ROLLING AND SURFACE COATING OF STEEL

Steel is initially produced in 20 cm thick slabs. Steel in this form is usually processed further before being sold to customers. This generally involves rolling it into thinner sheets (and sometimes forming it into tubes). This steel is now conveniently shaped, but is prone to rusting so for applications where it is exposed to the weather it is often galvanised (and sometimes painted as well) to prevent corrosion.

Step 1 - Hot Rolling
In the hot rolling process, slabs are reheated and fed into the rough rolling mill where it is reduced from 210mm to 25mm thickness. The thin sheets are then wound onto spools to make 'coils' of rolled steel.

Step 2 - Cold Rolling
Hot rolled coils are welded into continuous sheets, and the iron oxides that have formed in hot rolling removed with hydrochloric acid:

$$Fe_2O_3{\cdot}xH_2O \quad + \quad 6HCl \quad \rightarrow \quad 2FeCl_3 \quad + \quad (x+3)H_2O$$

The sheets are then oiled to prevent further corrosion and rolled. This rolling further reduces the thickness of the sheets and gives them a smoother surface.

Step 3 - Galvanising
Hot alkali solutions are used to remove the remaining grease, then the steel is treated with acid to clean and etch the surface. The steel is repeatedly heated and cooled to strengthen it and then galvanised by dipping it in zinc. The steel can then be used as is for roofing, or further processed.

Step 4 - Paint Coating
The steel is again cleaned and then coated with primer. Solvent in the primer is evaporated by a hot air jet and the paint baked on. Finish coat is then applied, baked and cured on top of the primer coating. Different grades of finishing paint are used for different applications.

INTRODUCTION

Steel, an alloy of carbon and iron, is a material which is both inexpensive and has great mechanical strength. However, it is initially produced as steel slabs which are too thick and heavy to be used. To convert the steel into useful products it must first be rolled into thin sheets and coiled onto spools. This steel is more useful, but it is still prone to rusting and will have its useful lifespan seriously shortened if it is used in a damp environment.

To prevent corrosion, the steel is coated with zinc in a process known as galvanising. Zinc is found above iron in the electrochemical series, which means that in galvanised steel the zinc is oxidised instead of the steel itself, thus lengthening the useful lifespan of the steel. Zinc is chosen for this purpose because it is the least expensive of the metals above iron in the electrochemical reactivity series and it can satisfactorily be coated on steel. If a suitable paint coating is applied on the galvanised steel surface, the protection effect can be further enhanced. The common uses of galvanised sheets and coils are the manufacture of roofing material, steel wall cladding and the steel bodies of home appliances. BHP New Zealand

Steel produces 180 000 tonnes of galvanised steel and 50 000 tonnes of painted steel annually.

FROM STEEL SLABS TO FINISHED PRODUCTS

Cast slabs of steel up to 210 mm in thickness and weighing up to 20 tonnes are produced in the steel making process. These are rolled into thin strips of steel in a two step process - first being rolled at high temperature and then at room temperature. This results in rolls of steel known as 'coils' which are either sold as is or galvanised and sometimes painted as well.

Step 1 - Hot Rolling

In the hot rolling process (**Figure 1**), slabs are heated in a gas fired reheating furnace until the temperature of the metal reaches 1250°C. Any iron oxides are then removed from the surface of the steel by high pressure jets of water as the metal is sent to the roughing mill. The slab passes through huge rollers, the roller direction is reversed, and it passes through again. After between five and nine passes through the roughing mill the thickness of the slab has been reduced from 210 mm to about 25 mm. After the last pass, the rolled slab is coiled into a roll in a coil box. About 40 % of the steel undergoes no further processing and is either cut into plates and sold or sold in coil form.

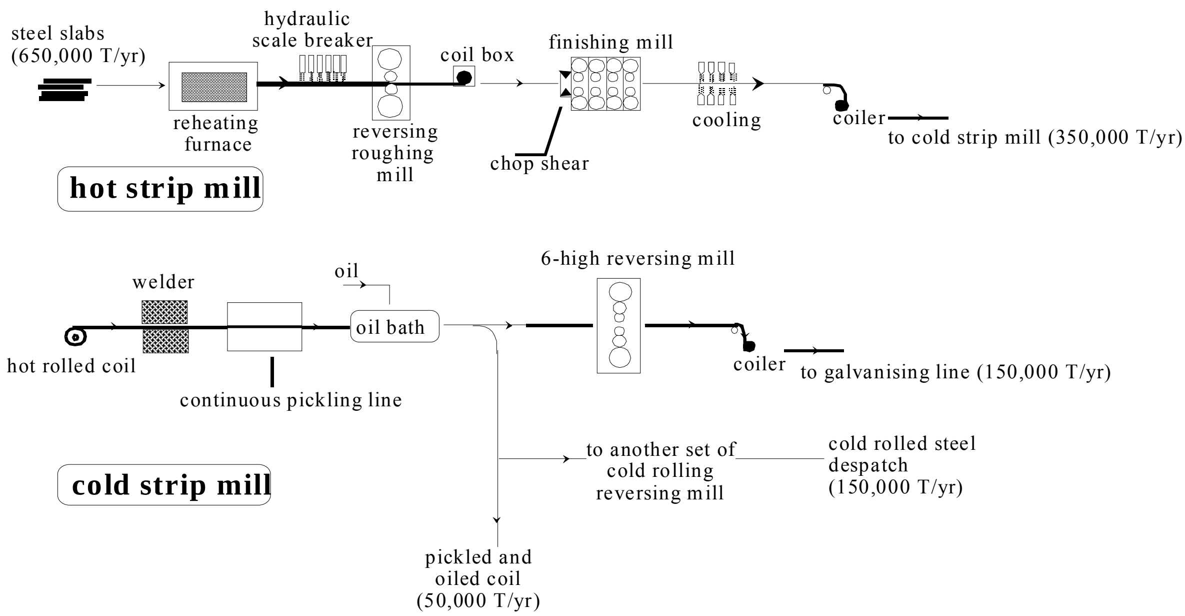

Figure 1 - Steel Rolling Mills

Step 2 - Cold Rolling

Cold rolling is a necessary precursor to galvanising and painting not only because it reduces the sheet thickness to one more appropriate to most applications but because it smooths the surface. As was stated above, the hot rolling mill is known as the 'roughing mill', and this is because the steel coming out of the mill has a rough surface. However, before cold rolling itself can begin the coils of steel are unwound, the tails of the coils chopped off and recycled[1], and the incoming coils butt-welded together to form a continuous strip.

During hot rolling a fine layer of iron oxide scale forms on the surface of the steel. To prevent this from contaminating the bulk of the steel, the welded strip of steel is 'pickled' in hydrochloric acid. As the steel passes through the pickling tanks the HCl solution reacts with the rust, $Fe_2O_3 \cdot xH_2O$ to form a solution of iron (III) chloride.

$$Fe_2O_3 \cdot xH_2O \quad + \quad 6HCl \quad \rightarrow \quad 2FeCl_3 \quad + \quad (x+3)H_2O$$

The sheet is rinsed, dried and oiled to prevent further corrosion then fed into the cold reversing mill. Here they are rolled out, recoiled and then passed through the mill in the reverse direction. Between five and seven passes are made until the correct gauge (thickness) is attained. The strip thickness is continuously measured using a gamma (γ)-ray gauge: γ-rays are fired at the steel, and the intensity of the back-scattered rays (which is proportional to the thickness of the sheet) measured (see article). The strip is then cut and recoiled in readiness for transfer to the galvanising line.

Step 3 - Continuous galvanising

The galvanising process (**Figure 2**), as with the cold rolling process, begins with the uncoiling and welding of the coils to produce a continuous steel strip. This strip is then cleaned and degreased in a continuous cleaning section. Here it is immersed in a bath of hot alkali, where it is cleaned both by the alkali itself and by the electrolysis of water. The bath contains an anode and a cathode which electrolyse the water, producing hydrogen which blasts off the grease. Roller brushes and hot water sprays also help to remove the oil. The clean steel is then rinsed to remove the alkali and passed through a hot pickle bath of hydrochloric acid that removes traces of rust and lightly etches the surface.

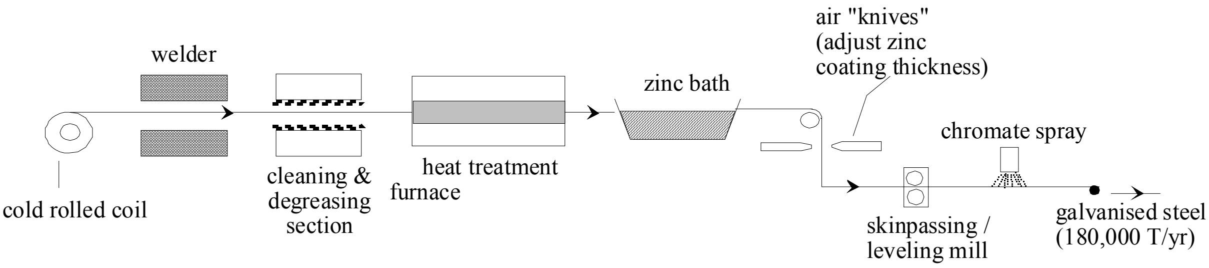

Figure 2 - Schematic Diagram of the Galvanising Process

The strip next enters the heat treatment furnace. This furnace is 150 metres long, brick-lined and has an atmosphere of nitrogen and hydrogen to prevent oxidation of the steel surface. Here the steel is subjected to a controlled heating and cooling cycle to alter its physical properties. Depending on the grade of steel being manufactured, the strip is either stress-

[1] The tails are the portions at either end of a strip of steel. Because these are located at the end they do not get properly rolled and are often thicker than the rest of the coil. They are removed to ensure product consistency.

relieved to produce high strength steel or annealed[2] to produce ductile grades (i.e. steels that can be made into cup-shaped forms).

The zinc coating operation is performed by passing the steel strip directly from the exit of the annealing furnace into a molten zinc bath. Excess zinc on the surface is wiped off by air "knives" after the strip leaves the bath. The zinc composition in the bath is carefully controlled to ensure that the optimum coating characteristics are achieved. Aluminium and lead are commonly added to control the fluidity of the molten zinc, the size of zinc crystal after solidification and the extent of zinc iron alloy formation on the surface.

The galvanised steel then passes through a set of rollers in the skinpass / leveller unit. Here any distortions that the strip has acquired in the annealing furnace are smoothed out, readying it for both repaint and general sheet metal applications.

From the leveller, the strip passes through a chromate spray which reacts with the fresh zinc to produce a passivation film of zinc and iron oxides:

$$2CrO_4^{2-} + 2Fe + 4H^+ \rightarrow Cr_2O_3 + Fe_2O_3 + 2H_2O$$
$$2CrO_4^{2-} + 3Zn + 4H^+ \rightarrow Cr_2O_3 + 3ZnO + 2H_2O$$

If the chromate spray is not used and this protective film is not formed the zinc is likely to corrode to "white rust"[3] if it is stored in a damp and poorly ventilated environment. Hence the chromate lengthens the expected storage life of the product.

Step 4 - Paint Coating
About 75% of all galvanised steel is sold directly to customer, with the remainder being painted before sale. Steel sheets are painted for both decoration and corrosion prevention.

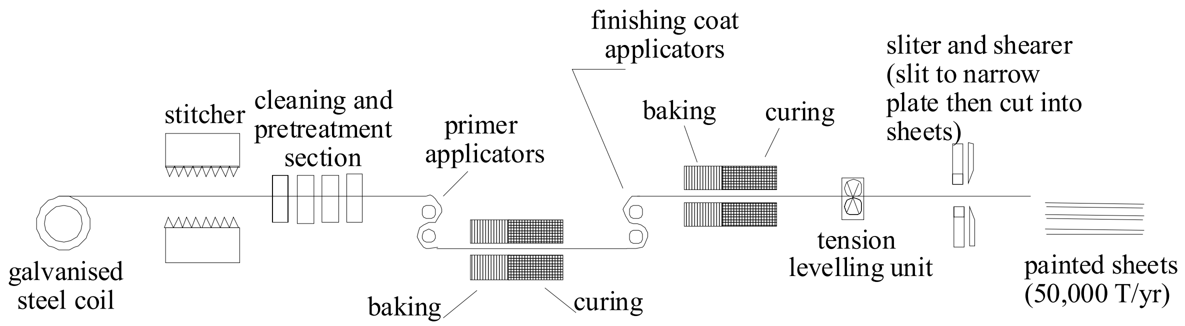

Figure 3 - Schematic Diagram of the Paint Coating Line

At the entry section of the coil painting line, feed coils are uncoiled and joined using a mechanical press called a stitcher. Then the coil is fed into the cleaning and pretreatment

[2] Annealing involves slowly heating a material to just below its melting point then slowly cooling it again. Annealed materials are less likely to exhibit stress fractures because the slow heating and cooling has resulted in a material of very consistent crystal structure.

[3] "White rust" is $Zn(OH)_2$, a porous substance formed by the reaction of zinc with water. When there is good ventilation white rust is not a problem as it quickly reacts with carbon dioxide to form the more protective $2ZnCO_3.3Zn(OH)_2$.

section to prepare the surface for coating. Mild alkali degreasing, brush scrubbing, hot rinsing, phosphate or chromate coating, cold rinsing and chromic acid sealing are done in this unit.

Primer is applied on the sheet when the strip passes in an "S" fashion around two large rubber coated application rollers. Excess paint drips off and the remainder is baked on at up to 240°C by a high temperature air jet. The strip travels at speeds of up to 65 metres a minute, and baking can take as little as 15 seconds. The paint is cured by further heating before leaving the primer oven.

On leaving the primer oven, the strip is cooled first by air jets, then by water sprays. It then travels to a second identical roller coating and oven baking operation where the top coat is applied. Four different top coats are used, producing four different grades of Colorsteel™ for use in different environments. These are:

- Colorsteel 5000, for use in mild environments such as domestic roofing
- Colorsteel 8000, which is similar to Colorsteel 5000 but has better colour and better corrosion resistance. It is also more flexible so can be curved or crimped.
- Colorsteel VP, which incorporates a highly resistant vinyl plastic coating for use in harsh environments such as marine and geothermal areas
- Colorsteel FL, which includes a highly flexible laminated film which is very resistant to corrosion. Gives a long term maintenance free finish to steel in high rise structures.

ROLE OF LABORATORY

The laboratory is involved in quality control and carries out a variety of tests including:

- impact test: test the adhesivity of the coating after bending
- solvent rubbing test: rub the paint with a ketone-based solvent to test the tolerance of the coating on solvent attack
- scratch test: scratch the coating surface before measuring the thickness of paint through microscope
- cleaning solution test: testing the strength of cleaning solutions to determine when they need to be replenished

ENVIRONMENTAL CONSIDERATIONS

Environmental damage is minimised both by waste minimisation and by the treatment of wastes before emission.

Waste minimisation

In all steel processing plants there is some waste of steel in the form of offcuts and out of specification product. This scrap steel is reprocessed in the steel-making plant.

The molten zinc slowly dissolves some iron from the steel strip, causing an iron zinc alloy known as top dross to form at the top of the zinc bath. This is skimmed off and cast into blocks before being sent to other manufacturers for pure zinc or zinc oxide production.

To minimise the hydrochloric acid consumption, an ancillary plant is built next to the cold rolling mill. Spent acid is recovered after the removal of accumulated iron oxide. Since iron oxide is also a useful by-product, this regeneration process does not make any extra waste.

Waste treatment

The major area of environmental concern in steel processing is heavy metal contamination. Zinc and chromium can cause serious environmental damage if allowed to escape to the enviroment *via.* wastewaters. For this reason wastewater is held for treatment to remove suspended solids and heavy metals before being released.

All gas is passed through dust collectors before being released to the environment. Dust collectors from the steel making and steel processing plants together collect up to ten tonnes of dust per day.

Article written for edition one by T.S. McDonald (N.Z. Steel) and K. Dance (Tuakau College). Revised by David Yuen following a visit to BHP New Zealand Steel Ltd. and with reference to "Steel Rolling" and "Finishing Plants" by the Public Affairs department of BHP NZ Steel. Edited by Heather Wansbrough and John Robertson.