Development of HSLA steels in Galvanized condition at Essar Steel

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Abstract

High Strength low alloy (HSLA) steels in Galvanized condition provide the dual purpose of high strength to weight ratio combined with high toughness and reasonable formability. The demand of high strength grades in Galvanized condition has picked up in recent years, especially in the automotive sector where fuel efficiency and pollution norms have become critical factors.

High strength hot rolled steel strip utilize precipitation strengthening through the addition of microalloying elements (Niobium, Vanadium and/or Titanium, each up to 0.1%), which form fine carbides or nitrides. HSLA steels need to have minimum proof (yield) strength of 275 Mpa. The dispersion strengthening effect in them leads to fine-grained structure having attractive combinations of strength and formability. Typical compositions are:

0.05-0.1 % C, 0.25-1.2 % Mn, 0.01-0.05 % Nb, 0.01-0.4 % Si for niobium alloyed HSLA grades.

With that motive, Essar Steel developed microalloyed steel sheet in galvanized condition through the galvanizing line CGL-1. Ti and Nb in the heat were added to the extent of 0.014% and 0.04% respectively. Extensive laboratory studies were carried out before deciding process parameters in the HSM, CRM and Galvanizing. HR coil thickness was 3 mm obtained from slab thickness of 220mm. HR coils were pickled and overall reduction of ~35% was given in CRM. Galvanizing process parameters like furnace, RTF and Soaking zone were planned to meet the required properties.

The required properties post galvanizing were YS-450 MPa (min), UTS-480 MPa (min) and Elongation-9% (min). However, with the aforementioned processing, properties achieved post galvanizing were YS-540-550 Mpa, UTS-580-590 Mpa and Elongation of 16-18%. Galvanized coating achieved was 350 gsm. These properties met the customer’s requirement as per the Australian standard AS 1397 G450.

Introduction

G450 steel to AS 1397 is a cold-reduced sheet steel with in-line hot-dip galvanizing. Its grade is 450 MPa yield and 480 MPa tensile strength. It is widely used all over the world for purlins, and is being used to fabricate lightweight portal frames, often by welding. The demand of the same has recently picked up in high strength horizontal roof members for structural steel design applications. To develop such high strength galvanized grade required closely controlled parameters in the Galvanizing stage.

Before galvanizing these grades, three factors have to be given due weightage. These are:

1) Chemical composition of the steel.
2) The strength rating of the steel (the yield strength in MPa).
3) The steel’s section thickness (which defines the annealing temperature and tonnage per hour in the Galvanizing line).
According to the Australian standard AS 1397 G450, the customer made the following property requirement in the galvanized product:

<table>
<thead>
<tr>
<th>Property</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTS</td>
<td>480 MPa min.</td>
</tr>
<tr>
<td>YS</td>
<td>450 MPa min.</td>
</tr>
<tr>
<td>Elongation</td>
<td>9 % min.</td>
</tr>
<tr>
<td>Coating</td>
<td>350 gsm</td>
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</tbody>
</table>

**Experimental Procedure**

The process route for the production of the galvanized steel strip was as follows:

Steel making in Electric Arc Furnace ↓
Steel Processing in Ladle Furnace ↓
Continuous Casting (CCM-1) ↓
Coil Production in Hot Strip Mill ↓
Continuous Pickling ↓
Cold Reduction in Cold Rolling Mill ↓
Galvanizing in Continuous Galvanizing Line (CGL-1)

Essar Steel developed microalloyed steel sheet in galvanized condition through the galvanizing line CGL-1 (Fig–2). Ti and Nb in the cast heat were to the extent of 0.014% and 0.04% respectively. Laboratory studies were carried out before deciding process parameters in the HSM, CRM and Galvanizing. HR coil thickness was 3 mm obtained from slab thickness of 220 mm. HR coils were pickled and overall reduction of ~35% was given in CRM. Galvanizing process parameters like furnace, RTF and Soaking zone temperatures were planned to meet the required properties. A typical galvanizing cycle is displayed in Fig-1 that shows temperatures in various zones of the furnaces.

The annealing cycle given in Fig-1 has been designed to accomplish complete recrystallization of the cold rolled microalloyed steel strip in the galvanizing furnace.
Aim of the trial

With increasing competition in the steel industry, the demand for high strength galvanized steel grades has picked up. These galvanized grades serve the dual purpose of high strength to weight ratio combined with high toughness and reasonable formability. Keeping that purpose at its core, Essar Steel planned a trial with microalloying grade steel in its Continuous Hot-Dip Galvanizing Line (CGL-1).

Theory

Influence of micro alloying elements

Micro-alloying elements impart strength and toughness to the steel through different strengthening mechanisms viz. grain refinement, precipitation hardening, dispersion hardening and dislocation density. The effect of precipitation strengthening and grain refinement on mechanical properties is shown in Fig-3. Micro-alloying elements predominantly affect the matrix of the steel via precipitation of second phase, besides “solute drag effect”. Since the solubility product and the physical properties of each element and each compound are different, there exists characteristic difference, which causes each of these elements to have their specific merit or purpose of addition in steel. The strength of micro-alloyed steels depends on the strength of the base material as well as on the number and size of carbonitride precipitates. The finishing temperature and the coiling temperature at hot rolling stage, and annealing temperature and time after cold rolling during continuous galvanizing, must therefore be designed to achieve the desired results in the final product. In an ideal case, continuous annealing during galvanizing should only reduce cold hardening by means of recrystallization and not result in grain growth or uncontrollable new
precipitation. It is well known to us that Ti and Nb in solution radically delay recrystallization \[4\]. The effect of Ti and Nb addition in steel is briefly described below.

**Titanium:** Titanium has an affinity towards Oxygen and Nitrogen. Upon reaction it forms TiO and TiN respectively and thus reduces the content of Oxygen and Nitrogen in the liquid steel. The reaction product depends upon the size and the shape, joins the slag and gets separated out. As the levels of Oxygen and Nitrogen in steel go down, the toughness increases. Titanium also has a tendency to form TiC, TiO and TiN. Finely dispersed and stable precipitates are able to control the austenite grain size during reheating and this helps in restraining the grain coarsening during welding in actual component manufacturing.

**Niobium:** Niobium is the most effective microalloying element for the solute drag effect \[1-3\]. Solute drag effect is helpful in grain refinement during thermomechanical controlled rolling process by

1. Preventing secondary grain growth during interpass time.
2. Retarding the onset of recrystallization as an initial step by NbC precipitation \[4\].

Strengthening by niobium is 35 to 40 MPa (5 to 6 ksi) per 0.01% addition. Niobium as a microalloying element has a double effect on dispersion hardening than that of Vanadium \[5\]. Niobium has tendency to precipitate in the austenite and this tendency is promoted by simultaneous hot working and hence the precipitation-strengthening effect can be seen only in low carbon grades or after high temperature hot working. Niobium precipitates also help in restraining the austenite grain size during reheating and thereby increasing the strength and toughness. Secondly, they retard recrystallization during austenite processing \[6-8\] resulting in grain refinement and finally lower the austenite to ferrite transformation temperature by solute drag effect \[1-3\].

**Continuous Hot-Dip Galvanizing**

**Principle:** As the name implies, continuous hot-dip galvanizing involves the coating of molten zinc onto the surface of steel sheet in a continuous process. The steel sheet is passed as a continuous
ribbon through a bath of molten zinc (also known as zinc bath) at speeds up to 100 meters per minute. In the molten-zinc bath, the steel strip reacts (alloys) with the molten zinc to bond the coating onto the strip surface. Using an air-wiping process, a controlled thickness of coating, usually expressed as weight (mass) of coating per unit area i.e. grams per square meter (gsm), is allowed to remain and cool on the strip surface.

**Process Route at Essar Steel Limited (CGL-1):**

![Process Route Diagram]

The cold rolled steel sheet in the form of coil is uncoiled from one uncoiler. There are two uncoilers so that the tail end of one coil can be welded to the head end of another coil thus making the supply of steel sheet continuous for galvanizing. The steel sheet first passes through the welding section where the tail end of one coil is welded to the head end of another. The steel sheet then passes through the Preheating zone where prior heating of steel is done before it enters the Direct Fired Furnace. Flue gases of Direct Fired Furnace are used as the heating medium to heat steel sheet in Preheating zone and temperature at this zone is around 500°C. After preheating, the steel sheet enters the Direct Fired Furnace where heating is done by burning natural gas. The temperature at this zone is maintained between 800°C and 1200°C by changing the flow rate of natural gas in premix region. In this zone, at such high temperature, residual coolant patches, grease, oil, etc. burn off leaving the steel sheet free of dirt. It is very imperative that the steel sheet be free of surface impurities before it enters the zinc bath otherwise surface impurities will lead to uncoated regions after galvanizing. The steel sheet then enters the Radiant Tube Furnace where the temperature of zone is around 650°C-800°C. In this zone heating is done by convection through radiant tubes. Further soaking of steel sheet is done in the Soaking zone where temperature is usually kept in the range of 650°C-800°C. It is the soaking temperature and percentage cold reduction that decide the continuous annealing cycle and has direct impact on the final mechanical properties. The steel sheet emerging out of Soaking zone has a very high temperature and it cannot be directly dipped into the Zinc bath having temperature around 450°C for galvanizing. The temperature of steel sheet after soaking in the Soaking furnace is lowered to around 460°C by passing through the Jet Cooling Furnace. In Jet Cooling Furnace, nitrogen is used as an inert medium to bring down the steel sheet temperature. The steel sheet is then passed through the Zinc pot which contains bath of molten Zinc, Lead and Aluminum. The composition of the bath is adjusted so as to obtain final galvanized surface appearance i.e. regular spangle, medium spangle or mini spangle. Air knives are provided just above the zinc pot to wipe off the excess zinc and obtain the required coating weight. After galvanizing, air-cooling is done in After Pot Cooling followed by tension leveling in Tension Leveler and passivation in Chromating tank. Tension leveler is used to flatten the galvanized steel sheet to meet the end use requirements.
**Passivation:** Zinc is amphoteric in nature and is prone to attack in basic as well as acidic environments. In humid atmosphere, zinc reacts with moisture to form zinc hydroxide and then zinc hydroxide further reacts with carbon dioxide to form zinc carbonate which is popularly known as White Rust. Thus it necessitates the protection of galvanized product by surface treatment known as Passivation. The protection of the top layer of galvanized coatings against rusting is, therefore, not only important from an aesthetics point of view but also plays an important role in increasing the durability of the coatings. At Essar Steel Limited, Chromating is done immediately after galvanizing to prevent rusting of zinc and formation of white rust. Chromating results in the formation a thin passivation film of chromium chromate \([\text{Cr(OH)}_3\cdot\text{Cr(OH)}\cdot\text{CrO}_4]\) which protects the galvanized coating. A detailed layout of the Essar’s Continuous Hot-Dip Galvanizing Line-1 is shown in Fig-2.

**Galvanized Coating:** Galvanizing forms a metallurgical bond between the zinc and the underlying steel, creating a barrier that is part of the metal itself. During galvanizing, the aluminum present in the zinc bath, due to its higher affinity towards iron, instantly reacts with iron and forms a very thin and brittle ternary intermetallic layer of \(\text{Fe}_2\text{Al}_{5-x}\text{Zn}_x\). The main purpose of adding aluminum in the zinc bath is to control the reaction kinetics between the molten zinc and the steel substrate. It further forms four iron-zinc binary alloys in layers on the already formed layer of \(\text{Fe}_2\text{Al}_{5-x}\text{Zn}_x\). The immediate layer that forms above \(\text{Fe}_2\text{Al}_{5-x}\text{Zn}_x\) is \(\text{Fe}_3\text{Zn}_{10}\) which is also known as \(\Gamma\)-layer. The layer that forms above \(\Gamma\)-layer is \(\Gamma'\)-layer (\(\text{Fe}_5\text{Zn}_{31}\)) followed by the formation of \(\delta\)-layer (\(\text{FeZn}_7\)) and \(\zeta\)-layer (\(\text{FeZn}_{13}\)). The top layer consists of pure zinc (\(\eta\)-layer). A typical photomicrograph of aluminum free galvanized coating is shown in Fig-3 and ternary alloy of \(\text{Fe}_2\text{Al}_{5-x}\text{Zn}_x\) is shown in Fig-4.
Results and Discussion

The properties of the finished galvanized coils for G450 grade are obtained in the following range:

- Hardness (HR_B) 85 – 90
- UTS (MPa) 580 – 590
- YS (MPa) 540 – 550
- Elongation (%) 16 – 18
- Coating (gsm) 350
- ASTM Grain Size 10

The properties are fully met as per the Australian standard AS 1397 G450 and desired by overseas market. The microstructures of the galvanized steel sheet (Fig–5) show the presence of fully recrystallized grains. The ferrite grains are very fine and equiaxed, and conform to the ASTM grain size number 10.

Conclusion

The Galvanized specification AS 1397 G450 is produced for the first time in India by Essar Steel. This high strength microalloying steel grade is now successfully processed for thickness 1.2 mm and greater through the Continuous Galvanizing route at Essar Steel. This has lead to a better product
penetration in the market that has a high demand for finished galvanized products in construction applications. Efforts are on to develop this grade in lower thickness (<1.2 mm) through continuous improvement of all the facilities. The high quality of the finished Galvanized product would ensure better product performance at the customer’s end.

Acknowledgement

The authors gratefully acknowledge Mr. Dilip Oommen, Chief of Hazira Works, Essar Steel Limited for his support for carrying out the trial successfully. The authors would like to place their sincere thanks to Mr. Pramod Shukla of CRM complex for his assistance during cold rolling of coils. Further they acknowledge with gratitude the active support given by professionals of CGL-1 and R&D Division for carrying out these studies.

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