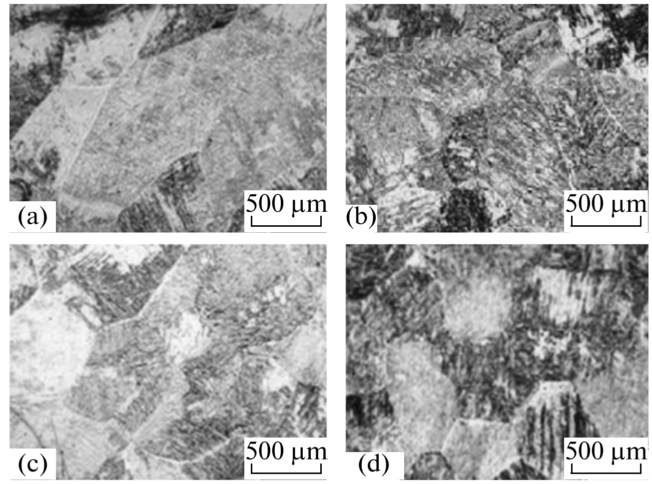

Fig. 4. Fusion zone microstructures of Ti6Al4V (a) without vibration (b) 100 Hz, (c) 200 Hz, (d) 330 Hz.

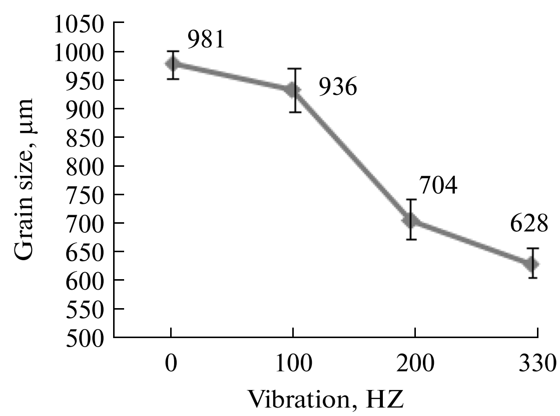

Fig. 5. Effect of vibration on mean grain size in WM.

3.2. Evaluation of Grain Size

Figure 4 shows the microstructure of specimens welded without vibrations and those welded with vibrations up to 330 Hz.

As seen in Fig. 4a, without vibrations, columnar grains with an average grain size of 981 μm formed in the metal weld. The specimens welded at vibrations of 100 Hz showed no significant differences in structure and grain size from specimens welded without vibration. Figure 4b shows that the average grain size was 936 μm.

Increasing the vibrations to 200 Hz developed a structure with equiaxed grains. Figure 4c shows that the structure was not completely equiaxed and the decrease in grain size was significant at 704 μm. Figure 4d shows the specimen welded at vibrations of 330 Hz. The microstructure is composed entirely of equiaxed grains. In this mode, the average grain size was much smaller than all other welding modes. It decreased by 36% to 628 μm.

Figure 5 shows the changes in mean grain size by vibration.

The mechanism of grain refinement in vibration welding is the result of an increase in the nucleation rate and a decrease in growth rate. Initially solidified grains are easily broken off disperse in the molten metal by the force of vibration; this increases the number of nuclei in the melt. In the presence of the force of vibration, overheated melt is driven from the center to the periphery of the welding pool during solidification. The oscillation of the molten metal contributes to an increase in the rate of heat transfer and the removal of the superheated melt, which decreases the likelihood of remelting of the initially solid grains.

The temperature gradient from the center to the edge of the pool decreased and the undercooled zone dispersed throughout the bulk liquid. Accordingly, crystallization proceeded simultaneously throughout the undercooled melt around the floating nuclei. Fragmentation, nucleation and growth occurred throughout the melt, giving rise to the refinement of grains [12].

A stream of cool argon gas was directed onto the free surface of the molten metal to cause thermal undercooling and induce surface nucleation. Small

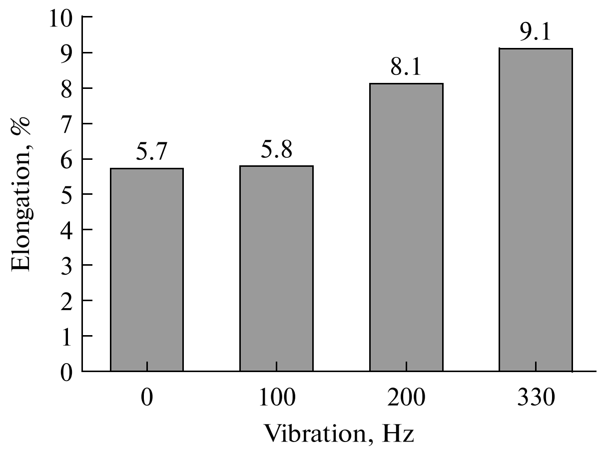

Fig. 6. Effect of vibration on elongation.

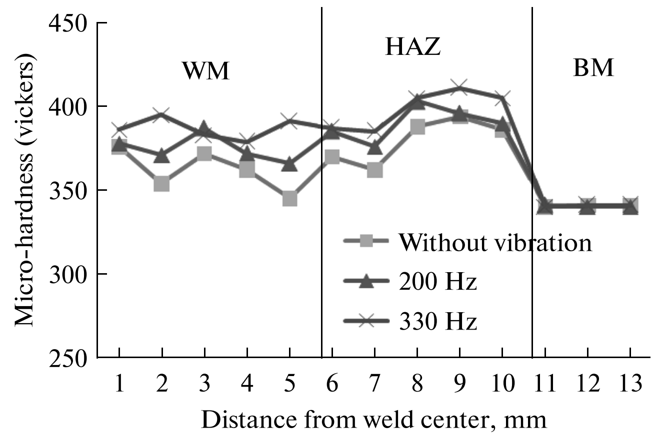

Fig. 7. Hardness profile of WM, BM and HAZ regions.

solidification nuclei formed at the free surface and showered down into the liquid metal. These nuclei then grew and became small equiaxed grains [11].

3.3. Tensile Testing

Table 3 shows the ultimate tensile strength and yield strength. The highest tensile and yield strength was observed for the specimen welded at vibrations of 330 Hz because of the presence of equiaxed grains and the decrease in grain size of the welded metal zone in the specimen. The lowest tensile and yield strength was observed for the specimen welded without vibration because of the presence of columnar grains and the large grain size of the welded metal zone in the specimen.

Figure 6 shows the elongation of various specimens. The highest percentage of elongation was recorded for the specimen subjected to vibrations of 330 Hz. Specimens exhibiting greater ductility showed an increase in equiaxed grains and decreased grain size.

Table 3. Effect of vibration on Tension properties

Vibration, Hz	Yield stress, MPa	Ultimate stress, MPa
Without vibration	792 ± 14	855 ± 16
100	797 ± 15	858 ± 17
200	823 ± 18	911 ± 16
330	845 ± 19	957 ± 21

3.4. Micro-Hardness

Figure 7 compares the results of micro-hardness testing of welded specimens at vibrations of 200, 330 Hz and without vibration.

As seen, the decrease in grain size increased hardness in all three specimens as they moved away from the welded metal toward HAZ. The maximum level of hardness of all welded specimens was for that at vibrations of 330 Hz. The decrease in grain size in this zone appears to be the cause of the increase in hardness.

4. CONCLUSIONS

(1) The specimen welded without vibration developed a solidification structure containing coarse columnar grains in the weld zone. Increasing the vibrations to 200 Hz produced a solidification structure that contained equiaxed grains. A completely equiaxed structure was observed for vibrations of 330 Hz.

(2) The average grain size decreased for the specimen welded at vibrations of 330 Hz in comparison with the other modes. The grain size decreased an average of 36% over that without vibration.

(3) The specimen welded at vibrations of 330 Hz produced the highest yield and tensile strength of all specimens.

(4) The hardness of the welding zone was greater than the hardness of the base metal for all specimens. The specimen welded without vibration showed the lowest level of hardness in the welding zone. The specimen welded with vibrations of 330 Hz had the highest level of hardness.

REFERENCES

1. Balasubramanian, V., Jayabalan, V., and Balasubramanian, M., *Mater. Design.*, 2008, vol. 29, pp. 1459–1466.
2. Balasubramanian, M., Jayabalan, V., and Balasubramanian, V., *Mater. Design.*, 2008, vol. 29, pp. 92–97.
3. Yunlian, Q., Deng, J., Hong, Q., and Zeng, L., *Mater. Sci. Eng., Ser. A*, 2000, vol. 280, pp. 177–181.
4. Sundaresan, S., Janakiram, G.D., and Madhusudhan, G., *Mater. Sci., Ser. A,* 1999, vol. 262, pp. 88–100.
5. He, X., Noel, J.J., and Shoesmith, D.M., *Corr. Sci.*, 2004, vol. 60, pp. 378–386.
6. Balasubramanian, M., Jayabalan, V., and Balasubramanian, V., *Mater. Design.*, 2008, vol. 29, pp. 1359–1363.
7. Gurappa, I., *Mater. Charact.*, 2003, vol. 51, pp. 131–139.
8. Kishorebabu, N., Ganesh, S.R.S., Mythili, R., and Saroja, S., *Mater. Charact.*, 2007, vol. 58, pp. 581–587.
9. Weite, W., *Scripta Mater.*, 2000, vol. 42, pp. 661–665.
10. Standard Test Methods for Tension Testing of Metallic Materials, vol. 03.01, ASTM E8/E8M.
11. Kou, S., *Welding Metallurgy*, 2nd ed., New Gersy, 2002, pp. 180–200.
12. Qinghua, L., Ligong, C.H., and Chunzhen N.I., *Mater. Sci. Eng.*, 2008, vol. 457, pp. 246–253.