Hot-Dip Zn-5% Al Alloy-coated Steel Sheets "JFE ECOGAL®"†

FUJISAWA Hideshi[*1] KANEKO Rie[*2] ISHIKAWA Hiroshi[*3]

Abstract:

A new hot-dip Zn-5% Al steel sheet "JFE ECOGAL®" has an excellent durability at forming portion, beautiful surface appearance free from spangles and excellent corrosion resistance by adding small amount of elements in the plating bath. Also "JFE ECOGAL®" has blackening resistance, alkaline resistance and weldability due to the chromate-free treatment, which meet ecological requirements for building materials, electronic appliances and so on.

1. Introduction

In Zn-coated steel sheets, corrosion of the steel substrate is stably suppressed by the sacrificial reaction of the Zn coating (galvanic reaction). Because Zn-coated materials offer both excellent corrosion resistance and economy, they are used in a wide range of fields, including not only building materials, but also home electrical appliances, automobiles, and others[1].

In the building materials field, there is an increasing need for long life of housing, as exemplified by stock housing policy under Japan's Basic Act for Housing, the 200 year housing concept under the draft of the Law for Promoting the Popularization of Long-term High Quality Housing, etc. In responding to this need, further improvement in the durability of sheet building materials is required. In particular, in parts which are subjected to forming, reduced corrosion resistance due to damage of the Zn coating and chemical conversion treatment film is a problem.

In other fields, in recent years, the European countries, which can be called "advanced environmental nations," have issued the RoHS Directive (Directive on the Restriction of the use of certain Hazardous Substances in electrical and electronic equipment) and ELV Directive (End of Life Vehicles Directive). Following their lead, Japan's domestic appliance makers, auto makers, and other manufacturers have introduced a unique system of "Green Procurement," and use of materials which contain environmental load substances, i.e., lead, mercury, cadmium, and hexavalent chromium, was banned. This trend in environmental measures has also begun to spread to the building materials field, and as a result, the steel industry is replacing the conventional chromate treatment with chromate-free treatments as conversion treatments for Zn-coated steel sheets. In 2007, chromate-free conversion-treated materials were standardized in JIS (Japanese Industrial Standards). In the same year, JFE Galvanizing & Coating established a 100% chromate-free process for its 55% Al-Zn-coated steel sheet "JFE Galvalume," which is widely used in building material applications.

Based on these trends, JFE Galvanizing & Coating, jointly with JFE Steel, developed a chromate-free conversion-treated Zn-5% Al alloy-coated steel sheet "JFE ECOGAL®" with excellent durability in forming portions, and began marketing this product in April 2008. This paper centers on the quality features of "JFE ECOGAL®."

2. Key Points in Development

2.1 Improvement of Conventional Zn-5% Al Alloy-Coated Steel Sheet

The following problems existed in the conventional

---

† Originally published in *JFE GIHO* No. 24 (Aug. 2009), p. 1–5

[*1] Staff Deputy General Manager,
Steel & Coil Sec.,
Product Development Center,
JFE Galvanizing & Coating

[*2] Senior Researcher Deputy Manager,
Electrical Appliance Steel & High-performance Components Res. Dept.,
Steel Res. Lab.,
JFE Steel

[*3] Executive Assistant,
Corporate Planning Dept.,
JFE Galvanizing & Coating

Zn-5% Al alloy-coated steel sheet (hereinafter, GF). These were taken up as issues in the development of "JFE ECOGAL®."

(1) Surface Smoothness (External Appearance of Surface)

Taking advantage of excellent formability of GF, this material had been produced and sold mainly as a base for prepainted steel sheets. However, because the spangle pattern, which is a non-uniform tortoise shell-shaped pattern that forms during solidification of the zinc coating, created irregularities (roughness) on the material surface,[2] and also reduced the appearance of the product after painting, GF could not be used in applications in which a beautiful surface appearance was required.

(2) Blackening Phenomenon

Because GF was produced using a chromate treatment, local blackening of the coated surface occurred over time. This blackening phenomenon was also an impediment to use. The blackening phenomenon in Zn-coated steel sheets is considered to be caused by chemical reduction of the ZnO film in the surface layer of the coating by the Al in the coating layer, which concentrates at the surface over time, resulting in the formation of an oxygen-depleted film[3].

2.2 Newly Improved Properties

In addition to solving the above-mentioned problems of the conventional GF, the following quality properties were improved in the new "JFE ECOGAL®."

(1) Corrosion Resistance

In order to meet higher durability requirements, in particular, the corrosion resistance of forming portions was improved by refinement of cracks in the coating in parts where forming is applied.

(2) Alkaline Resistance

For dairy farming/livestock applications, durability in high alkaline environments was improved.

(3) Weldability

With conventional chromate-free conversion treatments, a thick film was applied to secure corrosion resistance, but this impaired weldability. In the developed product, satisfactory weldability was secured by improving the quality properties of the conversion treatment and reducing the thickness of the film.

2.3 Development Concept

Many attempts have been made to improve the quality properties of the coating of various types of Zn-Al coated steel sheets, generally by modifying the composition ratio or adding different elements[4].

In 1990, GF was standardized under JIG G 3317 "Hot-dip zinc-5% aluminium alloy-coated steel sheet and strip," and prepainted products of this material were

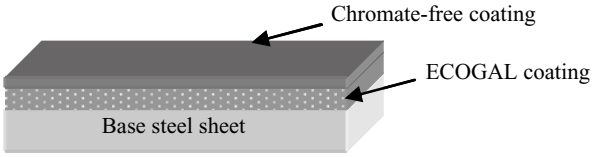


Fig. 1 Coating structure of "JFE ECOGAL®"

standardized under JIG G 3118, "Prepainted hot-dip zinc-5% aluminium alloy-coated steel sheets and coils". In addition to Zn and Al, these standards permit trace amounts of elements such as Mg and the rare earth elements, etc. in the coating bath.

"JFE ECOGAL®" was designed to achieve a balance of various quality properties by adding the total concentration of elements up to less than 1% to improve the above-mentioned problems of GF.

Figure 1 shows a schematic diagram of the coating structure of "JFE ECOGAL®." In "JFE ECOGAL®," a trace amount of Mg is added in the coating bath to suppress formation of spangle, resulting in a large improvement in surface smoothness. This improves the image clarity of the painted surface when used as a substrate for prepainted steel sheets, and has also made it possible to expand applications as a galvanized product.

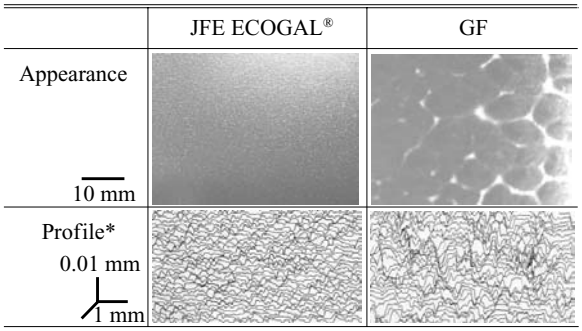
Addition of a trace amount of Ni to the coating bath simultaneously with the above-mentioned Mg improved blackening resistance, corrosion resistance, and alkaline resistance, and the use of a newly-developed chromate-free conversion treatment secured the stability of blackening resistance, thereby imparting surface quality properties compatible with various applications, including building materials, home electrical appliances, and others.

In particular, because these features are realized by holding the addition of elements to the coating bath up to trace amounts, "JFE ECOGAL®" is not simply a product conforming to the JIS Standards, but is a Zn-5% Al alloy-coated steel sheet in which surface smoothness, blackening resistance, and corrosion resistance are improved while also maintaining the superior features of coating formability and weldability unique to GF, and achieves excellent durability of forming portions by satisfying both formability and corrosion resistance.

3. Quality Properties

3.1 Coating Surface Appearance

Photo 1 shows the surface appearance of "JFE ECOGAL®" and GF, together with the 3-dimensional roughness profiles of the two materials as measured by a surface roughness meter. The surface of the conventional GF has a tortoise shell-shaped spangle pattern, and surface irregularities corresponding to this pattern can be



*Surface profile of substrate measured by 3-dimensional meter

Photo 1 Surface appearance and profile

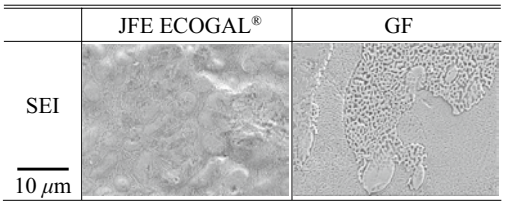


Photo 2 Scanning electron microscope (SEM) images of surface texture

observed. In contrast, the surface of "JFE ECOGAL®" is uniform, smooth, and beautiful.

Photo 2 shows scanning electron microscope images of the coating surfaces. On the surface of the conventional GF, Zn-Al binary eutectic crystals have segregated, showing a spangle pattern, whereas a uniform surface has formed on "JFE ECOGAL®," in which the Zn-Al binary eutectic crystals are refined as a result of the trace content of Mg.

3.2 Blackening Resistance

Photo 3 shows the external appearance of specimens of "JFE ECOGAL®" and conventional GF after a blackening resistance test of chromate material (in which two 50 mm square water-wetted specimens were stacked and wrapped with a polyethylene sheet, and then exposed in a constant temperature, constant humidity chamber at 50°C, RH 98% for two weeks). The "JFE ECOGAL®" has a more satisfactory blackening property than the conventional chromate-treated GF material.

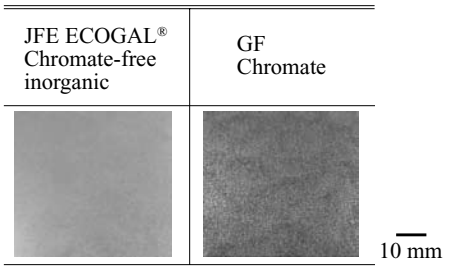


Photo 3 Appearances of specimens after blackening resistance test (After wrapping 2 pieces of water wetted specimens with polyethylene sheet, exposed under the condition of 50°C, RH: 98% for 2 weeks)

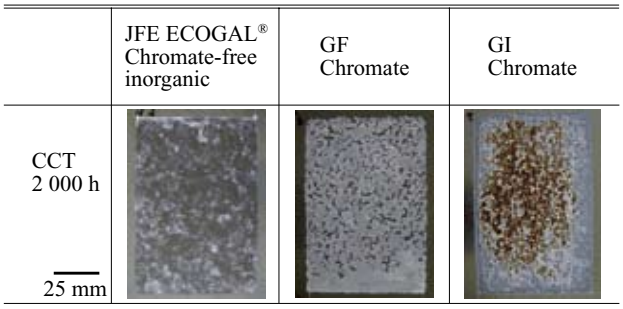


Photo 4 Appearances of flat portion after cyclic corrosion test (JIS G 0594, C-method) for 2 000 h (Zn coating weight: 90 g/m^2)

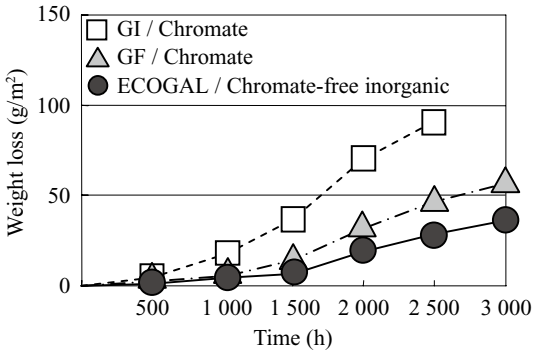


Fig. 2 Corrosion weight loss in cyclic corrosion test (JIS G 0594, C-method) (Zn coating weight : 90 g/m^2)

3.3 Corrosion Resistance

Photo 4 shows the condition of corrosion after an accelerated cyclic corrosion resistance test CCT (JIS G 0594, C-method) of flat sheets for 2 000 hours. **Figure 2** shows the corrosion weight loss of the specimens in the same test. "JFE ECOGAL®" displayed greatly improved corrosion resistance in comparison with the conventional material as a result of the composite contents of Mg and Ni. In the corrosion weight loss in Fig. 2, the corrosion rate of the "JFE ECOGAL®" coating after consumption of the initial conversion treatment film showed satisfactory corrosion resistance, approximately three times that of GI (Zn-coated steel sheet) and approximately 1.5 times that of the conventional GF.

3.4 Formability of Coating Layer and Corrosion Resistance of Forming Portions

Photo 5 shows the surface of the bent parts and the condition of cracking of the coating layer in the cross section in a 2T-180° bending test (inner radius: 1.6 mmφ) with "JFE ECOGAL®" and conventional GF. In both cases, the sheet thickness was 0.8 mm and the Zn coating weight (one side) was 90 g/m^2. With the conventional GF, the point of origin of cracking was the interface between the Zn-Al binary eutectic crystals and β-Zn phase, corresponding to the spangle pattern. In contrast, with "JFE ECOGAL®," due to the formation of a uniform surface, cracking was limited to fine cracks,

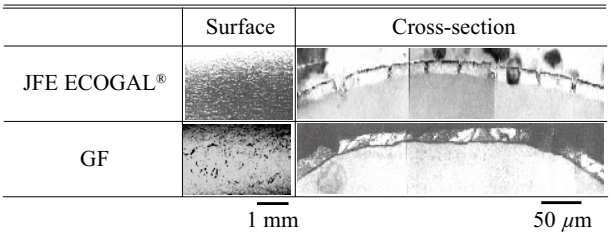


Photo 5 Scanning electron microscope (SEM) images of bended portion (Bend angle:180°)

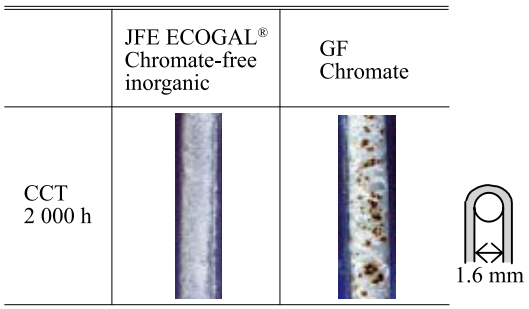


Photo 6 Appearances of bended portion after cyclic corrosion test (JIS G 0594, C-method) for 2 000 h (Thickness: 0.8 mm, Zn coating weight : 90 g/m^2)

and the sacrificial corrosion protection performance was improved.

Photo 6 shows the appearance of corrosion in the portion subjected to 180° bending after a CCT (JIS G 0594, C-method) for 2 000 hours. As is clear from Photo 6, "JFE ECOGAL®" has satisfactory corrosion resistance, including formed portions.

3.5 Comparison of Corrosion Resistance of Post-Coated Materials

In structural applications and similar uses, there are cases in which so-called post-coating is performed by the flux method after a structure is erected in order to prevent corrosion of joints and cut-edges of steel sheets. **Photo 7** shows the appearance of corrosion of "JFE ECOGAL®" with a thickness of 2.3 mm and coating weight (one side) of 90 g/m^2 and a chromate-treated material with the same thickness and a post-coating (one side) coating weight of 500 g/m^2 after a salt spray test SST (JIS Z 2371) for 500 hours.

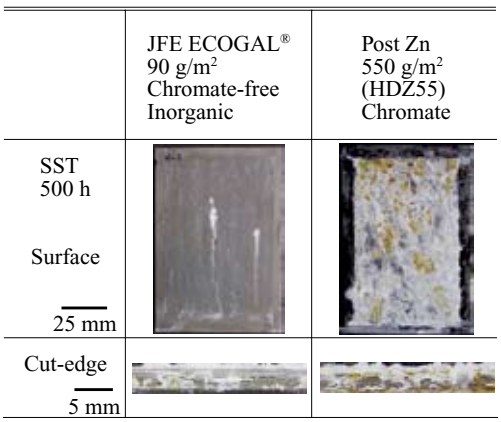


Photo 7 Appearances of specimens after salt spray test (JIS Z 2371) for 500 h

As is obvious from Photo 7, in the flat part, "JFE ECOGAL®" shows equal or greater corrosion resistance with a coating weight approximately 1/6 that of the post-coated material. The cut edges of "JFE ECOGAL®" also show the same corrosion resistance as the post-coated edges.

3.6 Alkaline Resistance

Durability against strong alkaline atmospheres such as ammonia, etc. is required in barns, poultry sheds, compost and manure sheds, etc. **Figure 3** shows the reduction of coating weight when specimens were immersed in a 5% ammonia solution (pH12) at 25°C for 24 hours. "JFE ECOGAL®" has excellent alkaline resistance as a result of its composite contents of trace amounts of Mg and Ni.

3.7 Weldability

3.7.1 Spot weldability

Figure 4 shows the optimum spot welding current ranges for "JFE ECOGAL®" and the conventional GF chromate-treated material. The optimum current range is determined by the minimum current capable of forming satisfactory nuggets as the lower limit value, and the current at which surface flash occurs as the upper limit value.

As is clear from Fig. 4, with "JFE ECOGAL®,"

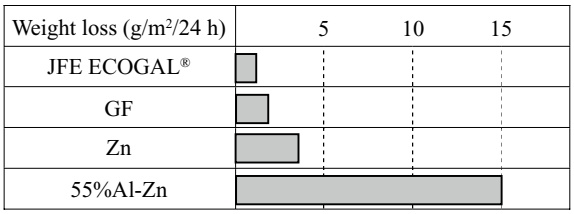
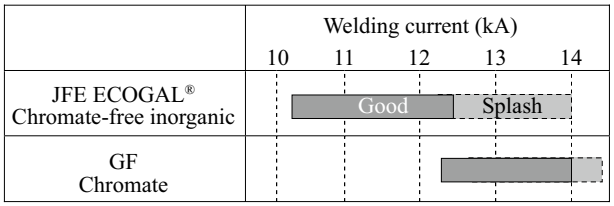
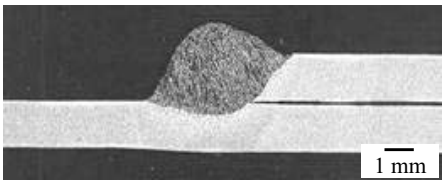


Fig. 3 Reduction of coating weight after 5% NH_4OH (pH12), 25°C immersion test for 24 h (Zn coating weight: 90 g/m^2)



Electrode: Cr / TypeCF /6.4 mmφ Flat tip
Welding conditions: 4 kN, 16 cycles
Materials: 1.6 mm thickness, Zn coating weight 275 g/m^2
Minimum acceptable nugget size: $3\sqrt{t} < \fallingdotseq 3.8$ mmφ

Fig. 4 Optimum spot-welding current range for "JFE ECOGAL®"



Welding wire: JIS YGW14 1.0 mmϕ

Welding conditions: 80 A/20 V, 50 cm/min

Material: Thickness 1.6 mm, Zn coating weight 275 g/m^2

Photo 8 Cross-section of CO_2 arc welded portion

welding is possible in a lower current range than with the conventional GF chromate-treated material due to the chromate-free conversion treatment film. As a result, reduced welding equipment costs and power costs can be expected with "JFE ECOGAL®."

3.7.2 Arc weldability

Photo 8 shows the cross section of the welding bead in CO_2 gas shielded arc welding. In this test, virtually no occurrence of blowholes in the welding bead was detected, and satisfactory weld strength was obtained.

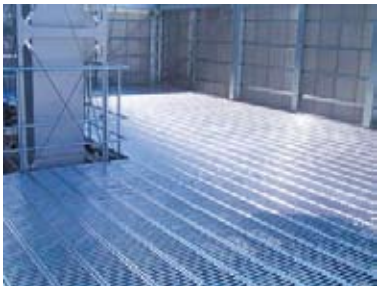
4. Examples of Application

Photo 9 shows two examples of application. "JFE ECOGAL®" has been used in a wide range of applications, including housing materials such as posts, beams and other structural members, roofing, walls, etc., steel flooring panels such as grating, scaffold boards, etc., building hardware such as C channels, L-shaped angles, joint materials, cable racks, etc., and in post-painted applications such as storerooms and steel stockers, in the agricultural and livestock fields, etc. Further expansion to home electrical appliances and other fields is expected in the future.

5. Conclusion

This paper described the key points in development and quality properties of a new chromate-free conversion-treated material, Zn-5%Al alloy-coated steel sheets "JFE ECOGAL®." To meet a diverse range of customer needs, "JFE ECOGAL®" is available in a wide

(1) Structural post and beam for residence



(2) Grating for floor panel

Photo 9 Examples of application of "JFE ECOGAL®"

line-up, including chromate-free organic conversion-treated, chromate-free inorganic conversion-treated, and chromate-treated products.

With increasingly high needs for long life and environment-friendliness, "JFE ECOGAL®" provides the ideal alternative for post-coating (cost reduction, process omission) and substitution of thinner coatings for Zn-coated steel sheets (resource saving). From this viewpoint, "JFE ECOGAL®" is expected to play a key role as a sustainable material.

References

1) Aenmekkikouhan Gosiyounotebiki. Jpn. Iron and Steel Fed. 2005, p. 4.
2) Adaniya, T. Kinzoku-hyoumen-gijyutu. 1982, vol. 33, no. 10, p. 474.
3) Uchida, Y.; Kouda, M.; Fukui, Y.; Hirose, Y. Tetsu-to-Hagané. 1986, vol. 72, no. 8, s1055.
4) Proc. of 167 ·168th Nishiyama-kinen Conf. of Jpn. Iron and Steel Fed. 1998, p. 25.