

Development of Prepainted Steel Sheet with High Formability and Outdoor Stain Resistance

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Abstract

Chromate free type “VIEWKOTE™ (VK)” is used for the outdoor panels of various outdoor electric appliances, for example, air conditioner outdoor units, and recently larger outdoor panels of heat pump water heater. Especially, since stain of rain was conspicuous in larger outdoor panels, self cleaning type “VIEWKOTE™”, which is superior to conventional VK in stain resistance because the stain is washed by rain, has been newly developed. It turned out that this product has the excellent outdoor stain resistance and formability, then it is suitable for various formed products.

1. Introduction

A prepainted steel sheet is a steel sheet painted in advance. Users can eliminate the painting process by using this sheet and can enjoy the merit of eliminating painting equipment; thus, it is widely used, particularly for building materials and household electrical appliances. Also in the use of steel sheets for outdoor applications, although a shift from conventional post-painting system to prepainted steel sheet system has been observed, chromate treatment and rust-preventing pigments were used widely for prepainted steel sheets from the viewpoint of corrosion resistance. However, since a law was enacted in Europe restricting the use of environmentally hazardous substances like RoHS, in Japan also, exclusion of environmentally hazardous substances has been promoted, particularly in the field of production of household electrical appliances. At much earlier time in this regard, Nippon Steel and Sumitomo Metal Corporation has commercialized “chromate-free type” prepainted steel sheet (hereinafter referred to as “conventional VK”) which is environmentally friendly and usable for outdoor applications.¹⁾ This prepainted steel sheet is not only environmentally friendly, but also equipped with corrosion resistance equal to or above that of the conventional chromate prepainted steel sheet. Further, it is highly excellent in formability, therefore, currently it is used in large quantity for outer panels of cabinets of outdoor units of air-conditioners.

On the other hand, in many cases, the stain adhering to the outer panels of cabinets installed outdoors becomes conspicuous as more stain comes to adhere to and becomes gradually streaked by rain. Particularly in recent years, application to large outdoor cabinets of heat pump water heaters and cogeneration systems of household use

is increasing. Since they are becoming larger in size and have broader panels, the stain on them becomes more conspicuous, and as such outdoor cabinets are installed facing streets and easily sighted, the need for improving stain resistance has increased. Then, “Self-cleaning type” prepainted steel sheet (hereinafter referred to as “SC-VK”), a steel sheet that evolves stain resistance higher than that of conventional VK by washing away the stain with rain, was developed and has been put into the market. Various types of SC-VK with varied hardness–formability balance have been commercialized. In this report, the characteristics and the results of evaluation of the performance of one of such type having the most excellent formability are stated.

2. Compositions of SC-VK

As Fig. 1 shows, SC-VK consists of the following: a chromate-free substrate treatment material on steel sheet to secure adhesion of coating film to the steel sheet, a chromate-free primer to secure corrosion resistance, and a top coating film to provide self-cleaning function (SC coating film). Wide variation of colors ranging from conventional colors to the colors with high-quality-feeling metallic outlooks and patterns is made available to SC-VK. Its ability to maintain such an

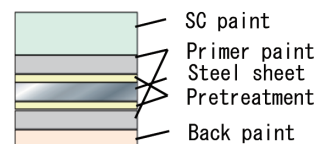


Fig. 1 Structure of SC-VK

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exterior to always appear clean can be considered as one of its merits.

3. Stain Resistance Technology of SC-VK and its Mechanism

Stain is less capable to adhere to the SC layer of SC-VK and it can be easily removed. Furthermore, the layer is designed to help penetration of water into the interface between the stain and the coating film. SC layer is explained as follows. The main compositions of the coating film of SC layer are the following: main resin, curing agent, and organosilicate. In the state of liquid paint, these compositions are uniformly dispersed. However, when solvent is evaporated during the drying process after painting, organosilicate is concentrated on the coating film surface layer due to the compatibilities of the main resin and the organosilicate and surface tension leading to the formation of a tight film made of organosilicate combined with organosilicate, the main resin, and cross linking agent afterwards. By controlling the concentration of the main resin and the organosilicate on the surface layer due to their compatibilities, free surface energy of the coating film surface layer can be controlled.

By measuring the angle of contact θ between one of the various solutions of which free surface energy γ_L (dispersion force γ_L^d , dipole-dipole force γ_L^p , and hydrogen bonding force γ_L^h) is known and SC-VK or conventional VK, and further by using the Young–Dupre’s equation and the extended Fowkes equation [Equation (1)], free surface energy γ_s (dispersion force γ_s^d , dipole-dipole force γ_s^p , and hydrogen bonding force γ_s^h) of SC-VK and conventional VK was calculated. Based on these results, adhesion work of SC-VK and VK for water and stain (carbon) was calculated. **Figure 2** shows the result of the calculation.

$$\gamma_L (1 + \cos \theta) = 2\sqrt{\gamma_s^d \gamma_L^d} + 2\sqrt{\gamma_s^p \gamma_L^p} + 2\sqrt{\gamma_s^h \gamma_L^h} \quad (1)$$

As opposed to the conventional VK having larger adhesion work for stain, SC-VK has larger adhesion work for water, and it is found that it has larger affinity for water rather than for stain. With this, SC-VK, different from the conventional VK, has the ability to wash stain away when it is hit by rain (**Fig. 3**).

4. Experiment

4.1 Samples catered

Specifications of the steel sheets catered for experiment are shown in **Table 1**. The developed SC-VK and the conventional VK were utilized. After applying chromate-free pretreatment and chromate-free primer coating (film thickness of 5 μm) to both sides of a galvanized

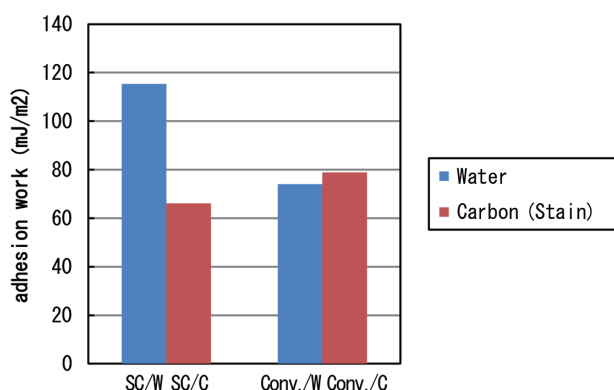


Fig. 2 Adhesion work of SC-VK

SC/W: Adhesion work between SC-VK and water

SC/C: Adhesion work between SC-VK and carbon

Conv./W: Adhesion work between conventional-VK and water

Conv./C: Adhesion work between conventional-VK and carbon

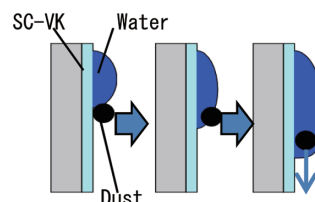


Fig. 3 Mechanism of SC-VK

Table 1 Test samples

	Coating		
	Chemical treatment	Primer	Top
Conventional-VK	Chromate-free	Chromate-free	Conventional
SC-VK	Chromate-free	Chromate-free	SC

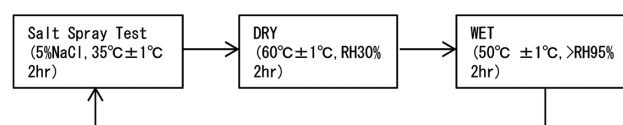


Fig. 4 Conditions for corrosion test

steel sheet (substrate steel sheet material of SGCD2, Z08), a top coating film of ivory color (film thickness 20 μm) was applied to the front side and a coating film of back paint (film thickness of 5 μm) was applied to the backside.

4.2 Content of experiment

4.2.1 Corrosion test

Test samples of the above materials having an up burr on its one cut edge and a down burr on another cut edge and having scribed cut were prepared. These samples were catered for the combined cyclic corrosion test (JASO M609) with 60 cycles (**Fig. 4**) and the width of the largest creep at each place was evaluated. As for the edges with upward and downward burrs, the mean value was taken.

4.2.2 Exposure corrosion test

Samples with edges having an upward burr and a downward burr and scribed cut that underwent OT bending test (a 180°T folding test conducted according to the test procedure of JIS G 3312 at an ambient temperature of 20°C) were exposed outdoors for 12 months for testing in an outdoor exposure test site in a coastal area in Okinawa prefecture (exposure in Okinawa).

4.2.3 Stain resistance for carbon black

10% suspension of a carbon black was dripped onto the entire surface of a prepainted steel sheet sample and the sample was dried at 80°C for one hour, and then the surface was washed with flowing water. Since in this test, the coating film is softened when drying at 80°C, the test condition is strict in which the carbon adheres more easily to the coating film. Moreover, carbon black is the most general staining material.

4.2.4 Exposure test

The samples were processed to the shape as shown in **Fig. 5** and an exposure test for 12 months was conducted in the outdoor exposure test site in a coastal area in Futtsu City in Chiba prefecture (exposure in a Chiba industrial area). The difference of color in the area shown in **Fig. 5** between the ones before and after the test (ΔL) was measured and the stain resistance was evaluated. In addition, samples were in as-tested state and no cleaning like washing with water had ever been made.

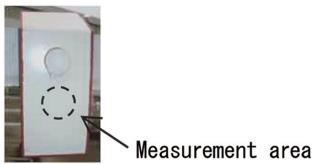


Fig. 5 Sample of exposure test

4.2.5 Weather resistance test

Prepainted steel sheet samples were tested for 500 hours using an open flame carbon arc weathering instrument (SWOM). The evaluation was made based on the change in color tone (ΔE) and the 60° gloss retention ratio of the coating film between the ones before and after the test.

4.2.6 Folding processing test

A 180°T folding processing test was conducted with the test procedure according to JIS G 3312. For the test, 1T bending test was conducted at an ambient temperature of 20°C wherein a 180° bending was applied with a steel sheet of the same thickness with that of the prepainted steel sheet sample to be evaluated being inserted in between. After the test, the state of damage of the coating film on the top of the tested piece was examined with an optical microscope for existence of cracks.

4.2.7 Deep drawing forming test

A cylinder forming test was conducted using a deep drawing test machine, and after the forming test, the state of damage of the coating film in the drawing-formed area was observed. The drawing ratio of the forming test was set to be 2.0 with the radius of curvature of the shoulder portion of the punch and the die of 5 mm, and the blanking force was set at one ton.

5. Results of Experiments

5.1 Corrosion resistance of SC-VK

Figure 6 shows the result of the JASO 60-cycle corrosion test. The result of the test of SC-VK expressed in terms of width of the creep at the scribed cut area and cut edge the sections was almost same with that of VK. Also, the appearances of the test samples that underwent the 12 months exposure test in Okinawa are shown in Fig. 7. In any of the area of scribed cut, cut edge sections, and T-bent area, SC-VK did not exhibit any signs of development of creep in the same manner as the conventional VK. Generation of blister was not observed in the area where the coating film was damaged by the work like T-bending. These observations suggest that with the result of accelerated test and the outdoor exposure, SC-VK has corrosion resistance equal to that of the conventional VK which already has been applied to the exterior panels of outdoor units of air-conditioners.

5.2 Stain resistance of SC-VK

Figure 8 shows the result of the test of stain resistance for carbon black. As for the conventional VK, carbon that adhered to the coating film could not be washed away with flowing water; however, the carbon adhered to the paint film tightly and continued to adhere to the coating film in spite of rubbing. On the other hand, the stain that adhered to SC-VK coating film could be easily washed away with flowing water, leaving the coating film almost unchanged from the initial state. These observations show that in SC-VK, carbon black is hard to adhere and stain resistance has been improved as compared to that of the conventional VK.

Figure 9 shows the appearances and stain resistance (change in color tone) of the test samples which were exposed outdoors for 12 months in Chiba industrial area. As for the conventional VK, rain-

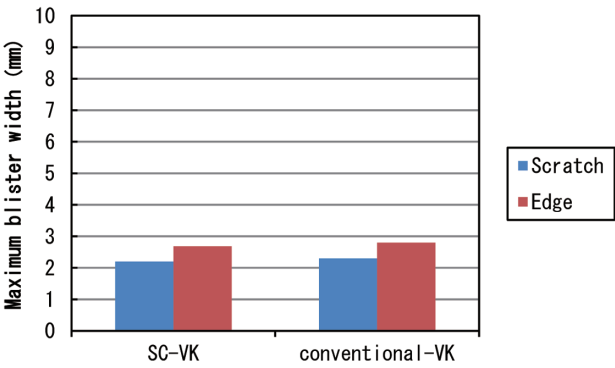


Fig. 6 Results of corrosion test

Sample	SC-VK	Conventional-VK
Appearances		

Fig. 7 Results of exposure test for one year in Okinawa

Sample	SC-VK	Conventional-VK
Appearances		

Fig. 8 Results of carbon black test

Sample	SC-VK	Conventional-VK
Appearances		
ΔL	0.9	3.6

Fig. 9 Results of exposure test

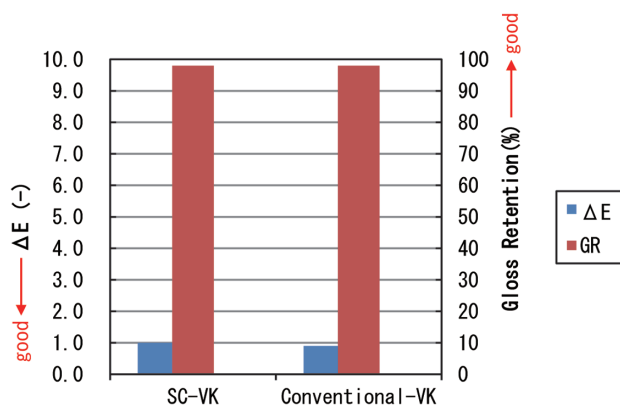


Fig. 10 Results of accelerated weathering test

streaked stain on coating film is noticeable with a large change in color tone and therefore, stain resistance is inferior. However, as for SC-VK, rain-streaked stain was almost unnoticeable and there was hardly any change in color tone. These observations suggest that SC-VK has excellent stain resistance against various kinds of stain in outdoor environment of industrial areas.

5.3 Weather resistance of SC-VK

Figure 10 shows the result of the accelerated test for weather resistance using a SWOM. Similar to the conventional VK, SC-VK shows no change in color tone and gloss after 500 hours of the SWOM test, thus exhibiting excellent weather resistance.

5.4 Workability of SC-VK

Figure 11 shows the result of 1T bending test. SC-VK does not develop any cracks on the coating film even after 1T bending and therefore it is found that it has a folding workability equal to that of the conventional VK. Figure 12 shows the photos of the appearance of the samples after drawing. These photos illustrate that developed SC-VK is also excellent in deep-drawing formability and no damage or peeling of coating film occurred at the drawn areas.

6. Conclusion

In this report, corrosion resistance, stain resistance, weather resistance, and workability of the newly developed prepainted steel sheet SC-VK, which is excellent in outdoor stain resistance, were compared and evaluated with those of the conventional VK and a conventional chromate-free prepainted steel sheet for outdoor use. The following results were obtained.



Sample	SC-VK	Conventional-VK
Bending part		
Crack	No crack	No crack

Fig. 11 Results of 1T-bending test



Sample	SC-VK	Conventional-VK
Appearances		

Fig. 12 Results of deep drawing test

- (1) The developed SC-VK has a corrosion resistance equivalent to that of the conventional VK, proved in the accelerated test of combined cycle test and the 12 months exposure test in Okinawa, and exhibits excellent outdoor corrosion resistance.
- (2) The stain resistance of the developed SC-VK for carbon black, which is used as representative stain, is improved as compared with that of the conventional VK, and the emergence of stain resistance in the outdoor exposure test in Chiba industrial area was also confirmed.
- (3) The results of the accelerated weather resistance test show that the weather resistance of the developed SC-VK is equivalent to that of the conventional VK, and it also has coating film durability for outdoor use.
- (4) The developed SC-VK produced no damage to the coating film and there was no peeling at the drawn area even after folding and drawing work and therefore, it has excellent workability.

From the above results, it was found that the developed SC-VK has excellent outdoor stain resistance and is applicable to outdoor products having various forms.

Reference

- 1) Ueda, K. et al.: Shinnittetsu Giho. (377), 25 (2002)



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