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*Technical Report*

# Electro Galvanized Steel Sheet with Hairline-like Appearance "FeLuce™"

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## Abstract

***FeLuce™ exhibits the texture of metal without using a decorative layer such as laminate. This paper describes how to realize the metallic feeling and the method of inscribing hairlines. In order to maintain the metallic impression, it was important to minimize the difference of the impression regarding the reflection between the bare material shape and the resin coated surface. FeLuce™, which was developed based on this understanding, has proved excellent in metallic texture. Hairline processing is applied to the Zn-Ni plating surface by introducing the facility into the electro galvanizing line, which makes it possible to produce it continuously from plating through hairline polishing to resin coating in one processing line in an integrated manner without lowering productivity.***

## 1. Introduction

When steel materials are used for home appliances or as building materials, various types of resin coating are applied to create the desired functions such as resistance to corrosion, scratches and stains. When steel sheets are used for external facing, compatibility with appearance design is an essential functional item, but in general, steel sheets plated with Zn and Zn-based alloys do not meet this requirement. To improve their appearance, they are often painted or laminated with another material to impart different appearances such as marble or wood grain patterns or a beautiful single-color tone in white or black.

In recent years, due to the growing preference for naturalism, the feel of the material itself has become a requirement. For example, stainless steel and aluminum which are expensive are widely used for applications in which a metallic feeling is required. Since the surface of these materials is covered with a strong and thin oxide film, they are used bare without painting, laminating or other resin coating even for applications where aesthetic design is required. The measures to enhance their appearance include polishing, embossing, anodizing and resin coating. Among various polishing processes, hairline polishing to engrave a pattern of many fine linear polish marks is widely used in appreciation of good luminance and a high-class feel, and also because scratches are barely noticeable. On the other hand, however, when resin coating is applied to hairline polished surfaces of stainless steel or aluminum, the metallic feeling is lost in most cases.

Other than stainless steel and aluminum, various materials have been used to create the metallic impression, but few of them have so far succeeded in capturing the market taste. When such materials are used to obtain the metallic feeling, they are generally not as good as stainless steel or aluminum, and are expensive, albeit less expensive than either of the two. The most common method for effecting a metallic appearance is the use of silver paint containing bright metallic pigments such as aluminum flakes.[1, 2] Although the effects achievable by such a method have been improved recently, it is still difficult to obtain the same appearance effects by such measures as silver painting as it is by hairline polishing and the like. It is also possible to obtain similar decorative effects by covering the surface with a film having an aluminum vapor deposition layer of a hairline appearance, but this is also expensive.

As a solution, by directly applying hairline polishing to steel sheets plated with a zinc-based alloy, we have developed a new brand of electroplated galvanized steel sheet having a hairline appearance, FeLuce™; as seen in **Fig. 1**, it has a special thin film of a

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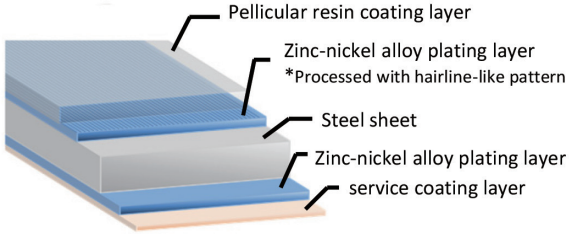


**Fig. 1 Coating structure of FeLuce™**

water base paint on the zinc-nickel plating layer on one side. In appreciation of exhibiting both the required functionality and metallic feeling, the developed product won the Good Design Award in 2020.

The present paper describes the studies into the method of realizing the metallic impression, a principal feature of FeLuce™, that of applying hairline polishing and the characteristics of the product.

## 2. Expression of Metallic Feeling

### 2.1 Evaluation of metallic feeling and measurement of luminance

In the development of FeLuce™, the first problem to be solved was how to express the metallic feeling. We noted the fact that stainless steel often maintained a metallic impression even when coated with a transparent resin film. Specimens of JIS SUS304 stainless steel sheets with B4 finish were prepared by applying hairline polishing with #150 abrasive grains and then coating with a transparent paint under different conditions, their surface impression was evaluated and the relationship between the metallic feeling and surface luminance was investigated. Five surface treatment researchers rated the metallic impression of the specimens by sensory assessment, and each sample was evaluated according to the total score of their ratings. Although the metallic impression differed from sample to sample depending on the score, it was considered high enough if the total score was 15 or more. Luminance was measured in a dark room as shown in **Fig. 2**: light was irradiated from a source of 27 W to a sample from a distance of 600 mm and the reflection was measured with a luminance meter (CS-150 of Konica Minolta) set at a distance of 600 mm. Although similar results could be obtained by measuring the glossiness, the measurement result of which was standardized using the intensity of light reflected from a reference plate, the metallic feeling was evaluated in the present study in terms of luminance because the result was close to the real visual impression.

### 2.2 Relationship between metallic feeling and flip-flop property

Flip-flop property,[3–5] which is often used as an index of the degree of metallic feeling of paint coating, was also evaluated, but there was little correlation with the metallic feeling of stainless steel surfaces coated with a transparent resin. Flip-flop is a phenomenon in which color appears to change depending on the angle of observation, that is, the intensity of reflected light changes greatly depending on the angle. **Figure 3** shows the results of measuring the flip-flop properties of the resin-coated stainless steel sheets of different metallic impression scores by fixing the incident angle and changing the observation angle; here the light source was fixed at −10° with respect to the normal state of the sample sheet, and the detection angle was changed from +10 to +85°. With all the samples, the change in luminance was large depending on the measurement angle: the luminance of the specular reflection measured at

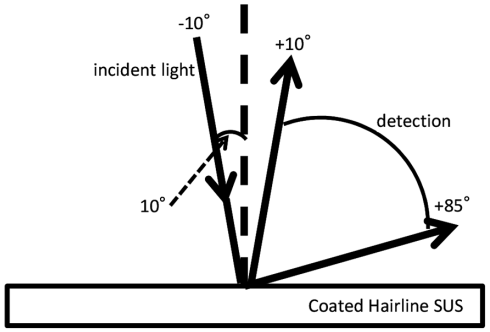


**Fig. 2 Variable angle luminance measurement method**

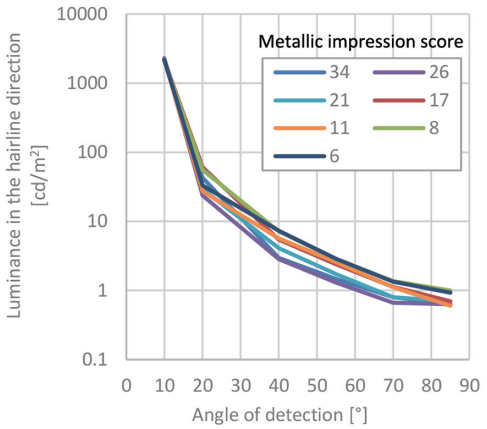


**Fig. 3 Relation between luminance in the hairline direction and detection angle**

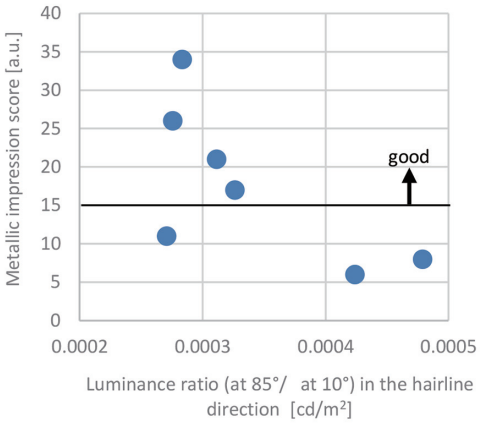


**Fig. 4 Relation between Δluminance in the hairline direction and metallic impression score**

+20° was less than 1/10 that measured at +10°, and that measured at +70° was also less than 1/10 that at +20°. This indicates that all the samples demonstrated a high flip-flop property, meaning a high metallic feeling. However, even though the flip-flop property was high with all the specimens, the metallic feeling differed from piece to piece. In consideration of this, the ratio of the luminance at +85° to that at +10° was selected as an index of the flip-flop property. **Figure 4** shows the relationship between the flip-flop property as de-

fined above and the total score of the metallic impression: the correlation between the two was not high. It was therefore concluded that the metallic impression of stainless steel sheets coated with a transparent resin could not be evaluated based on the flip-flop property.

### 2.3 Relationship between metallic feeling and specular reflection luminance

Next, **Fig. 5** shows the relationship of the metallic impression score with the specular reflection luminance measured at an irradiation angle of 60° and a detection angle of 60° in the direction of the hairline pattern, and **Fig. 6** the same relationship measured in the direction orthogonal to the hairline pattern. Although there was a positive correlation between the specular reflection luminance in the hairline direction and the metallic impression score, the variation was large. On the other hand, a very good correlation was observed between the two in the direction orthogonal to the hairlines.

The correlation between the reflection luminance and the metallic impression score in the hairline direction differed significantly from the same in the hairline orthogonal direction as stated above. For this reason, the existence of the hairline pattern and the way it looks seemed to affect the metallic feeling of hairline polished stainless steel sheets coated with a transparent resin film. When stainless steel sheets are hairline processed, the surface roughness in the hairline direction is reduced by the polishing, and the scattering of light is also reduced in this direction. In the direction orthogonal to the hairlines, on the other hand, the surface is made rough because of the hairlines, and light is strongly scattered. Let us consider now a case in which such a surface is coated with resin by painting. Since paint is liquid, when applied to the sheet surface, its surface becomes smoother than the base material owing to a leveling effect, and the resin surface after baking is also smoother. It follows, therefore, that the difference in the surface roughness between the base metal, which was smoothed by polishing before the paint application, and the resin coating is small in the hairline direction, but in the direction orthogonal to the hairlines is large because the roughness of the base metal surface is large in this direction. Consequently, the impression of the reflection of surrounding objects on a bare sheet which is affected by the shape and other characteristics, is different from the impression of the reflection on a surface of coated resin. It was presumed that if this difference was small, it would be difficult to notice the resin coating and the metallic feeling would not be impaired, but if the difference was large, the resin coating would become noticeable and the metallic impression would be impaired. The conditions of the paint coating of FeLuce™ were set based on this understanding.

According to the findings of the previous paragraph, the specular luminance in the orthogonal direction was standardized as follows. In Fig. 6, the correlation between the specular luminance and the metallic feeling of stainless steel sheets was studied only in the direction orthogonal to the hairline pattern, but in this way, it is difficult to compare it with that of a different base material. As a solution, the specular luminance in the orthogonal direction was standardized by dividing it by that in the hairline direction. This enabled minimization of the influence of the surface condition of the base material before the hairline processing such as undulation across the entire surface. After this, based on the understanding in the previous subsection to the effect that the metallic impression is strongly affected by the difference in impression between the resin-coated surface and bare material surface, the result of the above standardization was further standardized by using the difference between the values after the resin coating and before it. **Figure 7** shows the evaluation results of FeLuce™ using the specular luminance thus standardized. As a result of the above standardization, the specular lumi-

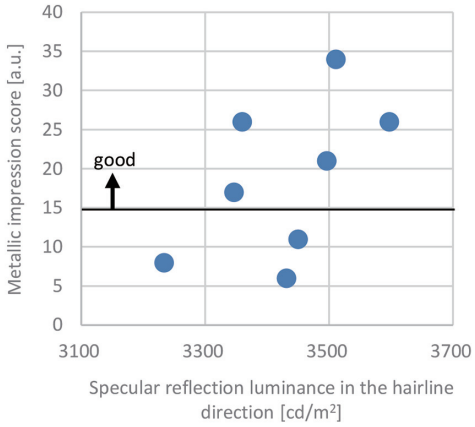


**Fig. 5 Relation between specular reflection luminance in the hairline direction and metallic impression score**

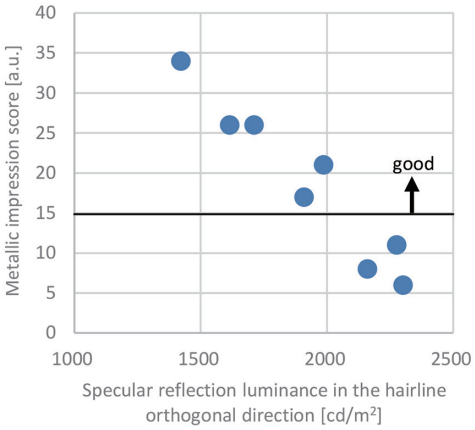


**Fig. 6 Relation between specular reflection luminance in the direction orthogonal to hairline and metallic impression score**

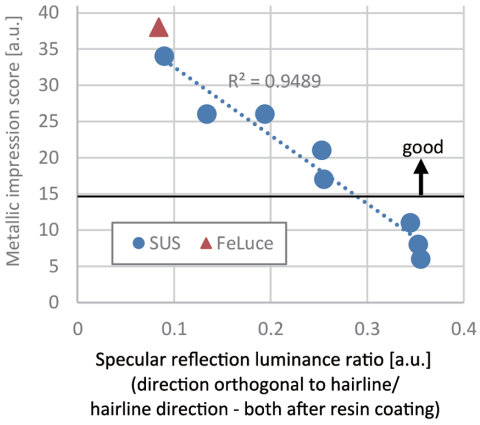


**Fig. 7 Relation between standardized specular reflection luminance in the direction orthogonal to hairline and metallic impression score**

nance in the direction orthogonal to the hairlines and the metallic impression score agreed well with each other, and the high metallic impression of FeLuce™ has been confirmed through measurement according to the above.

## 3. Method of Hairline Processing

Metallic luminance is imparted to FeLuce™ by directly applying hairline polishing to the plating layer of the Zn-Ni alloy, which guarantees corrosion resistance, in the electrolytic galvanizing line (EGL), an unprecedented manufacturing method. The weight of the electroplated layer is usually 10 to 40 g/m$^2$, roughly 1.4 to 6.6 $\mu$m in thickness. Since an electroplated layer is as thin as this, when it is polished, excessive grinding is likely to occur depending on the operating conditions of the polisher, and the coating layer may disappear locally as shown in **Fig. 8**(a), which is an EPMA mapping of Zn of the Zn-Ni plating layer after the hairline processing. Since Zn-based plating is excellent in sacrificial (galvanic) corrosion protection, it is capable of protecting the steel substrate even when the coating partially disappears and part of the steel is exposed, but when the area where the coating is lost is large, galvanic corrosion easily advances, and corrosion resistance is impaired. For this reason, when hairline polishing was required in the past, it was not applied directly to the plated layer but to a laminated decorative layer or the like that was not related to corrosion resistance.

For the commercial production of FeLuce™, the manufacturing process was designed so that the product would be ready for shipment at the exit from the EGL. If the hairline polishing is performed in an EGL using a conventional polisher, the productivity is greatly lowered, and in consideration of this, we looked for solutions based on brush grinders that had proven track records of high-speed processing. In the study of the brush grinder, through examination of a variety of brush specifications and machine settings, a set of conditions was developed to obtain excellent hairline density and uniformity, while avoiding the exposure of the steel substrate. The brush grinder was installed between the electroplating section and the painting section of the EGL, and by this it became possible to continuously produce FeLuce™ from Zn-Ni alloy electroplating through hairline processing to resin coating in one line without lowering productivity.

Figrure 8(b) shows an EPMA mapping of Zn of a hairline polished Zn-Ni plated steel sheet manufactured on the EGL equipped with the brush grinder, and **Fig. 9** shows the appearance of another specimen. As seen in Fig. 8 (b), Zn is detected in the entire area of observation, which indicates that the steel substrate is not exposed by the manufacturing method of FeLuce™.

## 4. Characteristics of FeLuce™

To realize a good metallic feeling and satisfy various performance items required, FeLuce™ is coated with a thin resin film. Thin film is advantageous for the metallic feeling, but thick film is required for improving other performance items. In order to meet the conflicting requirements, a new type of resin film has been developed that meets the requirements even when it is thin. In addition, two color variations of FeLuce™ have been developed: Silver with colorless resin film preserving the metallic feeling; and Black with resin film colored in black maintaining the hairline appearance and the metallic feeling. To confirm some of the various functional items of the product, fingerprint resistance and chemical resistance were evaluated and a forming test was conducted. Note that bare sheets of JIS SUS304 stainless steel and JIS A1050 aluminum, widely used for applications in which the metallic feeling is required, were used as comparative specimens.

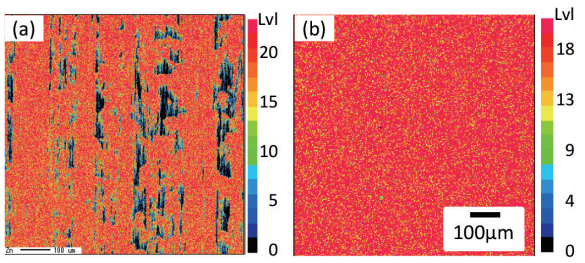


**Fig. 8 EPMA Zn mapping of Zn-Ni plating after hairline processing (a) Excessive grinding, (b) Processed in EGL**

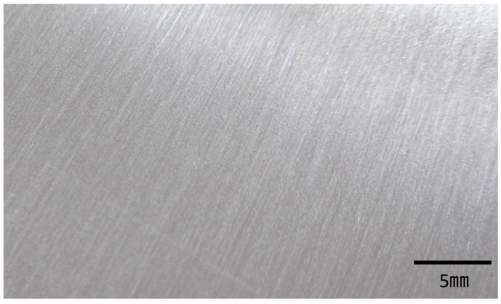


**Fig. 9 Appearance of hairline-processed Zn-Ni plating manufactured on an electroplating line**

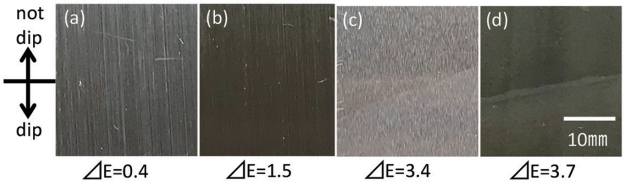


**Fig. 10 Appearance of samples after fingerprint resistance test (a) FeLuce™ Silver, (b) FeLuce™ Black, (c) SUS304, (d) Al (A1050)**

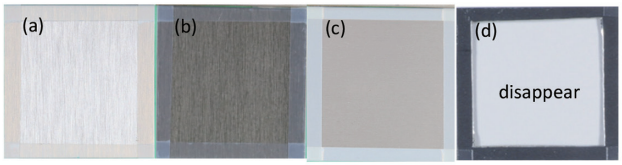


**Fig. 11 Appearance of samples after chemical resistance test (a) FeLuce™ Silver, (b) FeLuce™ Black, (c) SUS304, (d) Al (A1050)**

**Figure 10** shows the results of the evaluation of fingerprint resistance. It was evaluated by immersing the test pieces in a solution of 5 mass% petrolatum at 20°C for 5 s and measuring the color difference ΔE between before and after the immersion. While the ΔE values of the unpainted SUS304 and A1050 were as large as 3.0 or more, the same of either Silver or Black of FeLuce™ was less than 2.0, and were difficult to distinguish with the naked eye.

**Figure 11** shows the results of a chemical resistance test. The specimens were immersed in 1 mass% NaOH solution at 20°C for 24 h and the changes in appearance were observed. While the aluminum sheets dissolved and disappeared, no change was observed

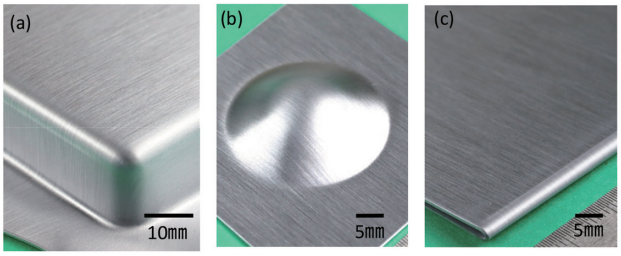


**Fig. 12 Example of processing FeLuce™ Silver**
**(a) Drawing a rectangular shell, (b) Bulging, (c) Hemming**

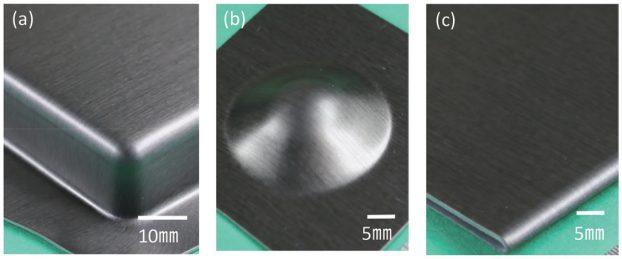


**Fig. 13 Example of processing FeLuce™ Black**
**(a) Drawing a rectangular shell, (b) Bulging, (c) Hemming**

with stainless steel and FeLuce™, which confirmed good chemical resistance of FeLuce™.

**Figures 12** and **13** show the samples of FeLuce™ Silver and Black, respectively, after the forming test; the specimen thickness was 0.6 mm. For the square drawing test (part a), the outer radius of the corners was set at 3.75 mm, and the drawing height at 15 mm. For the bulging test (part b), an Erichsen cupping tester was used to form the sheets to a bulging height of 7 mm. In the hemming bending test (part c), the test pieces were bent 180° to grasp another sheet 1.2 mm in thickness. In the square drawing and bulging tests, the hairline pattern in the formed portions of both the Silver and Black of FeLuce™ remained, although it was somewhat distorted as a result of the influx of the material into the dies and its elongation during the forming work. In addition, no cracks were visually confirmed either at the corners of the drawing work or at the 180° bend of the hemming bending.

As described above, FeLuce™ maintains a good metallic impression and is excellent in fingerprint resistance, chemical resistance and formability.

## 5. Conclusion

The present paper has described how to create a metallic impression, the most important point in the development of FeLuce™ and the method of hairline polishing, and introduced the characteristics of the product. The present studies have clarified that when metal sheets are coated with resin film, it is important for maintaining a metallic feeling to minimize the difference between the impression of the reflection on the bare material surface, which is affected by its shape, and that with resin coating. As for hairline processing, a brush grinder having proven track records of high-speed processing was selected, and an optimum operation condition was established to inscribe fine hairlines in the desired density and uniformity while avoiding exposure of the steel substrate. In addition, the developed product has been confirmed to have excellent fingerprint resistance, chemical resistance and formability.

Two color variations of FeLuce™, Silver and Black, have been launched onto the market, and in addition, an anti-virus version has been developed as a new functional variation. The details of the anti-virus version are reported in another article of this special issue. FeLuce™ is manufactured continuously and efficiently on an EGL that integrates the processes of alloy plating, hairline polishing and resin coating. Thus, FeLuce™ expands the potential in aesthetic design as well as complies with the growing environmental awareness in recent years, and its application is expected to expand in the future.

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**References**

1) Nomura, E., Hirayama, T.: Research on Coatings. 132, 22 (1999)
2) Takiguchi, K., Owa, K.: Nisshin Steel Tech. Rep. 99, 72 (2018)
3) Sakamoto, M., Okuda, H., Futamata, H., Hattori, M.: SIKIZAI (J. Jpn. Soc. Colour Mater.). 67 (10), 632 (1994)
4) Kawaguchi, Y., Takahashi, T., Yamanaga, S.: Research on Coatings. 145, 14 (2006)
5) Tachi, K.: J. Jpn. Soc. Colour Material. 80 (8), 329 (2007)

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