# Hot-Dip Galvanized Sheet Steel with Excellent Press Formability and Surface Quality for the Automotive Panels*



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***Synopsis:***

*A new type of a hot-dip galvanized steel sheet (GI steel sheet), excellent in press formability, weldability and surface appearance, for automotive bodies has been developed. As for press formability, through the optimization of surface roughness effected by texture control with skin-pass rolling and by the use of a high-lubricating oil, sliding characteristics has been improved. Concerning an advantage in weldability, with the suitable selection of coating and substrate chemistry, the life of welding electrode has been extended. Improved surface quality for the better exterior appearance was achieved through the introduction of such measures as the prevention of bath wrinkle patterns by adjusting a wiping condition, the avoidance of dross adherence with the use of bath exclusive for GI use, and the substantial reduction of spangles by using cooling rate control after galvanizing. The hot-dip galvanized steel sheet demonstrates distinguished characteristics as a material sheet for automotive outer panels. The newly developed GI sheets are put into commercial production,*

## 1 Introduction

In response to the problem of auto body corrosion, sheet steel for automotive body panels has undergone a great change from the conventional cold rolled sheet steel to coated steel sheets. As a countermeasure against corrosion caused by road salt in North America and other countries of cold climates, various types of coated sheet steels were developed and began to be used in the second half of the 1970s. Therefore, the percentage of coated products increased, reaching more than 2/3 of all automotive panels in the 1990s.

Coated sheet steels which are used in automobiles must not only provide excellent corrosion resistance, but must also satisfy a variety of other performance requirements, including press formability, weldability, phosphatability and paintability. In actual production, the priorities and concepts which are adopted in corrosion prevention countermeasures differ among auto makers and various types of corrosion-resistant sheet steels are applied as required, by taking advantage of the features of the respective materials.

For example, the mainstream product in North America is electrogalvanized sheets (EG) with a comparatively heavy galvanized coating. In contrast to this, many auto makers in Japan use galvannealed steel sheets (GA), which have an alloyed coating, in preference to EG. In Europe, in addition to EG or GA, auto makers mainly use hot-dip galvanized sheets (GI), which are produced by hot-dip galvanizing in the same manner as GA sheets, but which are not given subsequent treatment to alloy the metal coating and steel substrate. Moreover, recently, there has been a continuing increase in makers who use GI sheets not only in inner panels but also in exterior panels, resulting in increased demand for this material.[1)]

Historically, GI steel sheets have been used mainly as a construction material. In comparison with electrogalvanized products, GI has the advantages of lower production costs and easy manufacture of products with a heavy coating weight. However, a number of problems

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remained to be solved with GI, including relatively poor surface quality and inadequate performance in the properties which are necessary for manufacturing and assembling auto bodies, such as press formability and spot weldability, and improvements were needed.

This report describes the quality criteria of a GI sheet steel which solves the previously-mentioned problems and has been applied successfully to automotive outer panels, together with a stable production technology for this GI product.

## 2 Properties of Hot-Dip Galvanized Steel Sheets (GI)

### 2.1 Corrosion Resistance

**Figure 1** shows the results of a corrosion test of various types of Zn coated steel sheets.[2)] In this test, which was conducted at seashore test site in Okinawa (approximately 10 m from the coastline), various types of coated steel sheets with different Zn coating weights were exposed for four years in the as-galvanized condition. Corrosion resistance was improved as the coating weight increased. Because a heavy zinc coating can easily be realized at low cost with GI sheets, high rust resistance can be obtained. In particular, GI demonstrates a rust-resistance effect in the hem and flange parts of the auto body, where paint coating cannot be expected to guarantee rust prevention.

**Figure 2** shows the results of an evaluation of the corrosion resistance of the various types of sheet steels with and without painting in cyclical corrosion test (CCT). Zn-Ni alloy coated sheets showed relatively high perforation corrosion resistance without painting, and GA sheets tended to exhibit excellent corrosion resistance when painted. It was found that GI sheets have excellent corrosion resistance after painting, even against perforation corrosion.[2)]

### 2.2 Press Formability

Even if a base steel sheet possesses satisfactory mechanical properties, the sheet metal flow will be limited in the part where the bead must pass if the galvanized coating layer has poor sliding properties with the press die, and this can cause cracks and other problems. As a result, there are cases in which it is impossible to take full advantage of the excellent mechanical properties of the base material in the press forming process.

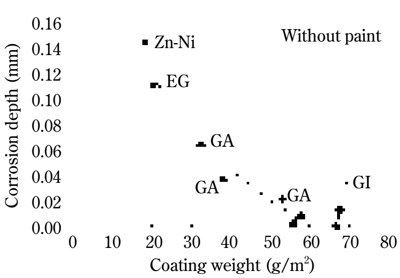



Fig. 1 Relationship between coating weight and corrosion depth examined in various Zn coated steel sheets exposed in Okinawa seashore for 4y

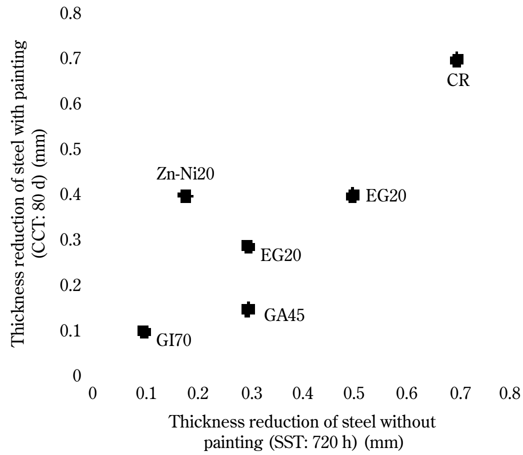



Fig. 2 Perforation corrosion resistances of pre-coated steel sheets with and without painting

**Figure 3** shows the friction coefficient in the case of plane sliding (flat type die) at a sliding speed of 20 mm/min for specimens of GA, EG, cold rolled, and GI sheets with a washing oil coating weight of 1.5 g/m$^2$. The die blocks were of SKD1 material, with dimensions of 20 mm in the sliding direction and 20 mm in the width direction, and were pressed against the surface of the steel sheets with a pressing force of 1 960 N. In comparison with the GA, EG, and cold rolled steel sheets it was found that the GI sheet had a superior sliding property, as seen in the smaller coefficient of friction.

An investigation was carried out to determine the effect of the surface roughness, anti-rust oil used, and pressing force during the test on the friction coefficient of GI sheets. High roughness and low roughness materi-

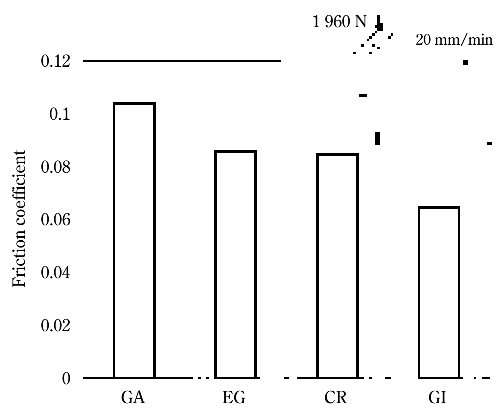



Fig. 3 Influence of coating type on friction coefficient (Washing oil: 1 g/m$^2$, Oil viscosity 17 mm$^2$/s, Sliding speed: 20 mm/min, Pressing force: 9.8 MPa)

als were manufactured by changing the roughness of the work rolls used in temper rolling after galvanizing. When a low pressing force was applied, the friction coefficient of the low roughness sheet was lower. However, it was found that the effect of roughness on the friction coefficient decreased as the pressing force increased, and there was no difference between the high roughness and low roughness materials when the pressing force exceeded 6 860 N (**Fig. 4**).

**Figures 5** and **6** show the friction coefficient in plane sliding (flat type die) and columnar sliding (roll type die) when three types of anti-rust oil were applied to GI sheets at a coating weight of 1.5 g/m$^2$. Here, the die blocks were of SKD11 material, with dimensions of 50 mm in the sliding direction and 20 mm in the width direction, but as in the previous test, the pressing force was 1 960 N and the sliding speed was 20 mm/min.

A comparison of two high lubrication type anti-rust oils (B: Kinematic viscosity, 36 mm$^2$/s, C: Kinematic viscosity, 26 mm$^2$/s) with a standard type anti-rust oil (A: Kinematic viscosity, 17 mm$^2$/s), the friction coefficient was reduced in both the flat die sliding test and the roll die sliding test by using a high lubrication oil. Thus, it is possible to obtain satisfactory press formability with GI sheets by imparting the appropriate roughness to the material and applying a high lubrication type anti-rust oil.

### 2.3 Weldability

Auto bodies are assembled by performing spot welding at 3 000 to 4 000 spots per automobile. In comparison with cold rolled sheets, the number of continuous spot welds with the same electrode is lower with Zn coated sheets. The reason for this is considered to include the following two points, which are due to the presence of a soft, low melting-point Zn coating layer:

(1) A high current welding is necessary in order to expand the route of current passage.

(2) As a result, the temperature of the electrode tip is high and the diameter of the worn electrode tip tends to increase.

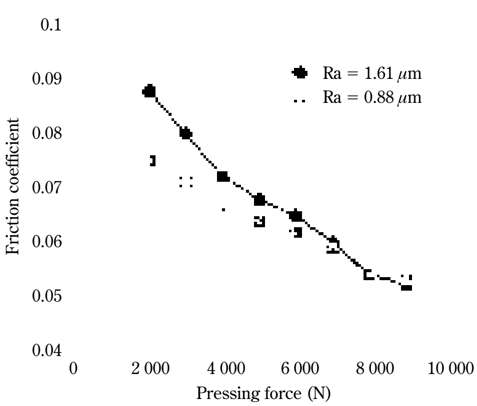



Fig. 4 Influence of roughness on GI friction coefficient

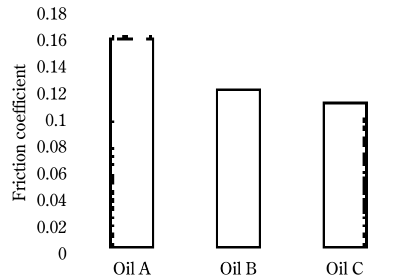



Fig. 5 Influence of corrosion lubricating oil on GI friction coefficient (Flat type die)

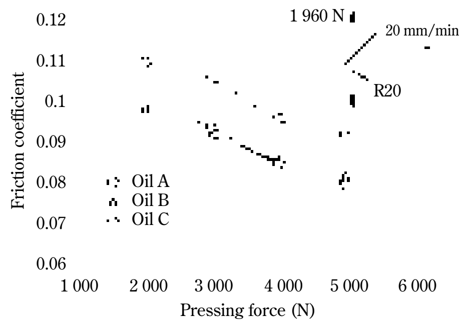



Fig. 6 Influence of pressing force lubricating oil on GI friction coefficient (3 roll type die)

Spot weldability (number of continuous spot welds) can be improved by adding the element boron (B) to the substrate steel sheet. It has been reported that the fatigue strength of spot welds can be improved by this measure, which suppresses grain growth in the heat affected zone (HAZ). However, preventing softening of the steel sheet by suppressing grain growth is also considered to be an effective measure for reducing electrode wear. As a result of various attempts to increase spot weldability by improving the characteristics of the steel sheet itself, as mentioned briefly here, it was possible to extend electrode life substantially, as shown in **Fig. 7**.

### 2.4 Phosphating Property

Phosphating is performed as a pretreatment before painting steel sheets, and has a tendency to improve corrosion resistance after painting and improve adhesion between the paint and the coating film or steel sheet. Phosphating characteristics are evaluated by observing the crystal structure of the phosphate coating after ordinary phosphating.

**Photo 1** shows the appearance of crystals observed by SEM when cold rolled steel sheets, GI sheets, and GA sheets were immersed in a phosphating solution for 2 min, washed in water, and then dried, using a PB-WL 35 manufactured by Nihon Parkerizing Co., Ltd. With the

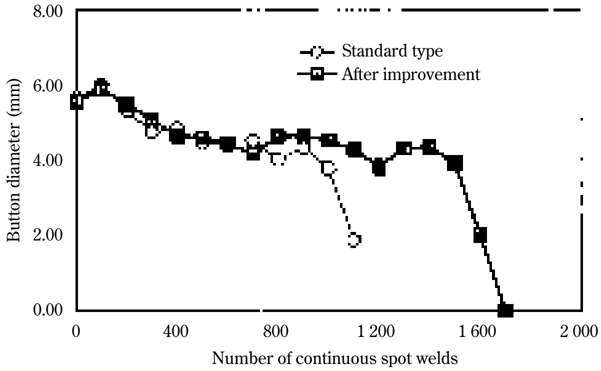



Fig. 7 Comparison between electrode life of GI before and after improvement

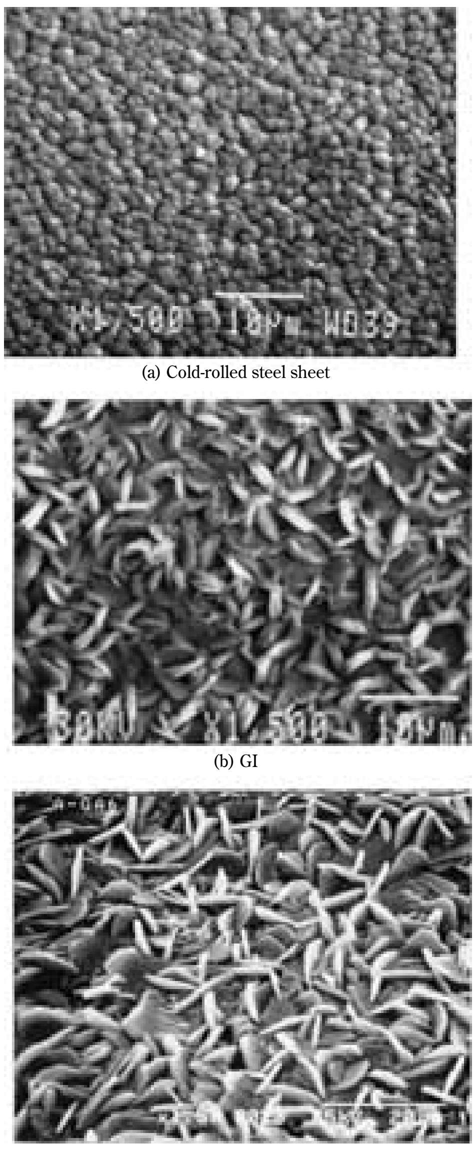



Photo 1 Scanning electron micrographs of phosphate coating formed on (a) CR (b) GI and (c) GA

cold rolled sheets, grains having a phosphophyllite crystals were seen, and there were no significant differences between the two types of sheet in either the size or shape of the crystals.

With GA steel sheets, it has been reported that a paint coating defect called "crater" tends to occur in electro deposition coating.[3,4] Therefore, Fe-P coating is performed as a top layer in order to prevent craters. In comparison with GA sheets, craters do not occur with GI sheets, which show satisfactory electro deposition coating performance.[2]

## 3 Production Technology for Hot-Dip Galvanized Steel Sheets (GI)

### 3.1 Improvement of Surface Quality (Appearance)

#### 3.1.1 Wrinkle pattern

When steel sheets are coated in a Zn bath, the Zn coating weight is controlled by an air or nitrogen wiping gas jet above the Zn pot. In this process, however, the wiping gas jet causes the steel strip to vibrate, and the flow of molten Zn in the coating layer is irregular. As a result, a wave-shaped flow pattern called a "wrinkle" pattern frequently occurs, as illustrated in **Photo 2**. In particular, this wrinkle pattern must be prevented in materials which are to be applied to the outer panels of automobiles because it is detrimental to the surface properties of the paint film, and especially to smoothness, when the Zn-coated surface is the substrate surface for painting.

For this reason, a wrinkle pattern prevention technology was established at the continuous hot-dip galvanizing line (CGL) at Mizushima Works by the control of wiping conditions (wiping pressure, gap between nozzle and steel strip, height of nozzle above Zn bath surface). **Photo 3** shows the surface property of a GI sheet after establishment of this technology.

#### 3.1.2 Countermeasures against spangle

When the zinc coating on a steel sheet solidifies, dendrite-type crystals form and grow around a core of solidified Zn. In some cases, this results in a flower-shaped pattern called "spangle" on the surface of the

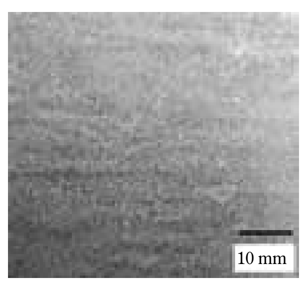



Photo 2 Wrinkle pattern of GI surface

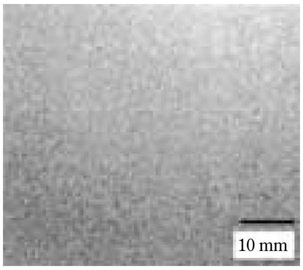



Photo 3 GI surface after improvement on the wiping conditions

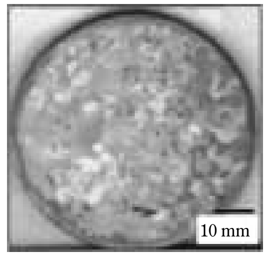



Photo 4 Spangle pattern of conventional GI (after etching with $CuSO_4$ aqueous solution)

galvanized sheet. Depending on the use, this flower pattern is considered desirable in some applications, such as building materials, where it contributes to the beauty of the material surface. Conversely, however, when a sheet is to be used as an automotive panel, a minimum spangle material with fine sized spangles is necessary because the surface irregularities and differences in crystal orientation mar the appearance after painting. It is known that the size of spangles is influenced by the Pb and Sb contents of the Zn bath and by the solidification rate of the coated layer. The effect of the Pb and Sb contents is explained as follows: Pb and Sb melt in molten Zn but have low solubility in solid Zn. For this reason, Pb and Sb are discharged from the Zn layer as it solidifies after coating, and this reduces the solidification point of the unsoldified parts. The solidification rate influences the spangle morphology because the growth rate of solidified crystal cores increases at higher solidification rates.

**Photo 4** shows the appearance of spangles on a conventional sheet; the photograph was taken after the sheet was etched by using a $CuSO_4$ aqueous solution.

With the new CGL at Mizushima Works, it is possible to manufacture steel sheets with a fine spangle size, as shown in **Photo 5**, by minimizing the Pb content of the Zn coating bath and controlling the cooling rate above the Zn pot.

#### 3.1.3 Dross adherence

Another quality problem with hot-dip galvanized sheets is dross adhering to the steel sheet. Dross is a problem because it crystallizes out of the solution in the Zn pot and causes a surface defect called “pimple” after press forming. Dross is formed by reactions between Fe, which is eluted from the steel strip into Zn coating bath, and the added Al and molten Zn in the bath, and is categorized as either or an Fe-Al and an Fe-Zn intermetallic compound. The Fe-Al dross (floating dross) floats in the pot, while the Fe-Zn dross is found at the bottom of the pot (bottom dross). It is known that the formation of both compounds is strongly affected by the Al concentration in the bath and the bath temperature.[5–7)]

When GI and GA are produced by using one pot, the Al concentration in the bath is increased greatly when the GA bath is switched to the GI bath, and a large amount of floating dross is formed by the reaction shown below.

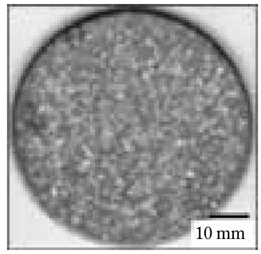



Photo 5 Spangle pattern after improvement

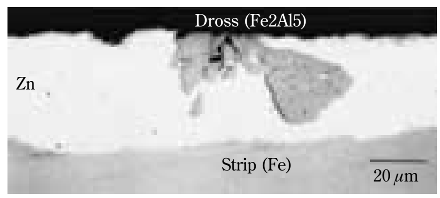



Photo 6 Cross sectional micrographs of dross on GI

$$2FeZn_7 \text{ (Bottom dross)} + 5Al \rightarrow Fe_2Al_5 \text{ (Floating dross)} + 14Zn$$

This floating dross adheres to the sheet surface and causes surface defects, as shown in **Photo 6**.

At CGL of Mizushima Works, one additional Zn pot was installed in November 2001, making it possible to manufacture products using exclusive pots for the GA bath and GI bath. This eliminated the need for bath switching, enabling production under stable bath conditions. As a result, the amount of generated dross is reduced to the minimum possible level, and the number of dross particles adhering to the steel strip can be greatly reduced, as shown in **Fig. 8**. This has made it possible to produce GI sheets with satisfactory surface quality.

### 3.2 Texturing Technology (Roughness Control)

As mentioned in the previous chapter, the roughness of the sheet has a large influence on press formability. Roughness can be controlled mainly by changing the work roll roughness during skinpass rolling, and by changing the skinpass rolling load and tension. As roll

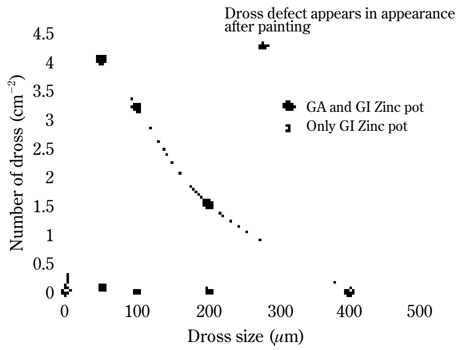



Fig. 8 Number of dross on GI sheet

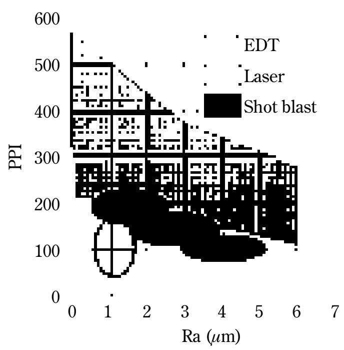
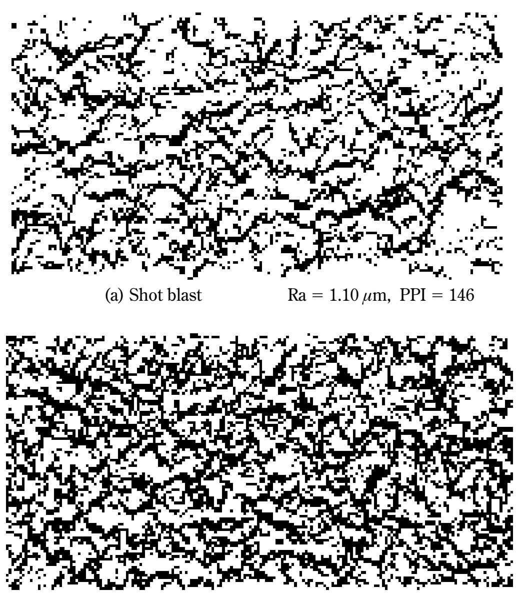



Fig. 9 Influence of skin-pass roll texturing technology on PPI and roughness



(a) Shot blast Ra = 1.10 μm, PPI = 146

(b) EDT Ra = 1.18 μm, PPI = 186

Fig. 10 Influence of skin-pass roll texturing on texture and roughness for GI sheet

texturing equipment, cold strip mill at Mizushima Works introduced an electro discharge texturing (EDT) device in December 1999, in addition to the existing shot blast and laser roll texturing devices. **Figure 9** shows the available texturing range with each of the roll texturing devices. EDT provides a wide texturing range for multiple indexes (Ra, PPI, Wca) and enables texturing with reduced deviation.

**Figure 10** shows the sheet surface profile of GI sheets which were rolled with shot blasted and EDT textured rolls. By using the EDT texturing equipment, it is possible to manufacture GI with excellent press formability by producing sheets with the proper roughness depending on the press forming application.

## 4 Conclusion

When hot-dip galvanized sheet steel (GI) for automotive applications is to be used in automotive panels, various problems arise, including the problems of press formability, spot weldability, and surface quality. Kawasaki Steel has improved the performance of GI sheets in each of these areas, as summarized below. As a result, it is now possible to produce GI sheets with excellent press formability and surface quality for use in auto body outer panels.

(1) Features of Hot-Dip Galvanized Sheets

(a) In addition to the good mechanical properties of the steel sheet, which had been established previously, the developed GI sheets also show satisfactory press formability as a result of improvement in sliding properties by roughness control and use of a high lubrication type anti-rust oil.

(b) The GI sheets show satisfactory continuous spot weldability as a result of improvement in the coating layer and substrate steel chemistry.

(2) Production Method for Hot-Dip Galvanized Sheets

(a) It was possible to prevent the “wrinkle” defect by optimizing wiping conditions.

(b) It has become possible to produce sheets with a fine spangle size by optimizing the coating bath composition and cooling rate after coating.

(c) It has become possible to produce sheets with minimal dross adherence by stabilizing bath conditions, which was achieved by adopting an exclusive-use pot for GI products.

(d) Control of the roughness profile of the skinpass work rolls by using an electro discharge texturing (EDT) device has made it possible to transfer the proper roughness to the steel sheet, as required by the press application.

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