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*Technical Report*

# Proposal of New Functional Prepainted Steel Sheets Utilizing the Color Tone of the Undercoat Film

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**Abstract**

***By providing a functional clear coating film on the surface of a colored layer of the prepainted steel sheet, it is possible to impart the function and, in addition, obtain a design that utilizes the color tone of the undercoat layer. We proposed three types of prepainted steel sheets based on this idea. (1) The oil- and water-repellent type prepainted steel sheet has excellent non-adhesiveness to many substances, and is expected to be applied to applications that simplify maintenance. (2) The retroreflective type prepainted steel sheet has excellent visibility due to light irradiation at night or in dark places, and is suitable for safety measures in dark places. (3) The thermochromic type prepainted steel sheet changes color depending on the temperature and can visually convey the danger caused by high or low temperatures, so it is expected to be applied to usages such as fire doors and warning signs for icy conditions.***

## 1. Introduction

Prepainted steel sheets (PCM) are steel sheets painted at steel mills. When steel sheet customers use prepainted steel sheets, they can omit their painting process, solve the volatile organic compound (VOC) problem, and make effective use of the space previously used for their painting equipment. Given these benefits, prepainted steel sheets are widely used mainly by home appliance and building material manufacturers. Nippon Steel Corporation makes and markets prepainted steel sheets under the trademarks VIEWKOTE™, Tecstar™, and Moonstar™ Color. **Figure 1** shows a typical cross-sectional coating structure of a prepainted steel sheet. Zinc-based coated steel sheets, such as hot-dip galvanized steel sheets (GI) and electrogalvanized steel sheets (EG), are mainly used as substrates. In recent years, Zn-Al-Mg alloy coated steel sheets, as represented by SuperDyma™ (SD), have been widely used from the viewpoint of corrosion resistance. The main purpose of chemical conversion coatings is to improve paint adherence and they are applied before painting. Two layer surface paint films are generally used. The lower primer paint is applied to ensure adhesion to the substrate and corrosion resistance. The top paint is applied to perform surface layer functions such as designability, hardness, formability, and stain resistance. The rear surface paint film is often a single coat of polyester paint. This is because the rear surface is basically hidden when the prepainted steel sheet is used and is not required to have high performance. When the rear surface is required to perform well or have high cut edge corrosion resistance, however, the rear surface is commonly painted in two coats.

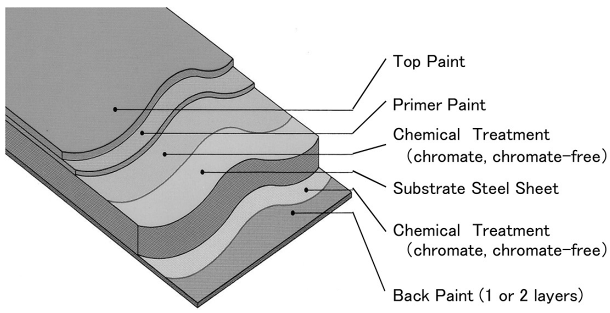


**Fig. 1 Cross section of general prepainted steel sheet**

As mentioned above, prepainted steel sheets have been widely recognized and used for building materials, home appliances, and some automobile parts, among other things. We think, however, that only some of the potential properties of prepainted steel sheets are

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used. Prepainted steel sheets are composite materials consisting of a base metal coating, a chemical conversion coating, and multiple paint coatings. When the number of these combinations is considered, there are many development factors. We believe that new applications will be possible if we move outside of the current general prepainted steel sheet specifications. We presently focus on “top clear” prepainted steel sheets in which a functional clear paint film is provided on the conventional colored paint film. The lower paint film can be seen through the top clear paint film and designs can be made by taking advantage of the color of the lower paint film. If the top clear paint film is provided with a specific function, that function can be demonstrated by using a single top clear paint, regardless of the color of the lower colored paint film. In that case, some ingenuity must be exercised with respect to the painting method on the existing painting line. If we can clarify that point, we can expect cost reduction from reduction in the number of paint types used or expansion of applications from the setup of new functions. In this paper, we propose three types of new functional prepainted steel sheets based on these ideas. None of them have been practically used yet and problems with them still remain. However, this is the first step to expanding the possibilities of prepainted steel sheets.

## 2. Oil and Water Repellent Prepainted Steel Sheets

### 2.1 Development aims

Many products made of prepainted steel sheets are available on the market. When they are used for an extended period, various stains adhere to their painted surfaces. The stained painted surfaces must then be cleaned for maintenance. The type of stain varies with the environment in which the product is used. Stain types include oil-based ink, water-based ink, oil, dust, food, and rainwater. Some stains cannot be removed by wiping with a solvent. If we can supply prepainted steel sheets whose stains can be removed simply by dry wiping, they can be applied to a variety of products and can contribute to the simplification of daily maintenance. We devised a new prepainted steel sheet that has an oil and water repellent paint film applied on a conventional prepainted steel sheet. As mentioned in Chapter 1, a clear oil and water repellent top paint film allows the color of the lower paint film to be exploited. Thus, the same oil and water repellent paint can be applied to all colored paints. When functions are separated and assigned to the topmost clear paint film, the cost can be reduced by optimizing the total paint film thickness and the performance balance can be adjusted, among other benefits.

### 2.2 Paint film composition

**Figure 2** shows the composition of our oil and water repellent prepainted steel sheet. **Table 1** shows the coating compositions of the samples manufactured on Nippon Steel’s Kimitsu color coating line (CCL) (Kimitsu Area of East Nippon Works).

### 2.3 Performance properties

#### 2.3.1 Oil-based ink wipeability

Each sample was marked on the coated surface with red and black oil-based inks (MAGIC INK™), left for 24 h, and wiped with a dry gauze. The results are shown in **Table 2**. **Figure 3** shows the photos of the markings on sample 2 before and after gauze wiping. **Figure 4** shows the photos of the markings on samples 3 and 5.

All the samples of the oil and water repellent prepainted steel sheets repelled the oil-based inks into small droplets and did not allow lines to be drawn, regardless of the color of the colored lower paint film and the thickness of the top clear paint film. The inks could be easily wiped off with a dry gauze and left no traces. In contrast, the oil-based inks could not be removed at all by dry wiping from the control prepainted steel sheet samples (samples 4 and 5).

#### 2.3.2 Food stain resistance

Samples 2 and 4 (both painted white) were investigated for food stain resistance.

Test method: Soy sauce, Japanese brown sauce, mustard, and ketchup were applied to the painted surface of each sample. The samples were heated in an oven at 80°C for 24 h, cooled to room temperature, and wiped off with benzine. The samples were then vi-

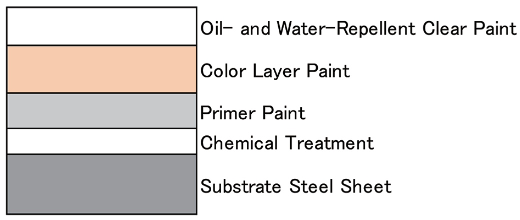


**Fig. 2 Cross section of oil- and water-repellent type prepainted steel sheet**

**Table 1 Samples**

| Sample No. | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Cross sectional structure of paint | Top clear paint | Water and oil repellent 3 $\mu$m | Water and oil repellent 1 $\mu$m | Water and oil repellent 1 $\mu$m | – | – |
| | Color layer paint | General white 16 $\mu$m | General white 16 $\mu$m | General metallic 16 $\mu$m | General white 16 $\mu$m | General metallic 16 $\mu$m |
| | Primer paint | General 5 $\mu$m | General 5 $\mu$m | General 5 $\mu$m | General 5 $\mu$m | General 5 $\mu$m |
| Substrate | | GI | GI | GI | GI | GI |

**Table 2 Oil-based ink repelling and wiping performances**

| Sample No. | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Red | Repelling | Repelling | Repelling | Repelling | No repelling | No repelling |
| | Dry wiping | No trace | No trace | No trace | Trace | Trace |
| Black | Repelling | Repelling | Repelling | Repelling | No repelling | No repelling |
| | Dry wiping | No trace | No trace | No trace | Trace | Trace |

sually evaluated for the stain traces of each food.

The photos of the results are shown in **Fig. 5**. On samples 4 of conventional prepainted steel sheets, the food adhered by heating and could not be removed. The oil and water repellent samples 2 show some traces of sauce and ketchup but are confirmed to have satisfactory food stain resistance.

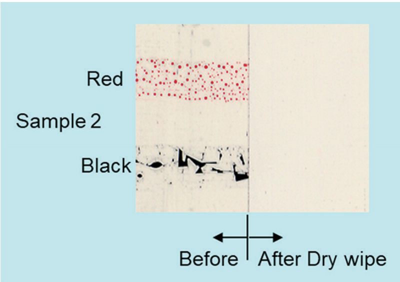


**Fig. 3　Oil-based ink repelling and wiping performances**

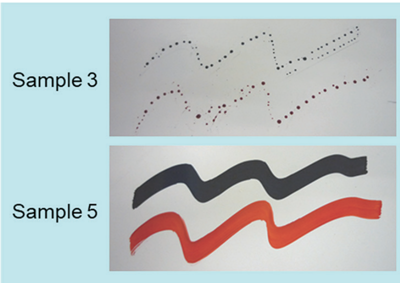


**Fig. 4　Oil-based ink repelling performance**

### 2.3.3 General properties

Samples 2 (white), samples 3 (metallic color), and samples 4 (control) were investigated for the properties generally required of prepainted steel sheets. The results are shown in **Table 3** and indicate the following:

- The white and metallic color oil and water repellent samples 2 and 3 both show results more than equivalent to those of control samples 4 in the pencil hardness test, crosscut adhesion test, Erichsen cupping test (5 mm), DuPont impact test, and T-bend test. They are considered to have as-formed adhesion high enough for application to general home appliances.
- The chemical resistance (acid resistance and alkali resistance), solvent resistance, and corrosion resistance of samples 2 and 3 are as good as those of control samples 4.

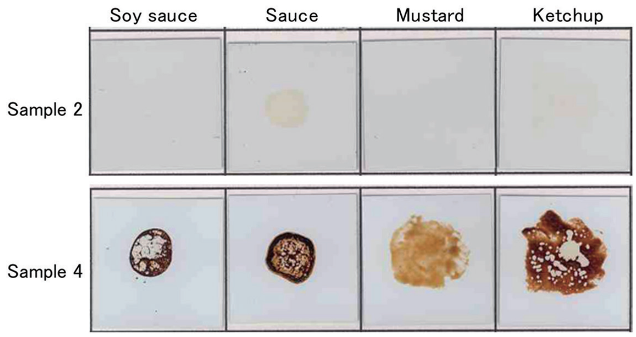


**Fig. 5　Food adherence resistance properties**

**Table 3　Basic properties of samples**

| Sample No. (Type of PCM) | | 2 White (Water and oil repellent) | 3 Metallic (Water and oil repellent) | 4 White (General) |
|---|---|---|---|---|
| Pencil hardness 500 gf | | H | H | H |
| Cross cut & peeling | | 100/100 | 100/100 | 100/100 |
| Erichsen 5 mm & peeling | | No crack<br>No peeling | No crack<br>No peeling | No crack<br>No peeling |
| Dupont impact & peeling<br>1/2 in., 500 g, 30 cm | | No crack<br>No peeling | No crack<br>No peeling | No crack<br>No peeling |
| T-bend & peeling | 0T | A few cracks<br>No peeling | No crack<br>No peeling | No crack<br>No peeling |
| | 2T | No crack<br>No peeling | No crack<br>No peeling | No crack<br>No peeling |
| Acid resistance<br>3%$H_2SO_4$ 20°C 24 h dip | | No blister | No blister | No blister |
| Alkali resistance<br>3%NaOH 20°C 24 h dip | | No blister | No blister | No blister |
| Solvent resistance<br>Ethanol 20°C 24 h dip | | No change | No change | No change |
| Solvent resistance<br>Petroleum benzine 20°C 24 h dip | | No change | No change | No change |
| SST 500 h<br>Max. blister from X-scratch | | <2 mm | <2 mm | <5 mm |
| SWOM 120 h<br>$\Delta E$ / Gloss-retention | | <1.5 / 95–105% | <1.0 / 95–105% | <1.5 / 95–105% |

**Table 4 Sustainability of oil-based ink repelling and wiping performances**

| Acceleration | Sample 2 (White) | | Sample 3 (Metallic) | |
|---|---|---|---|---|
| | Repelling | Dry wiping | Repelling | Dry wiping |
| JASO-CCT 40cyc. | Excellent | No trace | Excellent | No trace |
| SST 240 h | Excellent | No trace | Excellent | No trace |
| SST 500 h | Excellent | No trace | N.D. | N.D. |
| HCT 50˚C90%RH 360 h | Excellent | No trace | N.D. | N.D. |
| Hot water boiling 2 h | Excellent | No trace | Excellent | No trace |
| Germicidal lamp 20 cm 6 h | Fair | No trace | Good | No trace |
| SWOM 500 h | Fair–Poor | No trace | N.D. | N.D. |
| 5%NaOH 8 h | Excellent | No trace | N.D. | N.D. |
| 5%$H_2SO_4$ 24 h | Fair | No trace | N.D. | N.D. |
| Toluene dip 1 h | Good | No trace | Fair | No trace |

Rating of repelling: Excellent > Good > Fair > Poor, N.D.: No data

- In the accelerated weatherability test with a Sunshine Weather-O-Meter (SWOM), samples 2 and 3 show no change in color and no decrease in the gloss value. They have good weatherability and are considered applicable outdoors.

### 2.4 Sustainability of oil and water repellency

To check whether the oil and water repellent prepainted steel sheets can maintain their properties when used under various conditions, we inspected them for oil-based ink wipeability after various accelerated tests. The results are shown in **Table 4**. There were cases where the repellency was reduced by ultraviolet rays and chemicals. This is probably because the paint film surface was slightly damaged by ultraviolet rays and chemicals and increased in roughness. However, the wipeability did not deteriorate. We think that the damage to the clear paint film was limited to the surface paint film and a sufficient amount of the clear film itself remained. This result indicates that our oil and water repellent prepainted steel sheets can maintain their oil and water repellency in various accelerated environments.

### 2.5 Assumed applications

We think that our oil and water repellent prepainted steel sheets will be applied to general home appliances. They may also be used in range hoods and microwave oven cooking chambers susceptible to edible oil stains, as well as in steel office furniture and partitions. Because the oil and water repellent paint film has excellent non-adhesiveness to adhesives and binders, the oil and water repellent prepainted steel sheets may be effectively used to prevent posters and graffiti on the walls of underbridges and public facilities.

## 3. Retroreflective Prepainted Steel Sheets

### 3.1 Development aims

Retroreflection refers to a phenomenon that when light illuminates an object in any incident direction, the reflected light inverts 360 degrees from the incident direction and returns to the light source. Products produced by applying this property are excellent in visibility from all directions when illuminated by spotlights at night and are widely used in various articles such as road signs, barricades, pavement markers, and retroreflective safety strips of vehicles and apparel. **Figure 6** shows an example of retroreflective safety strips on work clothing. By providing retroreflective prepainted steel sheets, we expect our products to be used mainly for safety measures at night and in dark places.

**Fig. 6 Example of use of retroreflection sheet**

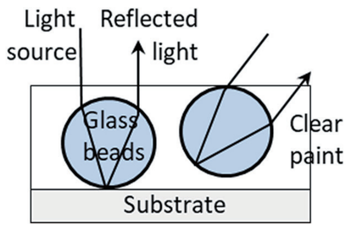


**Fig. 7 Concept of retroreflection light PCM**

The application of a glass-beaded paint is one method of exhibiting retroreflectivity. The method is schematically illustrated in **Fig. 7**. The light incident on the glass beads is reflected on the rear surface of the beads and returned in the direction of the light source. We considered applying this method to our prepainted steel sheets. However, it is difficult to apply a paint containing large glass beads (about 60 $\mu$m in diameter) with roll coaters generally used on prepainted steel sheet production lines. This is because the glass beads cannot pass through the gap between the roll and the steel sheet when the glass-beaded paint is applied and are consequently rejected. If the curtain flow coater on Nippon Steel's Kimitsu CCL is used, the steel sheet can be coated with a glass-beaded paint without rejecting the glass beads because the curtain flow coater paints the steel sheet in a non-contact way. If the lower paint film of the prepainted steel sheet is colored to form an effective paint film composition as described later, the reflection efficiency and color of the retroreflected light can be expected to improve.

### 3.2 Coating composition

#### 3.2.1 Preparation of samples

Samples A, B, C, and D with cross-sectional structures as shown in **Fig. 8** were prepared in a laboratory. **Table 5** shows the base sheets used and the paint of each paint film. First, a white primer was applied with a bar coater to the chemical conversion-coated base sheet to a dry film thickness of 5 $\mu$m and dried at a peak metal temperature (PMT) of 215°C (common to all samples). A metallic color paint as a retroreflective paint film was applied with a blade to the primer to a dry film thickness of 10 $\mu$m. Samples A and C were dried at a PMT of 230°C. Next, a glass-beaded clear paint was applied with a blade to the dried metallic color paint for samples C and to the wet metallic color paint for samples B and D, respectively, to the desired dry film thickness and were dried at a PMT of 230°C. Figure 8 shows the results of the samples together with the coverage (a percent area of the glass beads to the painted area as measured with a microscope from the paint film surface).

#### 3.2.2 Check of retroreflectivity

To compare the retroreflectivity of the samples, the results of the samples strobe photographed in a dark place are also shown in Fig. 8. Samples B and D have the lower reflective paint film (metallic color paint) and the upper clear paint film (containing glass beads) applied in a wet condition and dried at the same time. The retroreflected light intensity with respect to the bead coverage is relatively high. The bead coverage of sample B is lower than that of sample C, but the retroreflected light intensity of sample B is higher than that of sample C. We think that the glass beads are embedded in the lower reflective paint film and efficiently retroreflect even the light incident from oblique directions. In the case of sample C, on the other hand, because the upper and lower paint films are sequentially applied and dried, the glass beads are not embedded in the lower reflective paint film and a clear film is formed between the bottom of the glass beads and the lower retroreflective paint film. When the incident light enters particularly from an oblique direction, the intensity of the reflected light is reduced. The above results show that when the upper glass-beaded paint and the lower retroreflective paint are applied in a wet condition with the curtain flow coater at the same time, the glass beads in the upper paint film are partially embedded in the lower retroreflective paint film. We expected the resultant paint film structure to improve the intensity of the retroreflected light.

**Table 5 Used substrate and paints for PCM samples**

| | |
|---|---|
| Substrate | 0.5 mm GI with chromate-free chemical treatment |
| Primer layer | White primer paint (polyester/melamine type) (contains white pigment & Chromate-free rust preventive pigment) |
| Reflect color layer | Metallic paint (polyester/melamine type) |
| Top layer | Clear paint (polyester/melamine type) (contains 60 $\mu$m glass beads) |

#### 3.2.3 Appearance of paints applied with curtain flow coater

Of the paints shown in Table 5, we changed the metallic color paint of the colored paint film to a white paint and conducted a painting experiment using the curtain flow coater. The lower colored paint film (white paint) and upper clear paint film (clear glass-beaded paint) were applied wet on wet in various thicknesses and dried at a PMT of 230°C in a hot air oven. The obtained prepainted steel sheet samples appeared strikingly white because the lower paint film was white. It was shown also here that we can present designs by making the best use of the color of the lower paint film. This is an

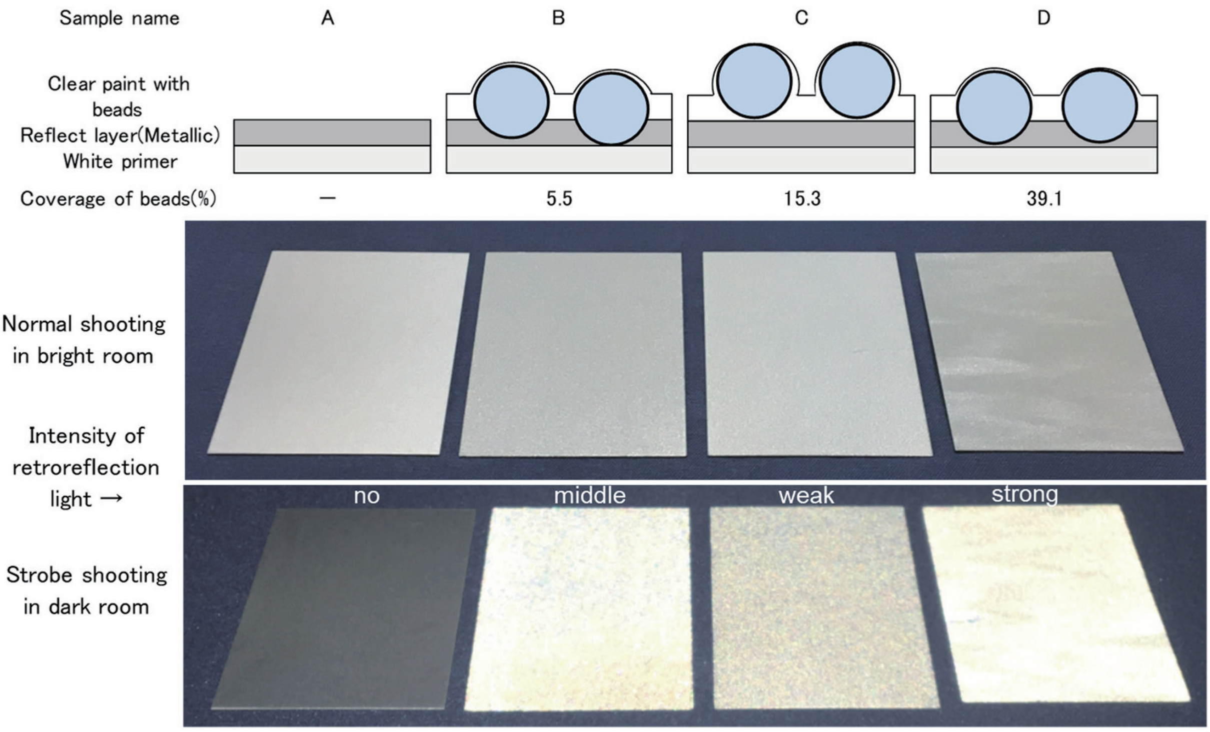


**Fig. 8 Cross section of samples and their intensity of retroreflection light**

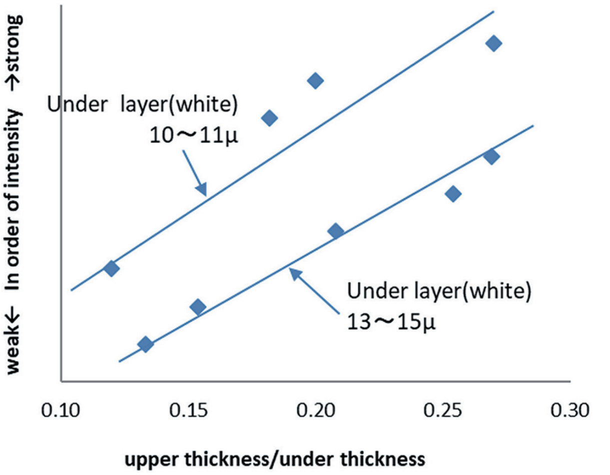

**Fig. 9 Change of intensity of retroreflection by under layer thickness**

advantage of the top clear type prepainted steel sheet.

The samples were visually ordered according to the intensity (brightness) of the retroreflected light. **Figure 9** shows the relationship between the retroreflected light intensity and the upper/lower paint film thickness ratio. These results indicate the following:

(1) The upper and lower paint films are generally grouped along two approximate lines. The thinner lower paint films lie on the upper line and the thicker lower paint films lie on the lower line. The thicker the lower paint film thickness, the lower the retroreflected light intensity tends to be. It is thought that when the lower white paint film is thick, the glass beads are embedded deeper than required in the lower white paint, resulting in lower retroreflected light intensity.

(2) Each approximate line shows that the retroreflected light intensity tends to decrease as the upper/lower paint film thickness ratio decreases. This is a natural result because the upper paint film thickness is proportional to the coverage of the glass beads.

The above results indicate that the retroreflected light intensity can be effectively increased by increasing the coverage of the glass beads through the appropriate control of the glass bead content and the top clear paint film thickness. When the color of the lower colored film does not allow the transmission of light as is the case with the white color in this experimental study, the maximum lower paint film thickness must be carefully controlled so that the glass beads are not excessively embedded in the lower paint film.

### 3.3 Formability

The retroreflective prepainted steel sheets have large glass beads protruding from the paint film surface. Their forming is thus feared to dislodge the glass beads. Using the samples prepared as described in Section 3.2 (the samples with the highest retroreflected light intensity in Fig. 9), we conducted the 0T bend test and 90-degree bend test (inside radius r = 0 mm) with the painted surface on the outside. The results are shown in **Table 6**. In both the 0T and 90-degree bend tests, there were no cracks or glass bead desorption in the paint film on the formed regions. The beads did not dislodge even when the adhesive tape was applied and then peeled off. When the samples were bent 90 degrees on a tool press, however, bead dislodgement was observed in the paint film of the flat region that was rubbed against the tool. When the samples were formed with a protective

**Table 6 Formability of retroreflection light PCM (substrate GI)**

| Test | | Guard film | Result | |
|---|---|---|---|---|
| 0T-bend | | Without | Visual | No crack |
| | | | After tape peeling | No film peeling<br>No beads desorption |
| V-bend (90°) inner r=0mm | Outer R part | Without | Visual | No crack |
| | | | After tape peeling | No film peeling<br>No beads desorption |
| | Mold rubbing flat part | | Visual | Some beads desorption |
| | | | After tape peeling | No film peeling<br>More beads desorption |
| | Outer R part | With | Visual | No crack |
| | | | After tape peeling | No film peeling<br>No beads desorption |
| | Mold rubbing flat part | | Visual | No beads desorption |
| | | | After tape peeling | No film peeling<br>No beads desorption |

film attached to the surface of the retroreflective paint film, the glass beads did not dislodge from the affected region.

### 3.4 Assumed applications

We expect that our retroreflective prepainted steel sheets will be used for ensuring visibility at night or in the dark. For example, they may be used as utility pole wrapping steel sheets and guardrails.

## 4. Thermochromic Prepainted Steel Sheets

### 4.1 Development aims

In recent years, erasable ballpoint pens have been developed and commercialized by stationery manufacturers. Erasable ink is made from a thermochromic dye that becomes transparent at high temperatures and develops color at low temperatures. **Figure 10** shows the chemical formula of a leuco dye that is a typical thermochromic dye. The molecular structure of the leuco dye changes with the use of a color developer that changes the surrounding $H^+$ concentration as the temperature rises and falls. As a result, the leuco dye becomes colored or colorless.

We conceived a thermochromic prepainted steel sheet that would change in color with temperature when a thermochromic dye was used as a colorant for the top paint film. Strictly speaking, this thermochromic prepainted steel sheet cannot be said to be a "top clear type", but the top paint film becomes colorless and transparent depending on the temperature and makes the color of the lower paint film visible. It can thus be called a "top clear type" in a broad sense of the term. It is also interesting to note that the color changing function itself utilizes the color of the lower paint film. Because this prepainted steel sheet allows people to visualize the temperature, it may be used in places where caution must be raised regarding, for example, prevention of burns or freezing of roads. The application of the thermochromic dye to the paint film involved a problem of the elution of the thermochromic dye in water. To solve the problem, we used a microencapsulated thermochromic pigment as a thermochromic dye (**Fig. 11**).

### 4.2 Preparation of samples

#### 4.2.1 Preparation of thermochromic paint

A thermochromic paint was prepared by dispersing the thermochromic dye in the clear polyester/melamine paint used on prepainted steel sheets for home appliances. Microcapsules containing the thermochromic dye in their cores as shown in Fig. 11 were used for the thermochromic die. The average diameter of the microcapsules was 5 $\mu$m. The clear paint, thermochromic pigment, and glass beads were mixed and dispersed in a paint shaker for 30 min. The glass beads were filtered out to produce the thermochromic paint. The details of the top paint film are shown in **Table 7**.

### 4.2.2 Preparation of thermochromic prepainted steel sheets

An electrogalvanized steel sheet (EG) with a thickness of 0.8 mm was chemical conversion coated on the top and back surfaces. A blue-colored primer paint was applied to the surface of the steel sheet to a dry film thickness of 5 $\mu$m and dried at a PMT of 215°C. Then, the thermochromic paint was applied to the surface to a dry film thickness of 15 $\mu$m and dried at a PMT of 230°C. A clear paint was applied to the thermochromic paint film to a dry film thickness of 5 $\mu$m and dried at a PMT of 230°C. The topmost clear paint film was covered to prevent handling scratches. **Figure 12** shows the cross section of the prepared sample.

## 4.3 Properties

### 4.3.1 Durability against repeated color change

To investigate the durability of the thermochromic function, the atmospheric temperature was cyclically changed using a programmable thermostatic bath. The temperature was raised from 30°C to 60°C at a rate of 1.5°C/min and lowered from 60°C to 30°C at a rate of 3°C/min. This temperature rise and fall was set as one cycle and repeated 10 000 cycles. The samples were removed initially and every 2 500 cycles thereafter and were investigated for the relationship between the temperature and the color. The samples were then placed on a hot plate and their color was measured when their temperature reached 20, 30, 40, 42, 45, 47, 50, and 60°C, respectively. The temperature of the samples was measured with a thermocouple welded to the samples. The $L^*$, $a^*$, and $b^*$ values of the color were measured with a Konica Minolta CR400 color difference meter.

The results are shown now. We confirmed that the thermochromic paint film changed from red at room temperature to blue as the temperature increased. The relationship between the sample temperature and the color is shown for the $L^*$ value in **Fig. 13**, for the $a^*$ value in **Fig. 14**, and for the $b^*$ value in **Fig. 15**, respectively. We

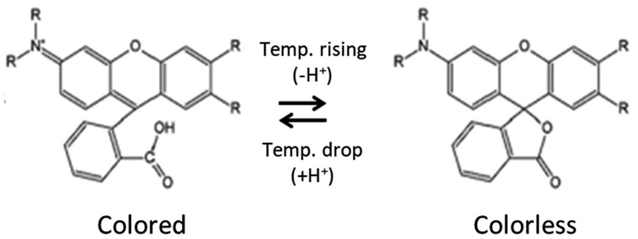


**Fig. 10 Molecular structures of thermochromic dye (Leuco dye)**

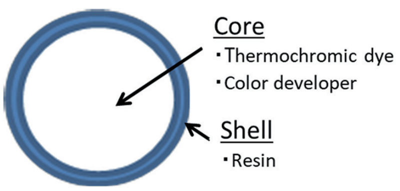


**Fig. 11 Structure of investigated thermochromic pigment**

**Table 7 Investigated thermochromic paint film**

| Resin | Thermochromic pigment | |
|---|---|---|
| | Color | Concentration [mass%] |
| Polyester/Melamine | Red | 30 |

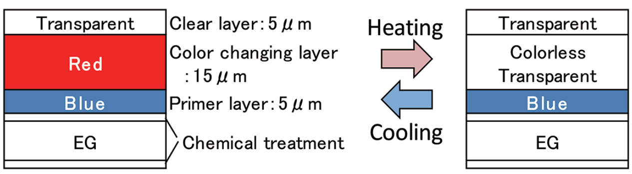


**Fig. 12 Cross section of sample**

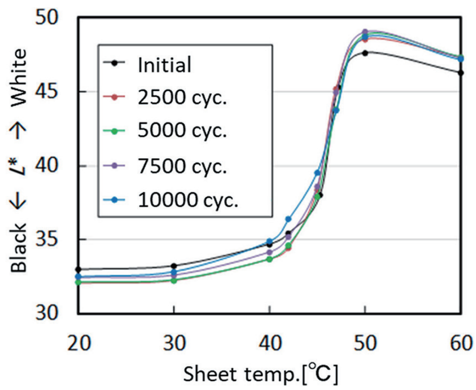


**Fig. 13 Relationship between sheet temperature and $L^*$ value**

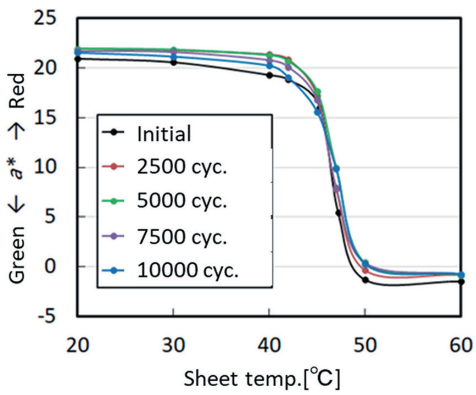


**Fig. 14 Relationship between sheet temperature and $a^*$ value**

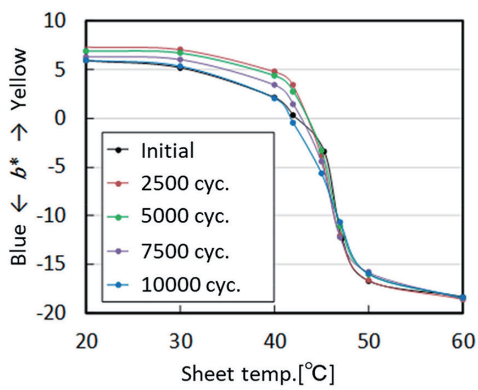


**Fig. 15 Relationship between sheet temperature and $b^*$ value**

confirmed that the $L^*$, $a^*$, and $b^*$ values change as the sample temperature changes. In other words, the samples have the thermochromic function. We also found that the samples retained the thermochromic function after 10000 cycles of color change. If one cycle is taken as one day, 10000 cycles are equivalent to about 27 years.

#### 4.3.2 Weatherability

We tested the samples for weatherability as described below and investigated the appearance and color difference ($\Delta E^*$) of the samples before and after the test. We also investigated the relationship between the temperature and the color as described above. The $\Delta E^*$ was calculated from the color difference ($\Delta L^*$ value, $\Delta a^*$ value, and $\Delta b^*$ value) before and after the test by the following equation:

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{0.5}$$

(1) Germicidal lamp test: The samples were irradiated with a fluorescent lamp with a wavelength of 253.7 nm at 20 cm. The test time was 240 h.

(2) Outdoor exposure test: The samples were outdoor exposure tested in Futtsu City, Chiba Prefecture. The test periods were 30 d and 60 d.

The results are shown here. **Table 8** shows the color difference ($\Delta E^*$) of the samples after each test. **Figure 16** shows the appearance of the samples after each test. The $\Delta E^*$ after 240 hours of germicidal lamp irradiation was 0.9 and did not change visibly. In the outdoor exposure test, the $\Delta E^*$ was 18.0 at 30 d and 22.8 at 60 d. Color changes were visible. The samples after the germicidal lamp test retained the thermochromic function as shown in Figs. 13 to 15. Although the data are omitted here, the samples after 60 d of the outdoor exposure test did not show the thermochromic function. We think that the thermochromic function was lost in the outdoor exposure test because the thermochromic dye in the microcapsules was decomposed in the weatherability test.

**Table 8 Color differences after weather resistance tests ($\Delta E^*$)**

| Weather resistance test | $\Delta E^*$ |
|---|---|
| Germicidal lamp 240 h | 0.9 |
| Outdoor exposure 30 d | 18.0 |
| Outdoor exposure 60 d | 22.8 |

#### 4.3.3 Other properties

We investigated the paint film hardness, as-formed adhesion, and corrosion resistance of the thermochromic prepainted steel sheets. Prepainted steel sheets for audio equipment housings were used as control materials.

**Table 9** shows the test methods and the performance evaluation results of the test samples. We confirmed that the thermochromic prepainted steel sheets we developed have the same properties as the control materials.

### 4.4 Summary

The results we obtained are summarized below.

(1) The thermochromic function was maintained even after 10000 cycles of the cyclic color change test.

(2) In the germicidal lamp test (240 h), the $\Delta E^*$ was relatively small at 0.9 and the color change was not visible. In addition, the thermochromic function was maintained.

(3) The $\Delta E^*$ was large at 23 after 60 d of the outdoor exposure test. Color change was visually confirmed. The thermochromic function disappeared. It is considered that the thermochromic dye in the microcapsules was decomposed by sunlight.

(4) The paint film hardness, as-formed adhesion, and corrosion resistance of the thermochromic prepainted steel sheets were equivalent to those of the prepainted steel sheets for audio equipment housings.

### 4.5 Assumed applications

We think that our thermochromic prepainted steel sheets may have problems with outdoor applications but are fully satisfactory for indoor use. Their color change temperature range can be controlled by selecting proper thermochromic dyes. They may be used in heating equipment such as cooking utensils and heating experiment apparatus to warn against burns by utilizing their ability to change color at elevated temperatures or may be used in fire doors to visually inform of a fire on the other side of the door. The thermochromic prepainted steel sheets may be designed to change their color below the freezing point and may be used in road tunnels to allow vehicle drivers to see that the road is frozen.

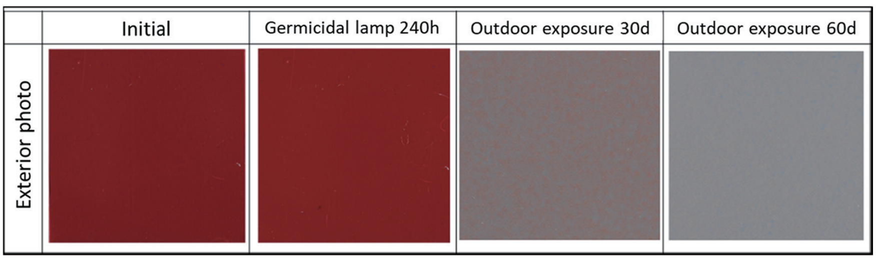


**Fig. 16 Exterior photos after weather resistance tests**

**Table 9 Performance test results**

| Property | Test | | Thermochromic PCM | Audio equipment PCM |
|---|---|---|---|---|
| Paint film hardness | Pencil hardness 1kgf | | F | F |
| Paint adhesion | 0T-bend and tape peeling | | No peeling | No peeling |
| Corrosion resistance | SST 72 h | Plane part | Good | Good |
| | | Formed part (Erichsen 7 mm) | Good | Good |

## 5. Conclusions

In this paper, we proposed three types of prepainted steel sheets in which a new functional clear paint was applied to the conventional colored paint film to exceed the specifications of conventional prepainted steel sheets and open new applications. We may have to improve our new prepainted steel sheets by considering their actual usage environments. We hope that the opinions and suggestions of our readers will help us to improve our products.


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