Evaluation of dirt-repellency of membrane materials for architectural membrane structures

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SYNOPSIS

This report summarizes the results of the studies on the dirt-repellency of membrane materials.
As the surface treatment materials for coated fabrics, one hundred percent fluorocarbon-resin clearly reduced dirt-repellency. Moreover, a top-coated titanium dioxide(TiO_2) photocatalyst markedly improved the dirt-repellency of coated fabrics.
Influence of location was investigated by an outdoor exposure test. The degree of dirt depends on the locations. Membrane materials were the most polluted in Tokyo and Osaka.
An apparatus for accelerating the dirt process was developed and the results obtained by this apparatus were in fair agreement with the results of the outdoor exposure test.
The relationship between the angle of the side wall and the rain water dirt streaks was investigated by the outdoor exposure test. When the exposure angle of the side wall against the horizontal plane exceeded 65 degrees, rain water dirt streaks appeared.

1. Introduction

Architectural membrane structures cannot avoid exposure to an outdoor environment. As dirt spoils the beauty of structures, several studies have been carried out to evaluate dirt-repellency of coated fabrics[1-7]. This report summarizes the results of these studies.

Membrane materials are made of woven fabrics coated mainly with polytetrafluoroethylene (PTFE) or polyvinyl chloride (PVC).

PVC-coated fabrics are especially easy to adhere dirt because the plasticizer contained in PVC migrates to the surface and absorbs dirt matters while they are exposed to sunlight, heat and rains. An effective way to cope with this problem is through prevention of plasticizer migration in PVC by top-coating the PVC surface with acrylic resin or fluorocarbon polymer, or by laminating fluorocarbon polymer film such as polyvinyl fluoride (PVF), polyvinylidene fluoride(PVDF), and also by treatment with a titanium dioxide(TiO_2) photocatalyst.

Dirt-repellency has been mainly evaluated by color difference after an outdoor exposure test. However, the outdoor exposure test takes a long time before the result can be obtained. Therefore, we developed a more rapid test method and investigated the relationship between the outdoor exposure angle of the side wall and the rain water dirt streaks.

2. Effect of color variation of PVC-coated fabric on dirt appearance

2-1 Purpose

The relationship between dirt appearance and the color of PVC coating was examined by an outdoor exposure test. Dirt appearance was evaluated by the sensory test and the colorimetry for outdoor exposed specimens.

2-2 Experimental

2-2-1 Specimens

Commercial PVC-coated fabrics with ten different colors of PVC coating were used. Table-1 shows the colors of PVC coating.

2-2-2 Outdoor exposure test

The outdoor exposure test was carried out at the site of Taiyo Kogyo Corporation at Hirakata city, Osaka pref.

Table-1 Colors of PVC Coating

	White	Ivory	Yellow	Yellow-green	Green	Sky-blue	Blue	Orange	Red	Brown
H	5.6GY	4.8Y	4.8Y	0.7G	5.3G	1.1PB	3.9PB	8.9R	3.3R	8.2R
V	9.4	9.0	8.4	6.5	5.1	5.5	4.8	6.0	5.2	4.0
C	0.2	3.2	10.0	7.4	6.0	8.2	8.1	10.7	14.0	0.9

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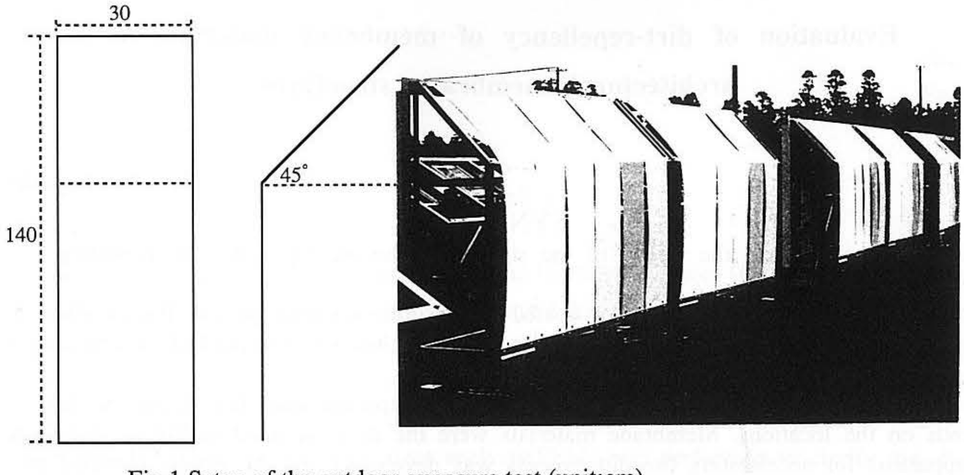


Fig.1 Setup of the outdoor exposure test (unit:cm)

Fig. 1 shows the setup of the test method which is the conventional evaluation method for ordinary building materials. Unloaded specimens, 30cm wide and 140cm long, were attached to a south-facing rack at an inclination of 45 degrees.

2-2-3 Evaluation

2-2-3-1 Sensory test

After the outdoor exposure for one year on each colored specimens, the specimens were cut into 4cm x 6cm pieces, placed next to the original sample of the same size, and pasted on cardboard. They were used as the samples for the sensory test. Inspectors were 50 healthy adults, who had been explained the purpose of this test in advance. According to the subjective degree of dirt on the initial specimen and the outdoor-exposed specimen, the samples for the sensory test were divided into the 3 groups of significant, average, and slight. According to decreasing degree of dirt they were numbered from 10 to 1 evaluation readings. The sensory test was conducted in the laboratory which maintains almost steady illuminance distribution(on the desk of height:50cm, average Illuminance:500 lx).

2-2-3-2 Measurements of color change

Color differences produced by dirt adhesion were measured using a Hitachi U-3410 spectrophotometer. The measurement conditions were as follows; the XYZ chromatic system based on the 2-degrees visual field, the range of wavelength of 380~780nm with CIE standard illuminant C.

After the outdoor exposure for several lengths of time to ten years, the specimens which were exposed at an inclination of 45 degrees facing south were cut into pieces for the measurement. Each piece has dimensions of 4cm×6cm.

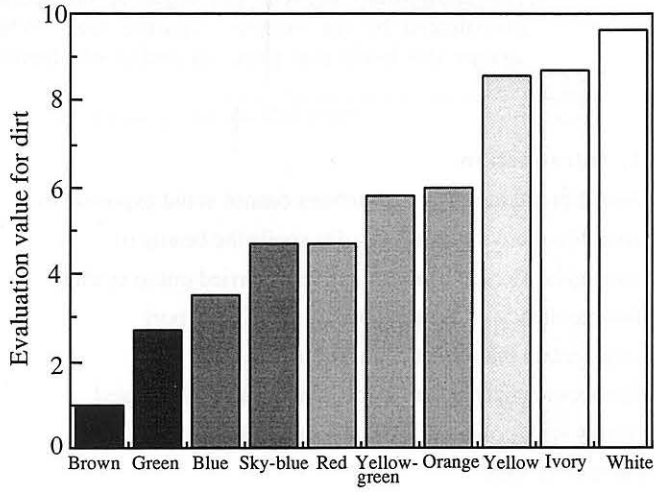


Fig.2 The result of dirt evaluation with the sensory test

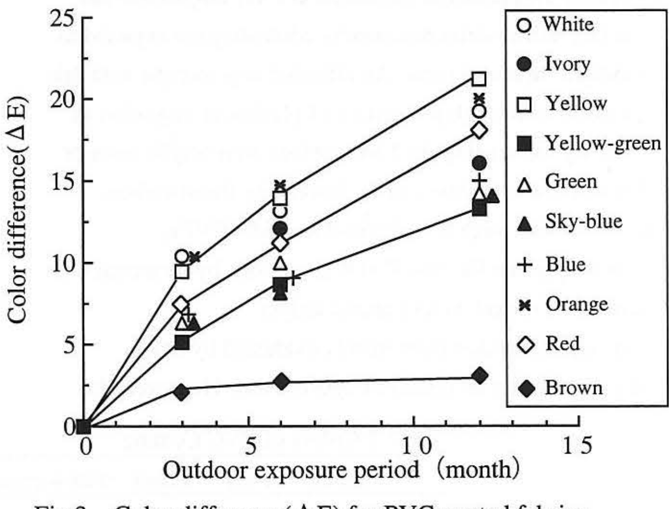


Fig.3 Color difference(Δ E) for PVC-coated fabrics with diffrent colors during the one-year outdoor exposure test at Hirakata, Osaka prefecture

The color differences(Δ E) between exposed and initial specimens were measured for three specimens and the average value was taken.

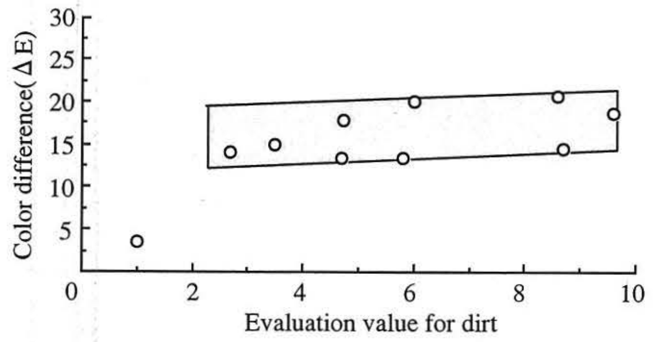


Fig.4 Relation between the color difference and the result of the sensory test after the one-year outdoor exposure test

2-3 Results and Discussion

Fig.2 shows the result of dirt evaluation with the sensory test classified by the base color of the specimen after outdoor exposure test for a year. The figure shows that the darker specimens such as brown and green hardly appeared dirty while the lighter specimens such as white and ivory easily appeared dirty.

Fig.3 shows the color difference after the one year outdoor exposure test. Fig.4 shows the relationship between the color difference and the result of the sensory test. Except for brown, the color difference was similar for all color tones examined.

Therefore the results suggest that the test method of color difference is adequate for evaluating on PVC-coated fabrics having different colors.

2-4 Conclusion

The dirt degree corresponds to the value of brightness of the materials. The evaluation by color difference is appropriate for evaluating the dirt-repellency for membrane materials.

3. Influence of surface treatment and outdoor exposure test locations on dirt levels of coated fabrics

3-1 Purpose

The effect of surface treatment on dirt-repellency of coated fabrics was evaluated. The surface treatment was mainly by top-coating with acrylic resin or fluorocarbon polymer, or by laminating fluorocarbon polymer film. For evaluation of the dirt-repellency of specimens, the outdoor exposure test was conducted and then the color difference was measured. Influence of exposure location on color difference was also investigated.

3-2 Experimental

3-2-1 Specimens

Both PVC- and PTFE-coated fabrics with different kinds of surface treatment were used. Table-2 shows the details of specimens for the surface treatment.

3-2-2 Outdoor exposure test, test locations and evaluation method

The outdoor exposure test was carried out at seventeen locations in and out of Japan(Table-3). The methods of the outdoor exposure test and of the color difference evaluation were the same as those shown in **2-2-3-2.**

3-3 Results and Discussion

3-3-1 Color difference classified by surface treatment

The surface treatment clearly reduced the change of color difference as shown in Fig.5. This change shows the mean values for the color difference measurement in each specimen and at different locations after exposure. The dirt adhesion of specimens A,D and E which were coated with one hundred percent fluorocarbon-resin did not increase much even after the three-year-exposure-period.

On the other hand, a far larger dirt-repellency was found on specimen B with acrylic resin coating after a three-year-exposure- period. Specimen C coated with acrylic resin containing fluorine on its surface had a improved dirt-repellency compared with specimen B.

After the ten-year-outdoor exposure test at Hirakata, the specimens treated with one hundred percent fluorocarbon-resin showed clearly improved dirt-repellency and their surface morphological changes were hardly observed (Figs.6,7). The specimens treated with polymethyl methacrylate and those without surface treatment had the worst dirt-repellency after the three-to five-year exposure period. However, the dirt was removed after the ten-year-exposure-period because the plasticizer contained in PVC migrated to the surface and dirts were released through the deterioration and exfoliation of PVC.

3-3-2 Color difference of PTFE-coated glass fiber fabric at several locations

Fig.8 compares ΔE of specimen D(PTFE-coated glass fiber fabric) after outdoor exposure for one year at different locations. It is noticed that the color difference differs remarkably with the location of the test. Tokyo and Osaka were found to be the two areas where the specimens were the most polluted.

The essential cause of dirt on coated fabrics is air pollution. Hence, it should be realized how heavily the coated fabrics are polluted depending on where it is actually used.

Table-2 Specimens

Specimens	Surface treatment	Coating material	Base fabric	Total Thickness (mm)	Total Weight (g/m²)	Color
A	PVF*[1]film(25 μ m) laminate			0.95	1102	White
B	Acrylic resin coating (matt surface)	PVC*[2]	Polyester	0.86	991	White
C	Fluorine containing acrylic resin coating (mirror surface)			0.59	652	White
D	PTFE*[3] coating		Glass	0.92	1366	White
E	Fluorine coating	PVC*[2]	Polyester	0.60	686	Ivory
F	Untreated			0.50	581	Ivory

*[1]: polyvinyl fluoride, *[2]: polyvinyl chloride, *[3]: polytetrafluoroethylene

Table-3 Outdoor exposure test locations

No	place	Adress
1	Sapporo	Shiraishi-ku , Sapporo City (Taiyo Kogyo Corp.,Sapporo Office)
2	Sendai	Kojo, Sendai City (Kohshin Rubber Co.,Ltd.)
3	Niigata	Hirashima ,Niigata City (Taiyo Kogyo Corp.,Niigata Office)
4	Tokyo	Meguro-ku, Tokyo (Taiyo Kogyo Corp.,Tokyo Office)
5	Osaka	Yodogawa-ku, Osaka (Taiyo Kogyo Corp.,Osaka Head Office)
6	Hirakata	Syodai tajika,Hirakata City (Taiyo Kogyo Corp.,Hirakata Factory)
7	Higashimatsuyama	Kaminomoto,Higashimatsuyama City(Taiyo Kogyo Corp.,Higashi-matsuyama Factory)
8	Hamamatsu	Takano-Cho, Hamamatsu City (Taiyo Kogyo Corp.,Hamamatu Factory)
9	Mizuho	Mizuho-cho, Funai-gun,Kyoto(Taiyo Kogyo Corp.,Mizuho Factory)
10	Fukui	Ishishinbo-cho,Fukui City (Taiyo Kogyo Corp.,Fukui Factory)
11	Fukuoka	Hakata-ku, Fukuoka City(Rentool Taiyo Co.,Ltd.)
12	Yamaguchi	Waki-cho,Kuga-gun Yamaguchi(Mitui Petrochemical Industries,Ltd.)
13	California	Hayward,Calfornia(Helios Industries Inc.)
14	Chicago	St.Addison,III(Helios Container Systems Inc.)
15	Choshi	Shinmachi, Choshi City (Japan Westhering Test Center)
16	Kagoshima	kine-cho,kagoshima City (Ebihara Co.,Ltd)
17	Okinawa	Hennoki,Kunigami-gun, Okinawa

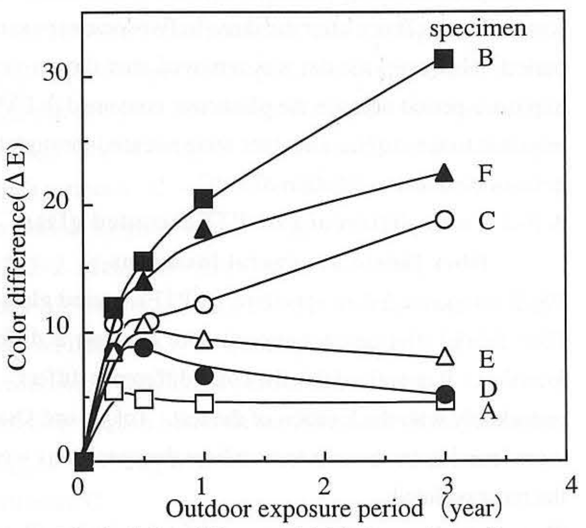


Fig.5 Color difference(Δ E) in each specimen at several locations

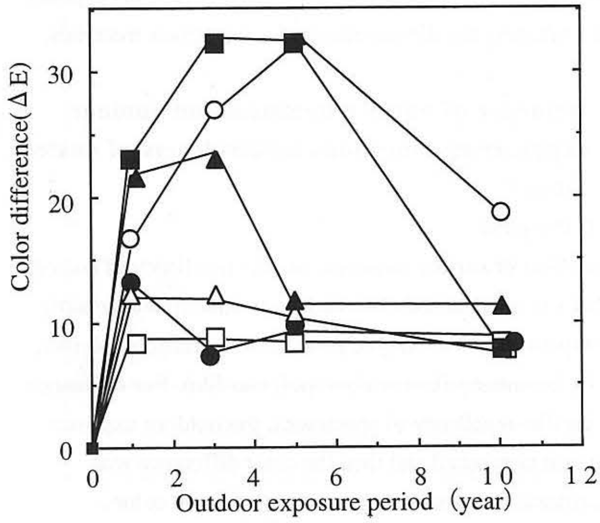


Fig.6 Color difference(Δ E) during the ten-year outdoor exposure test at Hirakata, Osaka prefecture

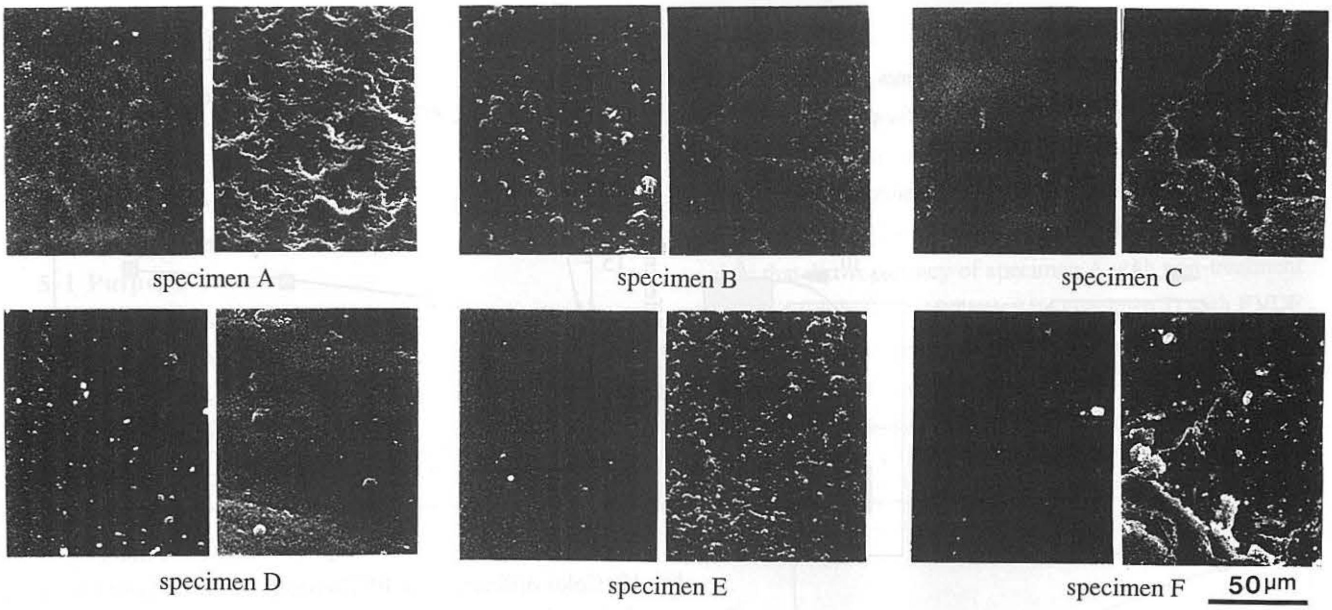
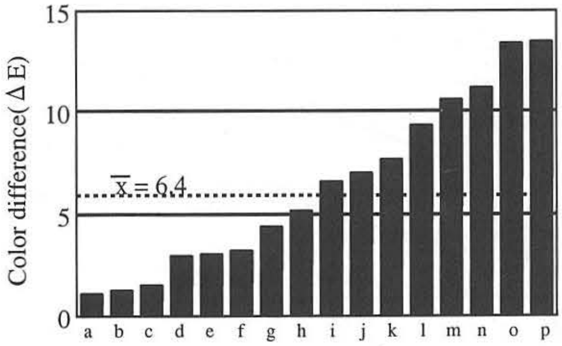


Fig.7 Scanning electron micrographs of surface of outdoor-exposed specimens at Hirakata, Osaka prefecture : unexposed(left) and after ten-years outdoor-exposure (right)



a : Choshi(Chiba Pref.)
b : Fukui
c : Henoki(Okinawa Pref.)
d : Hayward(California,U.S.A)
e :Hamamatsu(Shizuoka Pref.)
f : Niigata
g : Sapporo(Hokkaido Pref.)
h : Mizuho(Kyoto Pref.)
i : Kagoshima
j : Sendai(Miyagi Pref.)
k : Yamaguchi
l : Fukuoka
m : Higashimatsuyama(Saitama Pref.)
n : Osaka
o : Hirakata(Osaka Pref.)
p : Tokyo

Fig.8 Color difference(Δ E) for PTFE-coated glass fiber fabrics at diffrent locations after the one-year outdoor exposure test

3-4 Conclusion

Surface treatment with one hundred percent fluorocarbon-resin clearly reduces dirt-repellency.

The degree of dirt depends on the location of the outdoor exposure. For example, Tokyo and Osaka were the most polluted sites.

4. Dirt-process accelerating tests on PVC-coated fabrics

4-1 Purpose

Although the outdoor exposure test is the most practical method for evaluating dirt-repellency of coated fabrics, there are some problems because this test is dependent on temperature, environment, area and season. Furthermore, it takes too long.

An apparatus for accelerating the dirt process was developed and a series of tests performed for several dirt-repellent specimens, to evaluate the dirt-repellency of PVC-coated fabrics more quickly.

4-2 Experimental

4-2-1 Specimens

Three kinds of commercial PVC-coated polyester fabrics were used as specimens in both the outdoor exposure and the accelerating tests. Table-4 shows the specimens of surface-treated PVC coating.

Table-4 Surface treatment for the specimens

Specimen	Surface treatment on PVC	Color
A	Polyvinyl fluoride(PVF) film laminate	white
B	Polyvinylidene fluoride(PVDF) coating	ivory
C	non treated	ivory

4-2-2 The dirt process accelerating test

A rotary-type tester to accelerate the dirt process was developed(Fig.9). The tester is a hexagonal cylinder with an opening of 6cm×6cm on each side wall on which test specimens(8cm×8cm) are attached. The standard dirt matter 2 grams(Table-5) was coated on glass beads 10 grams(1~2mm ϕ) uniformly, and the dirt coated glass beads were put into the tester. The cylinder was rotated with 30 r.p.m. then the dirt matter adheres on each specimen. In this experiment, the tester was placed in a hot oven for 30 minutes at 70℃.

Prior to the test, the specimens were treated for one hour at 70℃ without rotation.

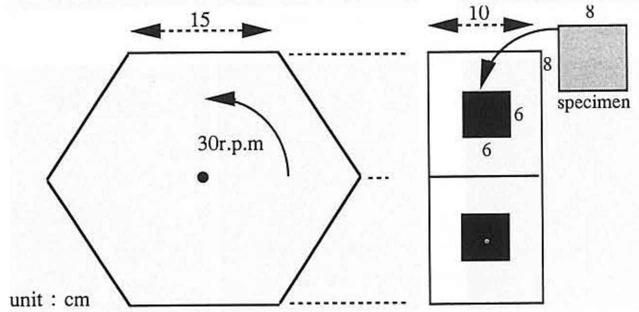


Fig.9 A rotary-type dirt process accelerating tester

Table-5 Content and percentage by mass of standard dirt matter

Content		Percentage by mass %
Peat moss		40
Portland cement	(JIS R 5210)	17
Kaolin	(JIS K 8746)	17
Diatomaceous earth	(JIS K 8330)	17
Carbon black	(JIS K 5107)	0.1
Iron(Ⅲ) oxide for ferrite	(JIS K 1462)	0.15
Nujol		8.75

4-3 Results and discussion

Fig. 10 shows the color difference after the dirt process accelerating test. Pollution was prevented most effectively on specimen A with PVF film lamination followed by specimen B with PVDF coating. Pollution was hardly prevented on Specimen C.

A one-year outdoor exposure test was carried out for comparison with the results of the dirt process accelerating test(Fig. 11). The results of the dirt process accelerating test for dirt-repellency on PVC-coated fabrics had a tendency similar to those of the outdoor exposure test.

Fig. 12 shows the relationship between the results of these tests. The results of the accelerating test corresponded well to those of the outdoor exposure test.

Consequently, regarding the evaluation of dirt-repellency on PVC-coated fabrics as judged by the $\triangle E$ values, the results of a dirt process accelerating test of conducted for 30 minutes at 70℃ were almost the same as those of the outdoor exposure test for one year.

4-4 Conclusion

This dirt process accelerating test was found to be more

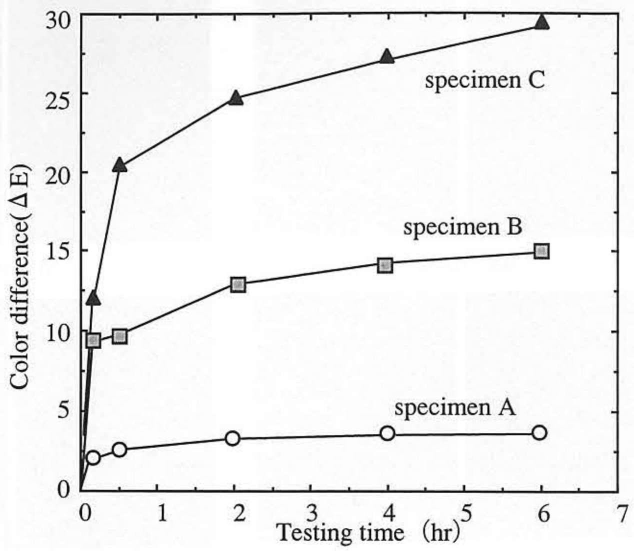


Fig.10 Color difference for PVC-coated fabrics obtained from the dirt process accelerating test. (Temperature of hot oven:70℃)

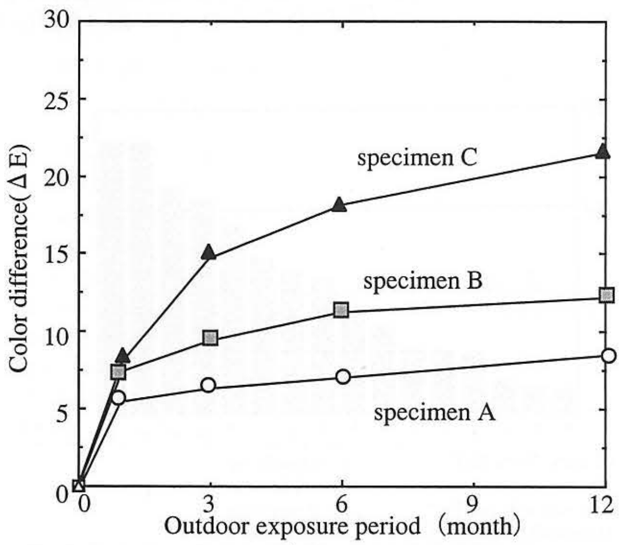


Fig.11 Color difference(ΔE) during the one-year outdoor exposure test at Hirakata, Osaka prefecture

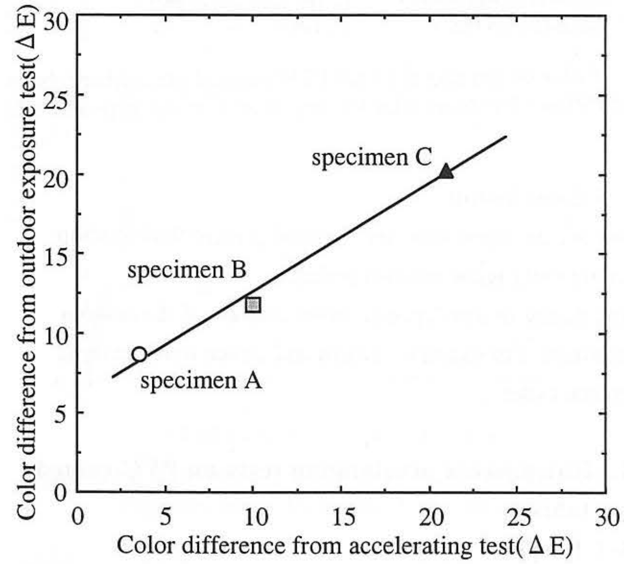


Fig.12 Correlation of the color difference betwen the outdoor exposure test and the accelerating test for evaluation of dirt-repellency of PVC-coated fabrics

useful to evaluate the performance of a PVC-coated fabric in a very short period.

5. Dirt-repellency of coated fabrics with titanium dioxide photocatalyst

5-1 Purpose

As an advanced technology of surface treatment, titanium dioxide(TiO_2) photocatalyst is widely applied for deodorization, sterilization and dirt-repellency of various building materials in Japan.

The dirt-repellency of the coated fabrics treated with TiO_2 was investigated by an outdoor exposure test.

5-2 Experimental

5-2-1 Specimens

Four kinds of PVC-coated polyester fabrics and two kinds of PTFE-coated glass fiber fabrics were used as specimens (Table-6). In specimen B, TiO_2 coating consisted of one protective-adhesive layer and one photocatalyst layer to avoid the oxidation of PVC itself from photocatalytic function of TiO_2. In specimen F, TiO_2 powder was mixed with the PTFE top-coating since oxidation does not occur for PTFE coating.

Table-6 Surface treatment for specimens of coated fabrics

specimens	Surface treatment
A	PVC*1 with non-treatment
B	PVC with TiO_2 *2
C	PVC laminated with PVF *3 film
D	PVC coated with PVDF*4
E	PTFE*5 with non-treatment
F	PTFE with TiO_2

*1 PVC: Polyvinyl chloride
*2 TiO_2: Titanium dioxide
*3 PVF: Polyvinyl fluoride
*4 PVDF: Polyvinylidene fluoride
*5 PTFE: Polytetrafluoroethylene

5-2-2 The outdoor exposure test

The outdoor exposure test was carried out at the sites of Taiyo Kogyo Corporation at Higashimastsuyama (a), Saitama pref. and at Hirakata(b), Osaka pref.

As for the site of (a), experimental tents were manufactured using specimens A,B,C and D. In (b), unloaded specimens of 30cm wide and 140cm long were attached to a south-facing rack at an inclination of 45 degrees using specimens E and F.

5-3 Results and discussion

5-3-1 Dirt-repellency of PVC-coated fabrics after the outdoor exposure test

Fig. 13 shows the results of ΔE for PVC-coated fabrics with different kinds of surface treatment. From Fig. 13, it is clear that dirt-repellency of specimen A with non-treatment is significantly weak, followed by specimen D with PVDF coating and specimen C with PVF film lamination in this order. The most pollution-repellent PVC-coated fabric was specimen B with TiO_2 top-coating. Specimen B remained almost dirt-free.

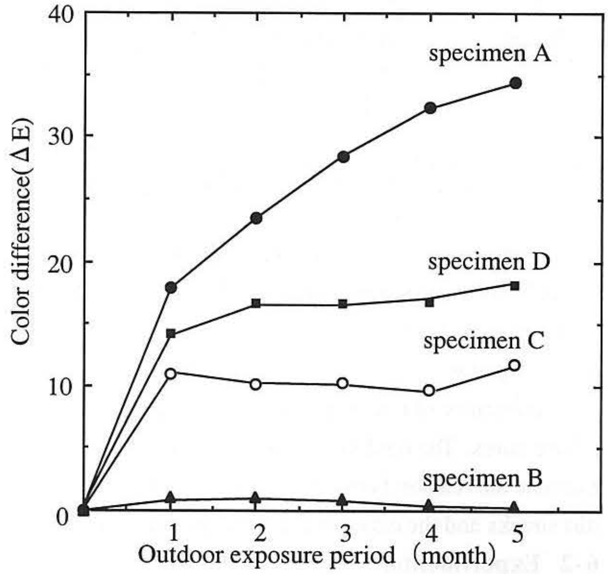


Fig.13 Color difference(ΔE) during the five-month outdoor exposure test at Higashimatsuyama, Saitama prefecture

5-3-2 Dirt-repellency of PTFE-coated fabrics after the outdoor exposure test

Fig. 14 shows the results of ΔE for specimens E and F. ΔE for specimen E with non-treated TiO_2 was in the range of five to ten. On the other hand, specimen F with TiO_2 maintained excellent dirt-repellency after the 2-year outdoor-exposure test. This result shows that PTFE-coated glass fiber fabrics which are said to have excellent dirt-repellency showed farther increased dirt-repellency with TiO_2 treatment.

5-4 Conclusion

The test results showed that the PVC-coated and PTFE-coated fabrics top-coated with TiO_2 hardly collected dirt. The fabrics became further superior in dirt-repellency with TiO_2 treatment.

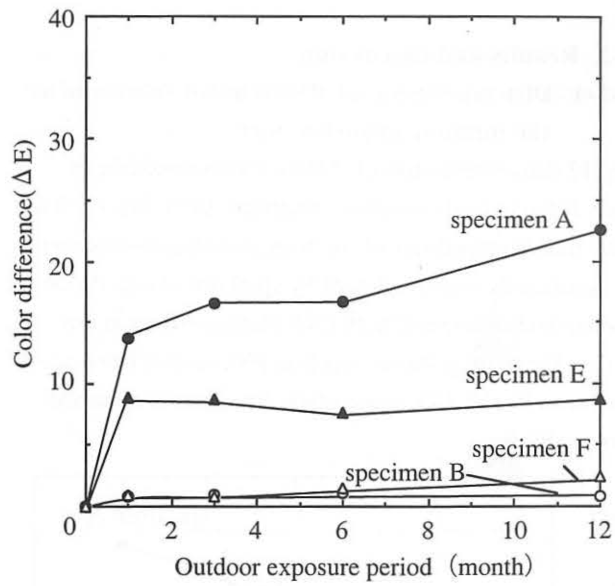


Fig.14 Color difference(Δ E) during the one-year outdoor exposure test at Hirakata, Osaka prefecture

6. Relationship between angle of the side wall and the rain water dirt streaks in the outdoor exposure test

6-1 Purpose

The appearance of rain water dirt streaks spoils the beauty of structures. The outdoor exposure test was carried out to examine the relation between the degree of the rain water dirt streaks and the exposure angle of the side wall.

6-2 Experimental

6-2-1 Specimens

Commercial PVC-coated polyester fabric and PTFE-coated glass fiber fabric without the surface treatment were used as specimens.

6-2-2 The outdoor exposure test

The outdoor exposure test was carried out using unloaded specimens 5cm wide and 100cm long. The specimen rack was divided into two parts: the roof fixed at 45 degrees, and a side wall fixed at an angle ranging from 45~90 degrees at an interval of 5 degrees(Fig. 15).

6-3 Results and discussion

Fig. 16 shows the rain water dirt streaks on the specimens after seven months. When the exposure angle of the side wall against the horizontal plane was 45 ~ 65 degrees, rain water dirt streaks were not observed. However, when the angle exceeded 65 degrees, streaks appeared.

As a structural requirement against the rain water dirt streaks on the side wall, the angle between the horizontal plane and the side wall should be as small as possible.

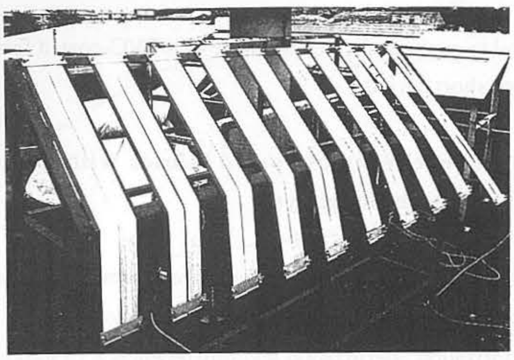


Fig.15 Scene of the outdoor exposure test with various angles of the side wall
(From right 45 degrees, 50 degrees ・ ・ ・ 90 degrees)

6-4 Conclusion

It was found that rain water dirt streaks appear when the exposure angle of the side wall exceeds 65 degrees.

7. General summary

(a) The degree of dirt is more conspicuous in the case of light-colored coated fabrics than darker ones.

(b) The surface treatment with one hundred percent fluorocarbon-resin clearly reduced dirt-repellency. Membrane materials were most polluted in Tokyo and Osaka.

(c) The dirt process accelerating test is useful in judging the dirt-repellency of PVC-coated fabrics in a short period.

(d) PVC-coated and PTFE-coated fabrics top-coated with TiO_2 hardly collect dirt and their dirt-repellency is superior to the treatment with one hundred percent fluorocarbon-resin.

(e) Rain water dirt streaks were not observed when the exposure angle of the side wall against the horizontal plane was 45~60 degrees, but the streaks appeared when the angle exceeded 65 degrees.

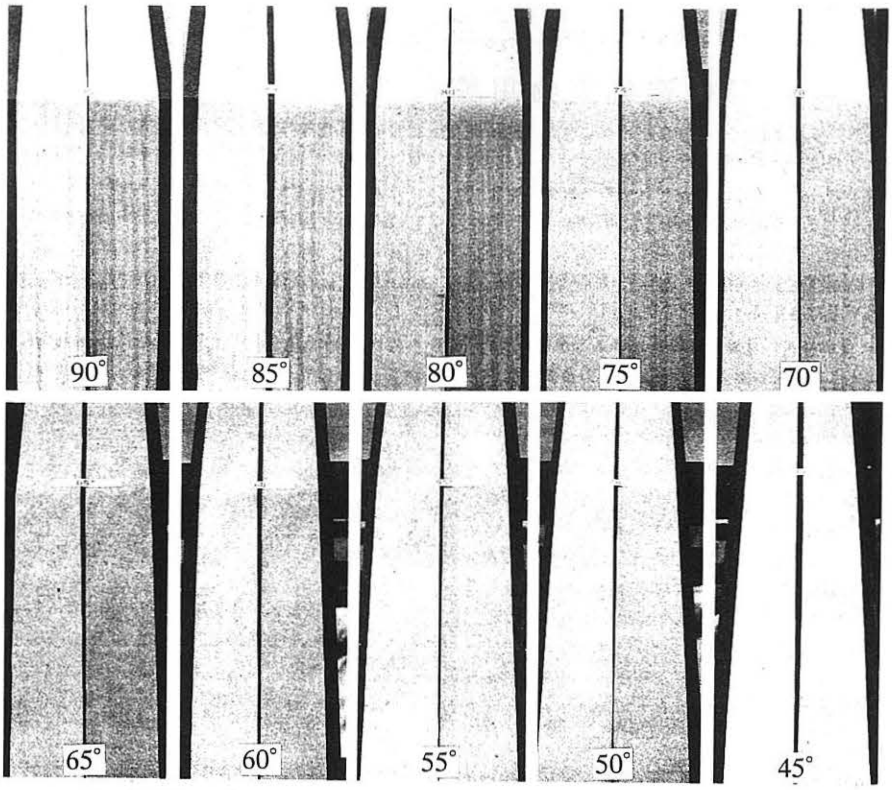


Fig.16 The rain water dirt streaks on the specimens after seven months

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膜構造建築物用膜材料の防汚性評価

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梗　概

膜材料の防汚性評価に関して一連の研究を行い、これらをまとめた。

膜材料の表面処理については、100%フッ素樹脂の処理は防汚効果があり、更に酸化チタン光触媒を用いると顕著に防汚効果が認められた。

膜材料の防汚性評価において地域差を調べたところ、東京や大阪では非常に汚れが付着しやすいことがわかった。

促進汚れ試験機を開発した。試験結果は屋外暴露試験結果と良く一致した。

屋外暴露試験における側面の角度が雨筋状汚れに及ぼす影響について調べた結果、側面の暴露角度が65°より大きくなると雨筋状汚れが発現することがわかった。

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