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Durability Evaluation of Highly Reflective Coating Materials for Roofing

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ABSTRACT

Highly reflective coating materials for roofing (cool roof paints) are becoming popular in Japanese market. It is expected that these coating materials can reduce the energy costs of buildings in the summer and also control the heat island phenomenon in urban regions.

In this context, various highly reflective coating materials obtained from the market were evaluated by an outdoor exposure test for up to three years and a sunshine carbon arc-type artificial aging test for up to 4000 hours. Reflectance of solar radiation, gloss retention, and the color difference of the painted specimens were monitored for 24 brands of highly reflective coating products (color: gray, N = 6.0) in the study.

Polymer binders can be classified as polyurethane resins, silicone resins, and fluoropolymer resins. In general, the gloss retention percentages of commercial reflective coating materials were higher in order of fluoropolymer resins, silicone resins, and polyurethane resins in the sunshine carbon arc irradiation test. The color difference of the specimens exposed to the outdoor condition increased after one year and did not change so much after two years. However, it changed to a large extent after three years again. The color differences of some products increased and those of other products decreased after three years.

The solar reflectance values did not show changes in both the outdoor exposure test and the accelerated aging test.

KEYWORDS

Accelerated aging, Coating material, Cool roof, Outdoor exposure, Solar reflectance.

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1 INTRODUCTION

The heat island phenomenon is becoming a serious problem in urban areas in Japan. Table 1 shows the estimated temperature rise in Japanese cities. For example, the annual average temperature in Tokyo is estimated to increase by 3.0 degrees Celsius after 100 years. On the other hand, the annual average temperature in small cities is estimated to increase by 1.0 degree Celsius. For this reason, the central government and local governments including large cities have adopted various countermeasures against the heat island phenomenon.

Table 1. Estimated temperature rise in Japanese cities. (Metrological Agency, Japan)

City	*Rise in average temperature per 100 years* [degree in Celsius]		
	Annual	*January*	*August*
Sapporo	+2.3	+3.0	+1.5
Sendai	+2.3	+3.5	+0.6
Tokyo	+3.0	+3.8	+2.6
Nagoya	+2.6	+3.6	+1.9
Kyoto	+2.5	+3.2	+2.3
Fukuoka	+2.5	+1.9	+2.1
Ave. in Large Cities	+2.5	+3.2	+1.8
Ave. in Small Cities	+1.0	+1.0	+1.0

The application of highly reflective coating materials for roofing is considered to be one of the effective countermeasures. Highly reflective coating materials, often called “cool roof paint,” are those coating materials that can form coated layers having high reflectance especially for the infrared ray region.

Figure 1 shows the solar reflectance distribution of a highly reflective coating layer and an ordinary coating layer. The color of both coating layers was gray (N = 6.0). As shown in Fig. 1, there was little difference in the reflectance percentage within the visible wavelength region; however, there was a large difference in reflectance percentage within the infrared wavelength region. Therefore, users can select reflective coating materials irrespective of the color of the coated layers. Highly reflective coating materials have a great potential in the market even though the color of roofing materials in Japan is mostly dark.

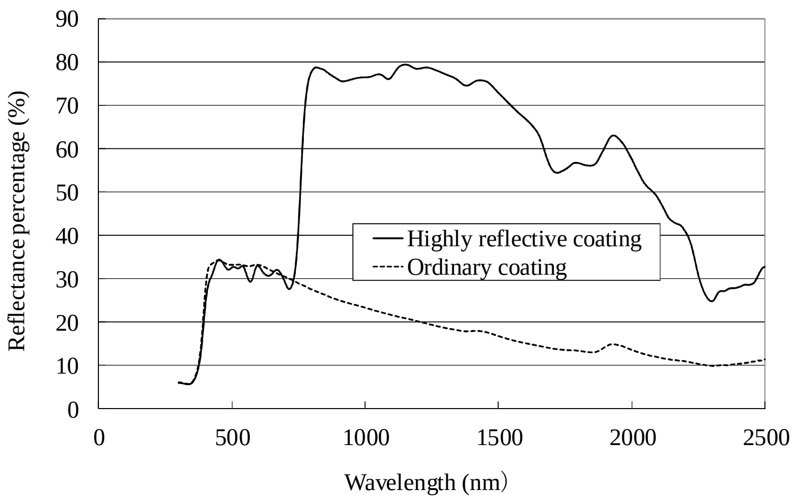

Figure 1. Solar reflectance spectra of a highly reflective coating and an ordinary coating.

There are various reflective coating materials in the Japanese market. To assist users in selecting appropriate coating products, standardization of such coating materials is in progress. As a part of such activities, JIS K 5602:2008 (Determination of reflectance of solar radiation by paint film) has been already standardized. The standardization of highly reflective coating products is also in progress. One important aspect for the standardization of reflective coating products is the durability of the materials and their solar reflectance performances over time. To investigate these points, their outdoor exposures for three years and accelerated aging for 4000 hours have been analyzed in this study.

2 EXPERIMENTAL

2.1 Objected Coating

The objected coating products are listed in Table 2. We evaluated 24 products of highly reflective coating materials in this study. The color of all the reflective coatings was gray (N = 5.9 ~ 6.1). Some tested coating products were applied on a metallic roof sheet, and such types of coating products were coated on an aluminum sheet (0.5-mm thick) standardized in JIS H 4000:2006 (Aluminum and aluminum alloy sheets and plates, strips and coiled sheets), according to the manufacturer's specifications.

The other coating systems of the objected coating projects were applied to cementitious roofing substrate; therefore, such coating products were coated on fiber-reinforced cement sheet (3.0-mm thick), standardized in JIS A 5430:2008 (Fiber reinforced cement boards), according to the manufacturer's specifications. The ordinary coating products listed in Table 1 have also been evaluated for comparison.

Table 2. Objected coating products.

Type	Binder	Color	Number of Products
Highly reflective coating	Solvent type polyurethane	Gray	4
	Solvent type silicone	Gray	7
	Solvent type fluoropolymer	Gray	1
	Water based silicone	Gray	11
	Water based fluoropolymer	Gray	1
Ordinary coating	Solvent type polyurethane	Gray	1
	Solvent type polyurethane	White	1
	Solvent type polyurethane	Black	1

2.2 Outdoor Exposure Test

The specimen size was 150 by 300 mm for both aluminum and fiber-reinforced cement sheets. The coated specimens were mounted on a rack at an angle of 45 degrees facing south at the outdoor exposure site of the Building Research Institute located in Tsukuba city, which is about 80 km north of Tokyo. The specimens were exposed for three years.

2.3 Accelerated Aging Test

The specimen size was 70 by 150 mm for both substrates. A sunshine carbon arc irradiation test standardized in ISO 4892-4:1994 was conducted for the coated specimens. Water spraying was applied for 18 minutes every 120 minutes. The ultraviolet irradiation intensity (wavelength range: 300-700 nm) was monitored at the position of the specimen surface by using an accumulated photometer. The test was conducted for 4000 hours.

2.4 Measurement of Color, Gloss, and Solar Reflectance

The color differences (delta E*ab), gloss values (reflection at 60 degrees), and solar reflectance were measured periodically in the outdoor exposure test and the accelerated aging test. The solar reflectance was measured on the basis of JIS K 5602:2008. According to JIS K 5602:2008, the solar reflectance is defined as follows;

$$\rho_e = \frac{\sum_{\lambda} [(E\lambda \times \Delta\lambda) \times \rho(\lambda)]}{\sum_{\lambda} (E\lambda \times \Delta\lambda)} \tag{1}$$

ρ_e : Solar reflectance
$\rho(\lambda)$: Specific reflection percentage (%)
$E\lambda \times \Delta\lambda$: Weighting coefficients based on ISO 9845-1:1992 (W/m^2)
λ : Wave length (nm)

3 RESULTS AND DISCUSSION

3.1 Changes in Color Difference

Figs 2 and 3 show the changes in the color difference values of typical reflective coating specimens for each type of polymer binder for the outdoor exposure test and the accelerated aging test, respectively. In the outdoor exposure test, there was little difference in the color difference values between after one year and after two years; however, the values of some products increased again, and the values of the other products decreased after three years. We speculated that soiling was the predominant deterioration within 2 years; however, chalking behavior or degradation of the surface polymers progressed in addition to soiling after three years.

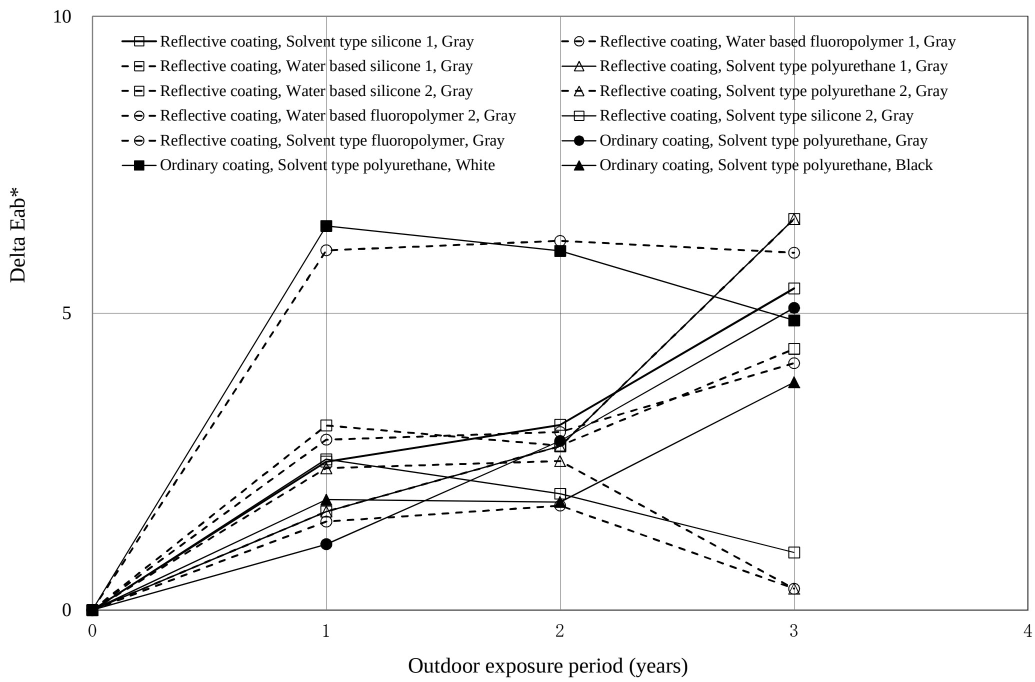

Figure 2. Changes in the color difference values of the specimens without washing in the outdoor exposure test.

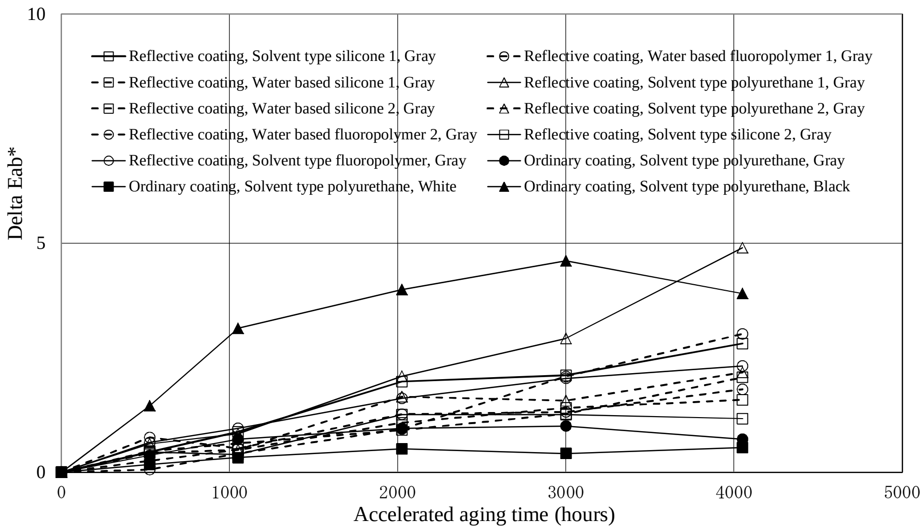

Figure 3. Changes in the color difference values of the specimens in the accelerated aging test.

In the accelerated aging test, the color difference values of most products seemed to increase gradually with the acceleration periods, and those of the other products seemed to reach almost constant values. The influence of the polymer binders on the color differences were different for the outdoor exposure test and the acceleration test. The deterioration of the polymer binders and the color changes of the pigments were the main factors for the color changes of the specimens in the acceleration test, and soiling was another factor in the outdoor exposure test.

3.2 Changes in Gloss Retention

Figure 4 plots the gloss retention percentages in the accelerated aging test. The gloss retention percentages decreased gradually with the acceleration time as shown in Figure 4. In general, gloss retention is related to the durability of the polymer binders of the coating products. The gloss retention values were higher in order of fluoropolymer resins, silicone resins, and polyurethane resins. This result was consistent with the past results reported by [Motohashi 1993] and [Motohashi *et al.* 1998].

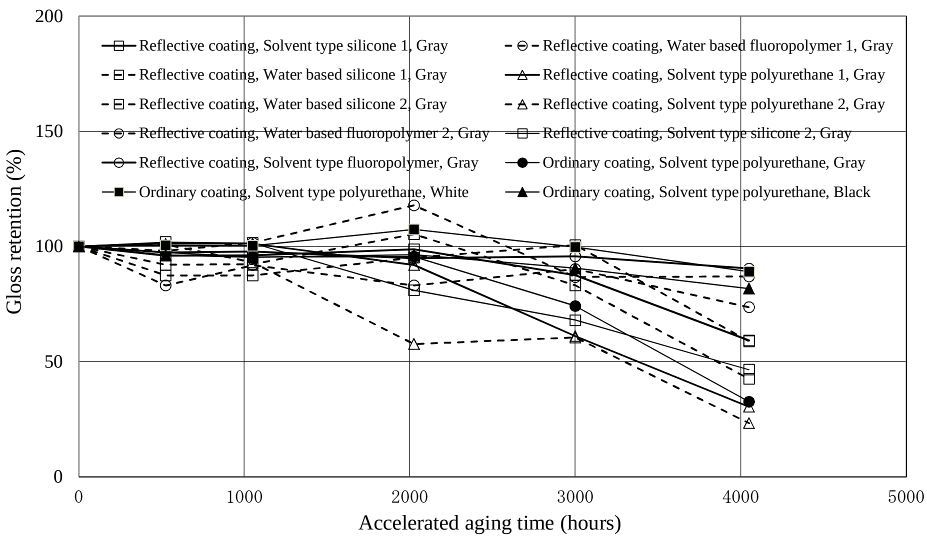

Figure 4. Changes in gloss retention of specimens in the accelerated aging test.

Although the data are not shown, we confirmed that the gloss retention percentages in the outdoor exposure test showed different tendencies from the results obtained in the acceleration test. The attachment of dirt affected the gloss retention values in the outdoor exposure test; however, the attachment of dirt could not be simulated in the accelerated aging test.

3.3 Changes in Solar Reflectance

Figure 5 shows the changes in the solar reflectance values of typical specimens without washing for each type of polymer binder for the outdoor exposure test. In general, there was little difference in the solar reflectance values for the outdoor exposure test and the accelerated aging test.

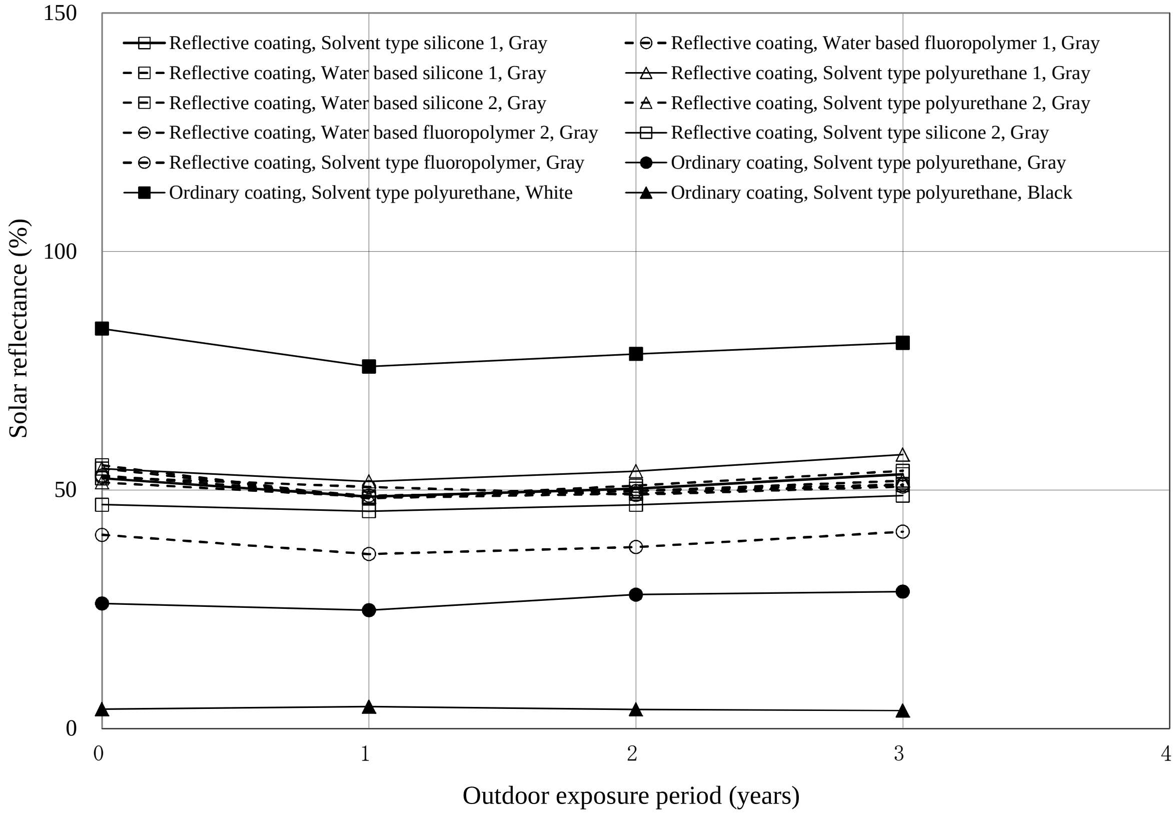

Figure 5. Changes in solar reflectance of specimens without washing in the outdoor exposure test.

Figure 6 shows the relationship between the color difference values and solar reflectance values before washing for all highly reflective coating specimens evaluated in the outdoor exposure test. As shown in Figure 6, a strong correlation exists between the delta E*ab values and the solar reflectance values for the specimens that had been exposed for one year and two years. However, there was no correlation between the two values for the specimens that had been exposed for three years.

It can be reasonably considered that the soiling phenomenon can affect the solar reflectance values. In other words, the solar reflectance values decreased because of soiling. The strong correlation between the delta E*ab and the solar reflectance for the specimens exposed for one or two years can be understood with this reason.

However, after three years, the specimens did not demonstrate the same tendency. Some of the specimens displayed chalking behavior after three years. As shown in Figure 2, the delta E*ab values after one year and after two years showed a uniform trend, i.e., they increased gradually. However, they did not show a uniform trend after three years. The delta E*ab values of some specimens considerably increased after three years, and the values of the other specimens considerably decreased; this suggests that the occurrence of chalking or discoloration of the specimens exposed for three years in outdoor conditions was probably the reason for no correlation between the delta E*ab values and the solar reflectance after three years.

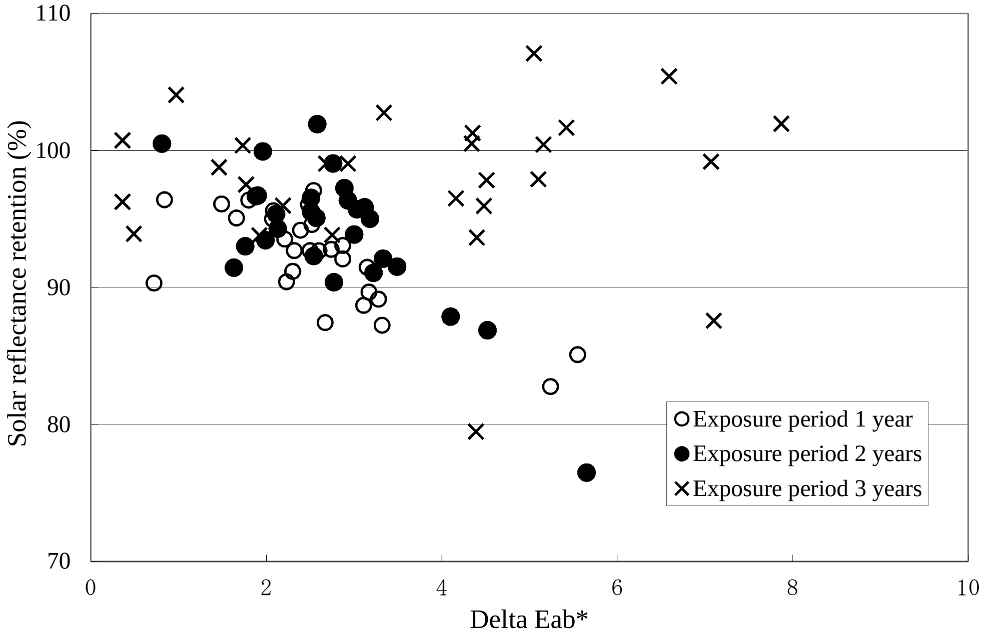

Figure 6. Relationship between color difference and solar reflectance for all the specimens that were coated with highly reflective coating products.

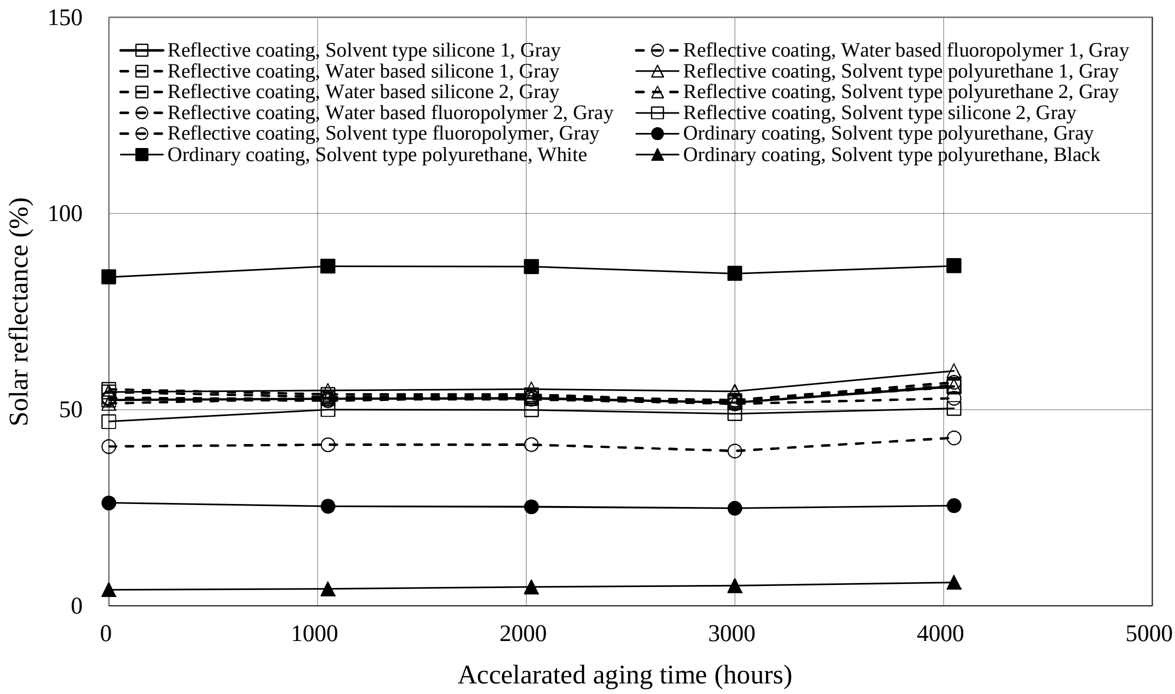

Figure 7. Changes in the solar reflectance of the specimens in the accelerated aging test.

Figure 7 the changes in the solar reflectance values of a typical specimen in the accelerated aging test. Compared to the outdoor exposure test, there were smaller changes in the solar reflectance values in the acceleration test because the soiling phenomenon (attachment of dirt) did not occur in the sunshine carbon arc type irradiation test. We recognized that the solar reflectance values of some specimens slightly increased after 4000 hours and speculated that chalking or degradation of the surface polymer might have occurred in those specimens after 4000 hours of irradiation. It can be reasonably considered that the chalking behavior increase the solar reflectance values of the specimens.

4 CONCLUSIONS

We evaluated the highly reflective coating products obtained from the market by an outdoor exposure test and a sunshine carbon arc-type artificial aging test. Changes in the color difference, gloss retention, and solar reflectance were monitored in the study. The main results are summarized as follows:

1) The color difference increased within one year and did not change much. However, it changed considerably after three years. The color difference of some specimens increased, and color difference of other specimens decreased after three years.

2) The gloss retention values gradually decreased with the aging time in the accelerated aging test. The gloss retention percentages were dependent on the types of polymer binders.

3) In general, the solar reflectance values showed little change in the outdoor exposure test as well as the accelerated aging test. A high correlation was recognized between the color difference and the solar reflectance for the unwashed specimens exposed for one year and two years in the outdoor condition. However, such correlation was not confirmed for the specimens exposed for three years, which seems to be because of the occurrence of chalking or discoloration of the specimens after three years.

ACKNOWLEDGMENTS

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