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Hot-Dip Galvanized Steel Sheet with Excellent Surface Quality for Automotive Outer Panels†

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Abstract:

A new type, hot-dip galvanized steel sheet (GI) with excellent press formability, weldability, and surface appearance was developed for automotive outer panels. The sliding characteristics of GI in press forming were improved by optimizing surface roughness by texture control in skinpass rolling and use of a high-lubricity anti-rust oil, while spot welding electrode life was extended by selecting a suitable substrate chemistry. Many process improvements were also adopted to improve the surface quality of GI for use of automotive outer panels. They included adjustment of wiping conditions to prevent bath wrinkle pattern, adoption of an exclusive bath for GI with an appropriate Al content to prevent dross adherence, and control of the cooling rate after galvanizing to produce a stable minimum spangle coating. The developed GI is now in commercial production.

1. Introduction

As a measure to prevent corrosion damage due to road salt in snowy regions in North America and elsewhere, various types of coated steel sheet were developed and adopted, beginning in the second half of the 1970s. Subsequently, the share of coated products increased until this product type accounted for more than two-thirds of all steel sheets used in automobiles in the 1990s.

Because the thinking on rust-prevention measures and performance priorities differ at each automaker, in practice, various types of coated steel sheets are applied selectively to take advantage of their respective features. Although European automakers use electrogalvanized (EG) and galvannealed (GA) steel sheets, non-alloy hot-dip galvanized sheets (GI) continue to represent the mainstream. Moreover, in recent years, the number of makers who apply GI not only to inner panels, but also to outer panels, has continued to increase, supporting growing demand.[1)]

Hot-dip galvanized sheets have long enjoyed advantages over EG, in which GI with heavy coating weights can be produced more easily and production costs are lower. On the other hand, improvement of various properties of GI, including surface quality and press formability, has been required for application to outer panels.

This paper describes the quality features and production technology of a newly developed GI which solves these problems and has been successfully applied to automotive outer panels.

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

2.1 Corrosion Resistance

Figure 1 shows the corrosion resistance test results for various coated steel sheets.[2)] They were obtained in the 4 year exposure test of various types of coated sheets with different Zn coating weights in the unpainted condition conducted in Okinawa (approx. 10 m from shoreline). Corrosion resistance improves with the coating weight. Because heavy coating weight can be produced easily at low cost with GI, this type of sheet is advanta-

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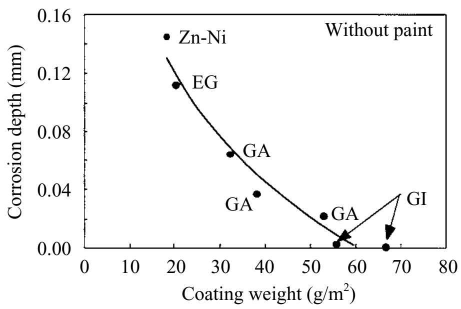


Fig. 1 Relationship between coating weight and corrosion depth examined in various Zn coated steel sheets exposed in Okinawa seashore for 4 years

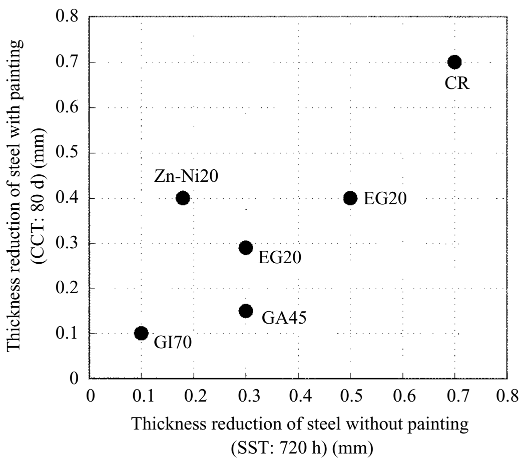


Fig. 2 Preforation corrosion resistances of pre-coated steel sheets with and without painting

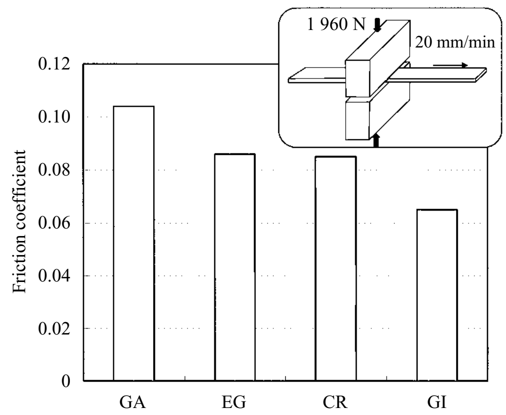


Fig. 3 Friction coefficient for various Zn coated steel and cold-rolled steel (Washing oil: 1 g/m^2, Oil viscosity: 17 mm^2/s, Sliding speed: 20 mm/min, Pressing force: 9.8 MPa)

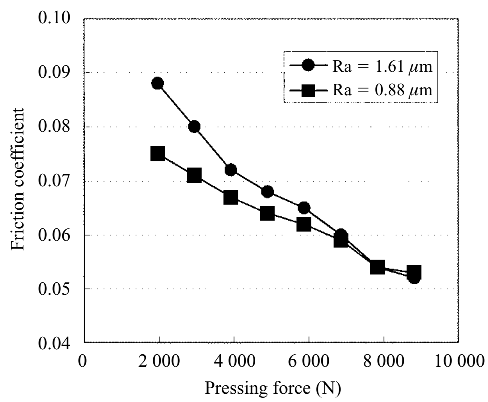


Fig. 4 Influence of surface roughness on friction coefficient for GI

geous from the viewpoint of rust prevention.

Figure 2 shows the results of an evaluation of the corrosion resistance of various types of steel sheets with and without painting in the cyclical corrosion test (CCT). Zn-Ni alloy coatings have comparatively high bare corrosion resistance in the unpainted condition, whereas GA tends to show high corrosion resistance after painting. GI offers excellent corrosion resistance both with and without painting.[2)]

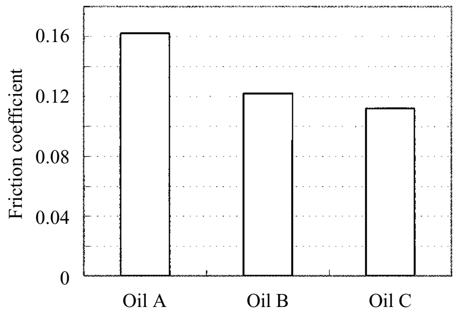
2.2 Press Formability

Even when a substrate steel sheet possesses excellent mechanical properties, there are cases where it is not possible to take advantage of these outstanding properties if the sliding characteristics of the coating layer and press die are poor and sheet metal flow at bead passing points is limited, as these problems can cause cracking.

Figure 3 shows the friction coefficient at a sliding speed of 20 mm/min and pressing force of 1 960 N on the steel sheet surface, using 20 mm wide samples of GA, EG, cold rolled steel sheet (CR), and GI with a 1 g/m^2 coating of washing oil and a flat die (material: SKD 11) with a length of 20 mm in the sliding direction. GI has a low friction coefficient and excellent sliding characteristics in comparison with GA, EG, and CR.

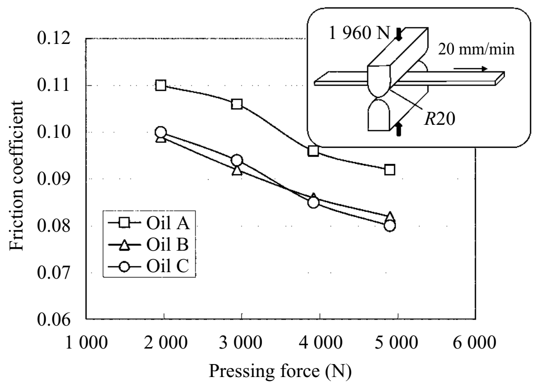
An investigation was also carried out to determine the effect of surface roughness, the rust-preventive oil used, and pressing force in the test on the friction coefficient of GI. Samples with high roughness and low roughness were prepared by varying the roll roughness in skinpass rolling after coating. The measured results are shown in **Fig. 4**. When a low pressing force is applied, the low roughness sheet shows a lower friction coefficient. However, the effect of roughness on the friction coefficient decreases as the pressing force increases, and there is no difference between high and low roughness materials when the pressing force exceeds 6 860 N.

Figures 5 and **6** show the friction coefficient in sliding at 20 mm/min with a pressing force of 1 960 N using 3 types of GI (width: 20 mm) with a 1.5 g/m^2 coating of anti-rust oil and a flat die and 3 roll die (SKD 11), respectively. In a comparison of standard anti-rust oil A (kinematic viscosity: 17 mm^2/s) and lubricant-type anti-rust oils B (kinematic viscosity: 36 mm^2/s) and C (kinematic viscosity: 26 mm^2/s), the use of a lubricant-type anti-rust oil reduced the friction coefficient in both the flat sliding test and the 3-roll sliding test. Thus, it is pos-



A: Viscosity 17 mm²/s (Standard anti-rust oil)
B: Viscosity 36 mm²/s (Lubrication type anti-rust oil)
C: Viscosity 26 mm²/s (Lubrication type anti-rust oil)

Fig. 5 Friction coefficient measured on GI with various anti-rust oil (Flat type die)



A: Viscosity 17 mm²/s (Standard anti-rust oil)
B: Viscosity 36 mm²/s (Lubrication type anti-rust oil)
C: Viscosity 26 mm²/s (Lubrication type anti-rust oil)

Fig. 6 Friction coefficient measured on GI with various anti-rust oil (Cylindracal type die)

sible to obtain satisfactory press formability with GI by imparting the proper roughness to the sheet and using a lubricant-type anti-rust oil.

2.3 Weldability

Auto bodies are assembled by spot welding at 3 000 to 4 000 spots per automobile. As one disadvantage of Zn-coated corrosion-resistant sheets, electrode life (number of continuous spot welds per electrode) is shorter than with cold-rolled sheets. The reason for this, which is attributed to the soft, low melting point Zn coating layer, is considered to be as follows:

(1) The welding current route is larger, necessitating high current welding.
(2) As a result, the temperature of the electrode tip is higher, increasing the length of tip wear.

Continuous spot weldability is improved by adding boron (B) to the substrate steel sheet. Although B addition reportedly suppresses grain growth in the heat affected zone (HAZ), and thereby improves the fatigue strength of spot welds, it is thought that B also functions effectively in reducing electrode wear by preventing grain growth, which reduces softening of the sheet.

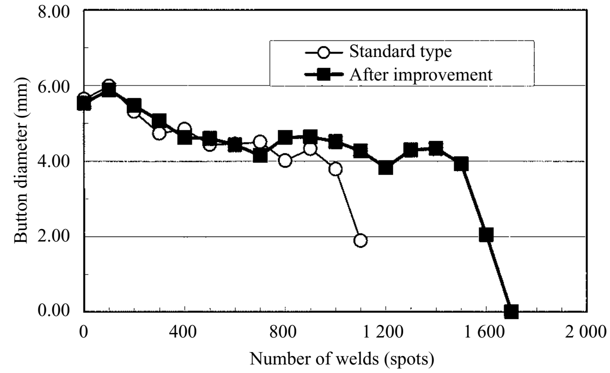


Fig. 7 Relationship between number of welds and button diameter in spot welding for GI

As a result of various attempts to improve spot weldability by improving the steel sheet in this manner, electrode life was extended as shown in **Fig. 7**.

2.4 Phosphating Property

Chemical conversion treatment, or phosphating, is performed as a pretreatment prior to painting steel sheets, and has the function of improving corrosion resistance after painting and adhesion between sheet and paint. The phosphating property is normally evaluated by observing the crystal structure of the phosphate coating.

Photo 1 shows the appearance of crystals obtained by SEM observation of CR, GI, and GA steel sheets after immersion for 2 min in PB-WL 35 (manufactured

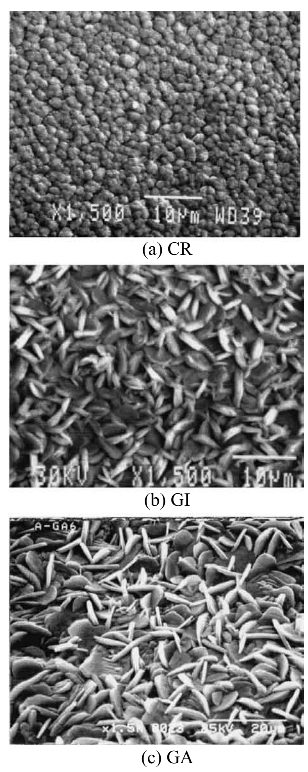


Photo 1 Scanning electron micrographs of phosphate coatings formed on (a) CR, (b) GI, and (c) GA

by Nihon Parkerizing Co., Ltd.), followed by washing in water and drying. With CR, crystals with a phosphophyllite structure were observed. In contrast, with GA and GI, phopite crystals were observed, and there was no significant difference in size and shape of the crystals.

According to various reports, GA is susceptible to the paint defect called "crater" during electro deposition coating.[3,4] Therefore, Fe-P coating is performed as a top layer to prevent cratering. However, in comparison with GA, cratering does not occur with GI, which shows satisfactory electro deposition coating performance.[2]

As described above, the developed GI shows satisfactory performance in all of the properties required in materials for automotive outer panels.

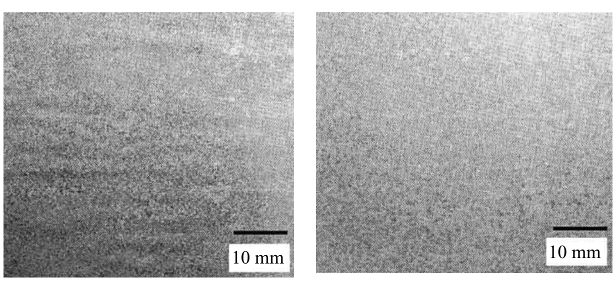
3. Production Technology for Hot-Dip Galvanized Steel Sheets (GI)

3.1 Technology for Improvement of Surface Appearance

3.1.1 Countermeasures against bath wrinkle pattern

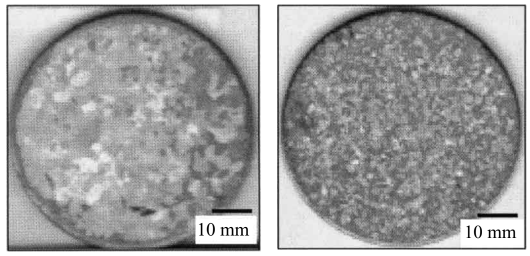
When a steel strip is coated in a Zn bath, the Zn coating weight is controlled by wiping with air or N_2 wiping gas above the bath. In this process, a wavy flow pattern called "bath wrinkle" frequently occurs on the coating surface, as shown in **Photo 2** (a), due to minute vibrations in the steel band caused by the wiping gas jet, irregular bath flow in the coating layer, or similar causes. When hot-dip galvanized steel sheets are to be used as the substrate for painting for application as automotive outer panel materials, it is particularly important to prevent bath wrinkle pattern due to its negative effect on the surface quality of the paint film, and especially paint film flatness.

At the continuous galvanizing line (CGL) in JFE Steel's West Japan Works (Kurashiki District), a technology for preventing bath wrinkle pattern was established by properly controlling wiping conditions (wiping pressure, nozzle-to-strip distance, height of nozzle above bath surface). Photo 2 (b) shows an example of GI surface quality after the establishment of this technology.



(a) Before improvement (b) After improvement

Photo 2 GI appearance before and after improvement in wrinkle pattern on the wiping conditions



(a) Before improvement (b) After improvement

Photo 3 Spangle pattern before and after improvement on the bath and cooling conditions (After etching with $CuSO_4$ aqueous solution)

3.1.2 Countermeasures against spangle

As the Zn coating on a steel sheet solidifies, dendritic crystals grow around a core of solidified Zn, and in some cases, a flower-like pattern called "spangle" forms on the surface of the galvanized sheet. In construction and certain other applications, the spangle pattern is considered desirable, as it gives the product an attractive appearance. However, in automotive sheets, the surface roughness and differences in crystal orientation associated with spangle impair the appearance of sheets after painting. For this reason, minimum spangle material (extremely fine spangle pattern) is required in exposed panels. It is known that spangle size increases as the Pb and Sb concentration in the Zn bath increases, and decreases as the solidification rate of the Zn coating layer increases. The effects of Pb and Sb concentrations are explained by the fact that the solubility of Pb and Sb in solid Zn decreases as the Pb and Sb contents in the molten Zn increases, reducing the solidification point of unsolidified parts. On the other hand, spangle becomes smaller as the solidification rate increases because the formation rate of solidified crystal cores increases at a higher solidification rate.

Photo 3 (a) shows the appearance of a conventional GI sheet which was etched with an aqueous solution of Cu_2SO_4 to emphasize the spangle size. In contrast, steel sheets with fine spangle, as shown in Photo 3 (b), can be produced in the CGL of West Japan Works (Kurashiki District) by minimizing the Pb content in the Zn bath and controlling the cooling rate above the bath.

3.1.3 Countermeasures against dross pickup

Another quality problem with GI is dross pickup by the steel strip. Dross is a substance which crystallizes out in the Zn bath and can cause a surface defect called "pimple" after press forming. Dross is classified as Fe-Al type and Fe-Zn type intermetallic compounds, which are formed respectively when the Fe eluted into the Zn bath from the steel strip reacts with the Al added to the bath or the molten Zn in the bath. Fe-Al type

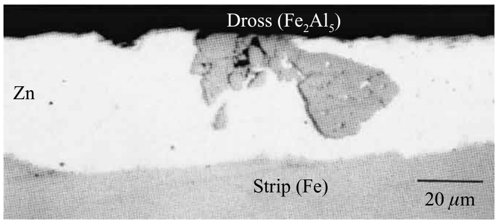


Photo 4 Cross-sectional micrographs of dross on GI

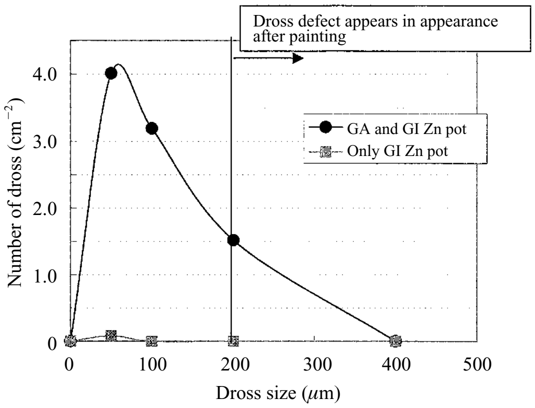


Fig. 8 Number of dross on GI sheet

dross (floating dross) floats in the pot, whereas Fe-Zn type (bottom dross) is found at the bottom of the pot. It is known that the formation of the two types is strongly affected by the Al concentration in the bath and bath temperature.[5–7)]

When a single pot is used to produce both GI and GA, the Al concentration in the bath is increased greatly when the GA bath is switched to the GI bath. As a result a large amount of floating dross forms by the following reaction:

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

Particles of floating dross adhere to the strip surface, as shown in **Photo 4**, causing surface defects.

In Nov. 2001, an additional Zn pot was installed in the CGL of West Japan Works (Kurashiki District), making it possible to produce GA and GI with exclusive pots. Eliminating bath switching has minimized dross generation by making it possible to produce GI under stable bath conditions. As shown in **Fig. 8**, the number of dross spots adhering to GI sheets has been significantly reduced, enabling production of GI with satisfactory appearance.

3.2 Texturing Technology for Surface Roughness Control

Sheet roughness is controlled mainly by adjusting the surface roughness of roll, rolling load, and rolling tension in skinpass rolling. As roll texturing equipment,

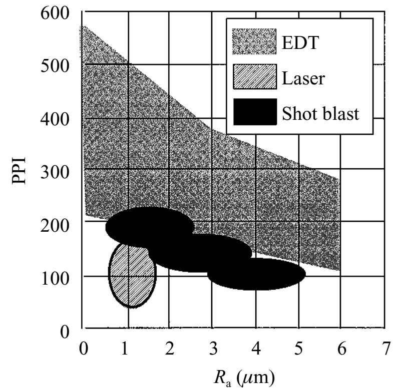


Fig. 9 Applicable surface texturing range with each type of roll texturing equipment

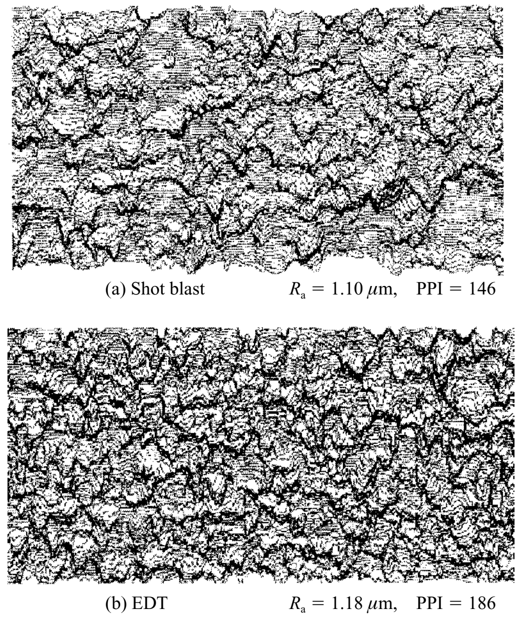


Fig. 10 3-D profiles of (a) shot blast and (b) EDT GI surface

in Dec. 1999, the Cold Strip Mill at West Japan Works (Kurashiki District) introduced electro discharge texturing (EDT) equipment in addition to the existing shot-blast dull texturing and laser dull texturing equipment. **Figure 9** shows the applicable surface texturing range with each type of roll texturing equipment. EDT has a wide texturing range with respect to multiple roughness indexes, including R_a, PPI, and W_{CA}, and also reduces deviations.

Figure 10 shows the sheet surface profile of GI after skinpass rolling with shot-blasted dull rolls and EDT textured rolls.

Using EDT, it is possible to produce steel sheets with excellent press formability by changing the roughness profile of the rolls to produce GI with the roughness required by specific press forming applications.

4. Conclusion

The press formability, spot weldability, and surface quality of hot-dip galvanized steel sheets (GI) for automotive use have long been problems limiting the use of GI in automobile outer panels. These respective properties were improved, as summarized below, making it possible to produce GI for outer panels with excellent press formability and appearance.

(1) Features of GI
- (a) In addition to the excellent mechanical properties, satisfactory press formability was obtained by improving the sliding characteristics of the sheet, which was achieved by controlling surface roughness and applying a lubricant-type anti-rust oil.
- (b) Continuous spot weldability was improved by optimizing the chemical composition of the substrate steel.

(2) Improvements in Process Technology for GI
- (a) Wiping conditions were optimized to prevent bath wrinkle pattern.
- (b) The bath composition and cooling rate after coating were optimized to enable production of steel sheets with minimum spangle.
- (c) Bath conditions were stabilized by introducing an exclusive pot for GI, making it possible to produce sheets with very low dross adherence.
- (d) Electro discharge texturing (EDT) equipment for control of the roll roughness profile was introduced, making it possible to impart the required sheet surface roughness for specific press forming applications.

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