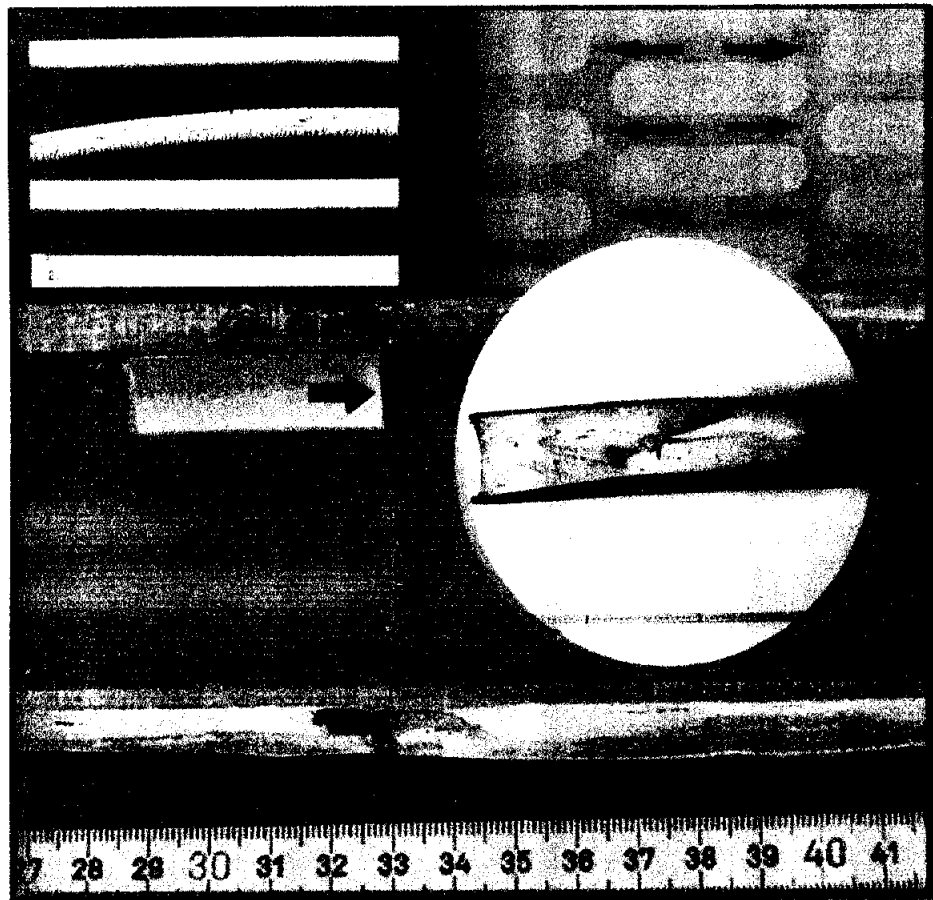




TISTR

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PLASTICS WEATHERING TEST AND EVALUATION PROJECT



THAILAND INSTITUTE OF SCIENTIFIC AND TECHNOLOGICAL RESEARCH

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PLASTICS WEATHERING TEST AND EVALUATION PROJECT

Report No.1

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By

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TISTR, Bangkok 1998
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(Dr. Kesha Lawanyawatna)
Governor

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โครงการการทดสอบและประเมินความคงทนของพลาสติกต่อสภาพภูมิอากาศ

ชโลธร ภมรสุด, รุจิภรณ์ นาคขุนทด, นพรัตน์ แก้วมงคล,
สรศักดิ์ สุภณไล้ และ เอกรัตน์ วุฒิเวทย์

บทคัดย่อ

ได้ทำการศึกษาความคงทนต่อสภาพภูมิอากาศของวัสดุประเภทพลาสติกในสภาวะแวดล้อมนอกอาคารที่ วท. กรุงเทพฯ ในระหว่างเดือนธันวาคม 2539 - สิงหาคม 2541 เป็นระยะเวลา 20 เดือน. ตัวอย่างแบ่งออกเป็น 2 กลุ่ม ตามวัตถุประสงค์หลักของโครงการ. กลุ่มที่ 1 ได้แก่ แผ่นพลาสติกชนิด PE, PVC, และ PC ทั้งที่ใส่และไม่ใส่สารเติมแต่ง (stabilizers) เพื่อศึกษาอัตราและลักษณะการสลายตัวของพลาสติกจากสภาวะแวดล้อม, และกลุ่ม 2 ได้แก่ พลาสติก 9 ชนิด ได้แก่ PE, LDPE, PP, PVC, PC, PA, PET, Par และ PS เพื่อศึกษาความเป็นไปได้ของการนำไปใช้เป็นวัสดุอ้างอิงมาตรฐานในการทดสอบผลกระทบของสภาวะแวดล้อมต่อพอลิเมอร์. จากการศึกษาพบว่าข้อมูลการสลายตัวของพลาสติก ซึ่งพิจารณาจากลักษณะการเปลี่ยนแปลงทางกายภาพ, การเปลี่ยนแปลงสมบัติทางกล และการเปลี่ยนแปลงโครงสร้างทางเคมี มีความสัมพันธ์โดยตรงกับข้อมูลทางสภาพภูมิอากาศโดยเฉพาะอย่างยิ่งปริมาณแสงแดดและอุณหภูมิ. การสลายตัวของพลาสติกทำให้มีการเปลี่ยนแปลงของสี, ค่าความเงาลดลง ซึ่งเป็นผลจากการเปลี่ยนแปลงบริเวณผิวของพลาสติกในช่วงแรกๆ ของการสลายตัว. นอกจากนี้ PE และ PVC จะมีความต้านทานต่อแรงดึง (tensile strength) และการยืดตัว (elongation) ลดลง ซึ่งเป็นผลจากการเปลี่ยนแปลงของโครงสร้างโมเลกุลของพลาสติก. พบว่าค่าความเงาของ PC ลดลงเหลือร้อยละ 90 ในช่วงเวลา 7 เดือน, PVC เปลี่ยนแปลงสีในช่วง 2 เดือน. นอกจากนี้ PE และ PVC มีค่าความต้านทานต่อแรงดึง และการยืดตัวลดลง ซึ่งเป็นผลจากการเปลี่ยนแปลงโครงสร้างโมเลกุล; ค่าความต้านทานต่อแรงดึง และการยืดตัวของ PE ลดลงประมาณร้อยละ 50 เมื่อผึ่งในบรรยากาศในกรุงเทพฯ เป็นเวลา 6 เดือน. การทดสอบฟิล์มพลาสติกพบว่า PE, LDPE, PVC, PC, PET และ PS มีการเปลี่ยนแปลงสมบัติทางการดูดกลืนคลื่นแสงสอดคล้องกับการเปลี่ยนแปลงปริมาณแสงแดดและอุณหภูมิ ซึ่งอาจใช้แสดงสภาวะแวดล้อมได้. สำหรับค่า carbonyl index ใน PE reference film สามารถใช้เป็นตัวชี้ถึงความรุนแรงของสภาวะแวดล้อมต่อการสลายตัวของพลาสติกได้ เพราะมีความสอดคล้องกับการเปลี่ยนแปลงคุณสมบัติของพอลิเมอร์หลายชนิด.

PLASTICS WEATHERING TEST AND EVALUATION PROJECT

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Sorrarak Suphonlai¹ and Ekarat Vutivat¹

ABSTRACT

The exposure test of plastic materials was conducted at TISTR, Bangkok during December 1996 - August 1998 (20 months). The specimens were divided into 2 categories for 2 objectives. Firstly, types of plastic sheets namely PE, PVC and PC, with and without stabilization for evaluating the weatherability of plastic materials and, secondly, 9 types of plastic films and sheets namely PE, LDPE, PP, PVC, PA, PET, PC, PAr and PS for investigating the possibility for reference materials in weathering tests. It was found that the degradation of plastic materials which could be identified by visual inspection, glossiness, colour change, tensile strength and elongation, IR and UV absorption of plastics showed certain correlation with the climatic data especially solar radiation and temperature. The exposed plastic sheets showed increasing of colour and decreasing of glossiness due to surface change in the early stage of exposure. Glossiness of PC reached 90% in 7-month exposure whereas unstabilized PVC changed colour within 2 months. Moreover, PE and PVC showed decreasing of tensile strength and elongation due to change in molecular structure. The tensile strength and elongation of PE decreased to 50% retention by 6-month exposure. The correlation of reference films characteristics such as IR and UV absorption of PE, LDPE, PVC, PC, PET films and PS with temperature and solar radiation showed a positive results and may represent environmental conditions. The value of carbonyl index of PE reference film can be used as an index to represent the exposure environment severity because they are related with changes of physical properties in many kinds of polymers.

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INTRODUCTION

The plastics weathering test and evaluation project has been conducted under the cooperation works in Southeast Asian countries and Japan in joint developing international standards on weathering resistance of industrial polymer materials based on regional interests in order to facilitate cooperation in APEC standards and conformance activities. The project has been supported by Japanese Standards Association (JSA) of Agency of Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI), Japan who has allocated a first stage budget for two-year program of polymer exposure. The cooperation program comprising four different exposure locations in four countries namely Japan Weathering Test Center (JWTC), Japan, Industrial Technology Development Institute (ITDI), Philippines, Indonesian Institute of Sciences (LIPI), Indonesia and Thailand Institute of Scientific and Technological Research (TISTR), Thailand started in December 1996 and ended in August 1998.

This report provided the results of all plastics exposure and measurement throughout the project which were carried out for 20 months (December 1996 - August 1998) in Bangkok and also included the data analysis.

1. Objectives

- 1.1 To study the weatherability of plastic materials.
- 1.2 To investigate the possibility of reference materials in weathering tests.

2. Introduction of the exposure site

2.1 Geographical of the exposure site

The exposure test site was located at an altitude of 12 on the roof of TISTR building near the traffic road, Bangkok, Thailand, situated at the latitude of 13.8°N and the longitude of 100.6°E (Figures 1 and 2). The climate was a tropical climate with strong sunshine throughout the year and there was no strong monsoon.

Due to the location of exposure site which was adjacent to traffic road even on the roof of the building, a lot of dust from transportation and construction tended to cover the specimens surface or cling to the surface so the specimens needed to be cleaned once a week.

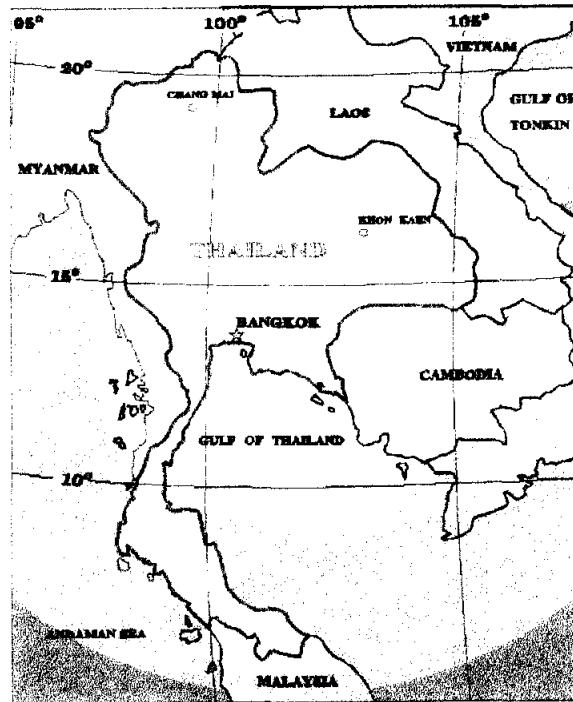


Figure 1. Exposure location in Thailand.

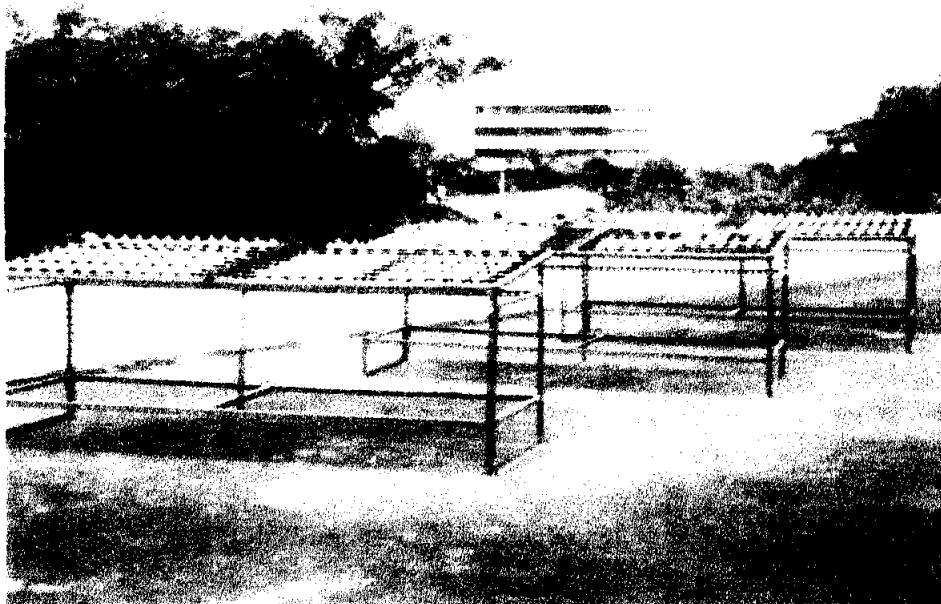


Figure 2. Exposure site at TISTR, Bangkok, specimens were placed on the roof of main building.

2.2 Local consumption of major plastic materials in Thailand.

In Thailand, some plastic materials such as PE, PVC, PP, PS, etc. have been produced for local supply and export. The local consumption of such major plastic materials is shown in Table 1.

Table 1. Local consumption of major plastic pellet

Unit : 1000 tons/year

Plastic pellet	1993	1994	1995	1996
PE	410	550	589	642
PVC	305	432	363	384
PP	287	299	291	434
PS	114	132	137	149
EPS	20	22	26	35
ABS/SAN	63	70	80	98
Total	1,199	1,505	1,486	1,742

Source : Petroleum Institute of Thailand, Focus Special Annual Issue 1996

MATERIALS AND METHODS

1. Test specimens

Test specimens were divided into 2 groups according to the objectives of the test. The first group ((1) - (6)) was to study on the weatherability of plastic materials and the second group ((7) - (15)) was to investigate the possibility of reference materials in weathering tests. Size, number and exposure period were described in Table 2.

2. Test method

Exposure test was performed on the roof of TISTR building by placing the test specimens at an angle of 5° tilted from the horizontal, in order to obtain maximum radiation, while providing definite run-off for rain-water, facing south without backing. Specimens were mounted with the uncoded side facing the sun (Figures 3 and 4). The exposure test site was located at the latitude of 13.8°N and the longitude of 100.6°E. Specimen's name and number were marked in Japan.

Table 2. Size and number of specimens used in the test

Materials	Size (mm)	Exposure period (months)	Number of specimens for each exposure period	Total number of specimens
(1) PE-A (*1)	150x70x2	1, 2, 3, 6, 9, 12, 15	6	42
(2) PVC-A	150x70x2	1, 2, 3, 6, 9, 12, 15	6	42
(3) PC-A	150x70x2	1, 2, 3, 6, 9, 12, 15	6	42
(4) PE-B (*2)	150x70x2	6, 12, 15	6	18
(5) PVC-B	150x70x2	6, 12, 15	6	18
(6) PC-B	150x70x2	6, 12, 15	6	18
(7) PE reference film	50x15x0.2	1 (*3)	4	60
(8) PP film	50x15x0.2	1 (*3)	4	60
(9) LDPE film	50x15x0.2	1 (*3)	4	60
(10) PVC film	150x70x0.2	2, 4, 6, 8, 10, 12,15	2	14
(11) PC film	150x70x0.2	2, 4, 6, 8, 10, 12,15	2	14
(12) PA film	150x70x0.2	2, 4, 6, 8, 10, 12,15	2	14
(13) PET film	150x70x0.2	2, 4, 6, 8, 10, 12,15	2	14
(14) Polyarylate film	150x70x0.2	2, 4, 6, 8, 10, 12,15	2	14
(15) PS	130x125x1	2, 4, 6, 8, 10, 12,15	2	14

*1: Without or low level of stabilization

*2: With high level of stabilization

*3: One- month exposure are repeated with new specimens for 15 months.

The climatic data was investigated over the exposure period. Temperature and relative humidity data were recorded by Hygrothermograph, and solar radiation energy was recorded by Pyranometer at the exposure site. The rainfall data was received from Don Muang Meteorological Station which is the nearest Bureau climate station to the site.

All specimens were exposed at the beginning of exposure test programme, except for (7)PE reference films, (8)PP films and (9)LDPE films. The exposure period started on December 2, 1996 in the dry and low temperature season and ended on March 2, 1998 (15 months). Revised program of reference films exposure test was conducted during September 1997-August 1998 (12 months).

Test specimens were taken out from outdoor exposure rack after the period specified in Table 2. The exposed specimens on the racks were cleaned to remove dirt once a week using deionized water and gauze, taking care not to scratch the surfaces.

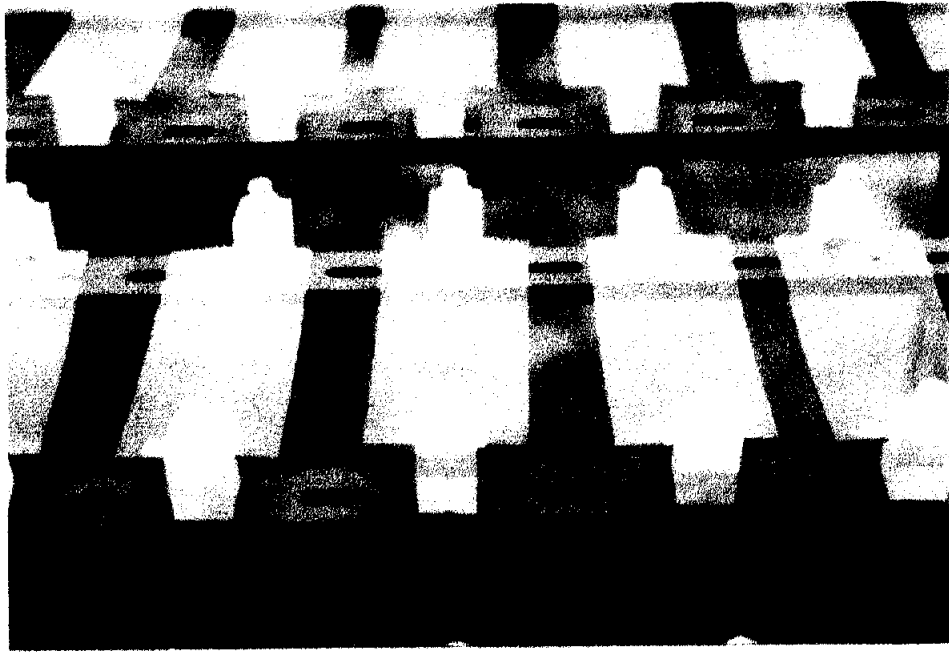


Figure 3. Mounting of plastic sheets on the exposure rack.

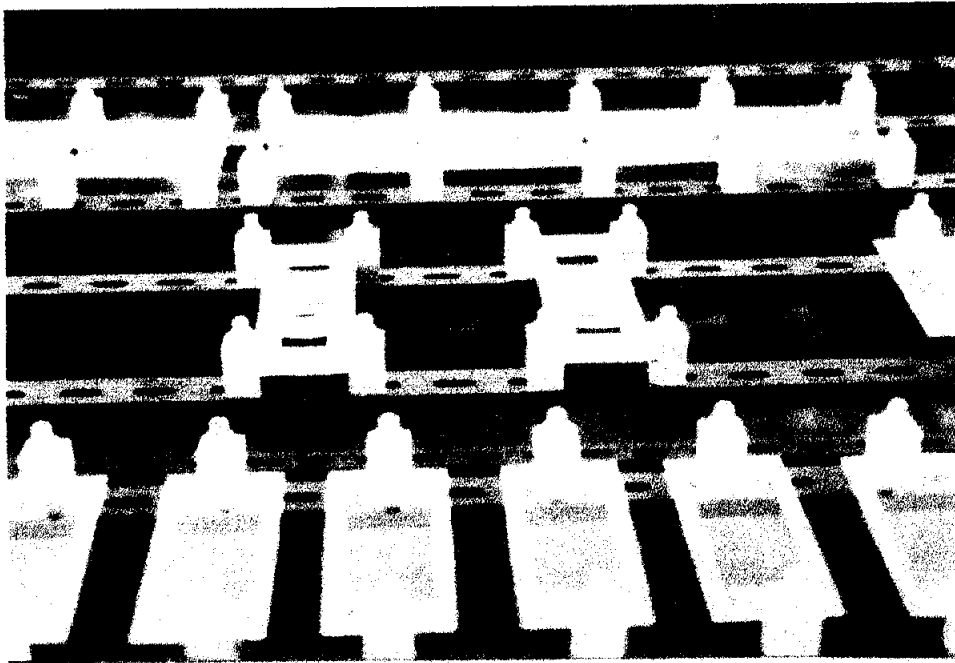


Figure 4. Mounting of plastic films on the exposure rack.

3. Measurement

After exposure test (as specified period), half of the number of the specimens were used for measurement of properties listed in Table 3. The other half of the number of the specimens were returned to JWTC (Japan).

Table 3. Measurement items for each material

Materials	Measurement items
(1) PE-A	colour difference, gloss, tensile strength and elongation
(2) PVC-A	colour difference, gloss, tensile strength and elongation
(3) PC-A	colour difference, gloss
(4) PE-B	colour difference, gloss, tensile strength and elongation
(5) PVC-B	colour difference, gloss, tensile strength and elongation
(6) PC-B	colour difference, gloss
(7) PE reference film	IR
(8) PP film	IR
(9) LDPE film	IR
(10) PVC film	IR, UV, colour difference, gloss
(11) PC film	IR, UV, colour difference, gloss
(12) PA film	UV, colour difference
(13) PET film	IR, UV, colour difference, gloss
(14) Polyarylate film	IR, UV, colour difference, gloss
(15) PS	UV, colour difference, gloss

3.1 Measuring instrument

1. Handy gloss meter SUGA : Model HG - GS (60°)
2. Handy colour tester SUGA : Model H-CT
3. Infrared spectrometer JAS. CO. : Model IR - 700
4. Ultraviolet spectrometer SHIMADZU : Model UV -2100S
5. Tensile & elongation testing machine SHIMADZU : Model AG - 5000A

3.2 Conditioning and measuring conditions

The samples were conditioned for not less than 48 hours in a dark place at the temperature of 23° C and relative humidity of 55-60 % before testing. The test was conducted in the same condition. Preparation for tensile test was performed by making them into a dumbel shape after exposure.

**4. Revised program for plastic films exposure test and measurement
(September 1997- August 1998)**

The program for plastic film testing during September 1997- August 1998 was changed as specified in Table 4 according to requirement in the second objective of the test.

Table 4. Revised program for plastic films exposure test and measurement during September 1997-August 1998

Materials	Exposure period (months)	Measurement items
8 PP film	no exposure test	-
10 PVC film	10,12,15	gloss, colour
	1 month (10,11,12,13,14,15)	IR,UV
	2 months (10-11,12-13,14-15)	IR,UV
11 PC film	10,12,15	gloss, colour
	1 month (10,11,12,13,14,15)	IR,UV
	2 months (10-11,12-13,14-15)	IR,UV
	3 months (10-12,13-15)	IR,UV
12 PA film	10,12,15	gloss, colour
	1 month (10,11,12,13,14,15)	IR,UV
	2 months (10-11,12-13,14-15)	IR,UV
	3 months (10-12,13-15)	IR,UV
13 PET film	10,12,15	gloss, colour
	1 month (10,11,12,13,14,15)	UV
	2 months (10-11,12-13,14-15)	UV
15 PS	10,12,15	gloss, colour
	1 month (10,11,12,13,14,15)	UV
	2 months (10-11,12-13,14-15)	UV
	3 months (10-12,13-15)	UV

RESULTS AND DISCUSSION

The results of December 1996 - August 1998 exposure test and measurement are reported as follows:

1. Climatic data

The climatic data in the year 1997 and 1998 were summarized in Figure 5. The average temperature of exposure environment was around 26-32°C. The maximum temperature was 36 °C in May and June which were in the hot season

where the highest solar energy was 620 MJ/m^2 in March 1998. Comparatively low temperature period was rather short, beginning a few months before the new year. The hot season took a few months after low- temperature period. Wet season started in June and ended in October with temperature around $25\text{-}32^\circ\text{C}$.

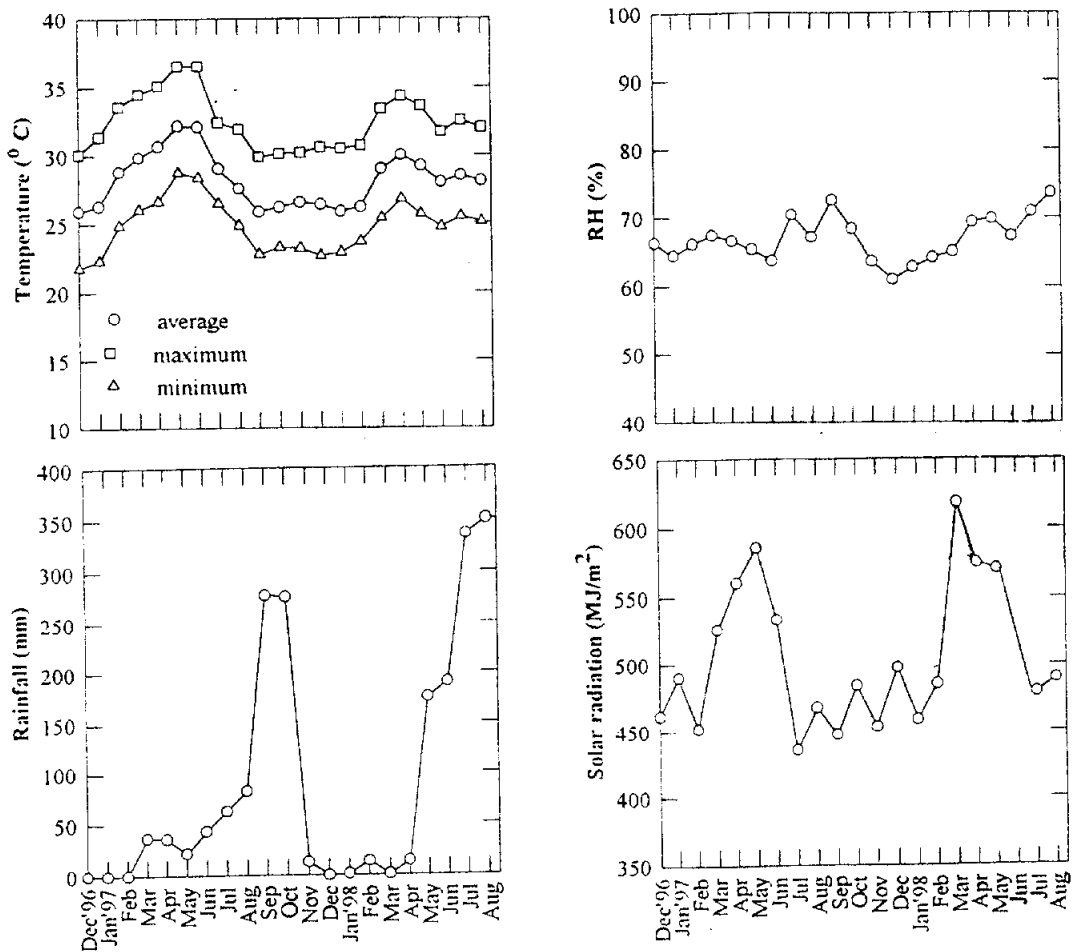


Figure 5. Seasonal change of climatic data at TISTR.

2. Colour measurement

The colour measurement data of specimens after 1-year exposure are presented in Figure 6. Colour difference (ΔE) of unstabilized PE and stabilized PE was about the same value (7) and lower than those of unstabilized PVC (17) and PC (24). For PVC, colour difference of the unstabilized one was higher than the stabilized one after 6-month exposure, but after that period which was in the hot season, surface of stabilized PVC was adhered more by dirt and hard to be cleaned due to the stickiness of the surface than unstabilized PVC. Colour difference of unstabilized PC (25) was higher than stabilized one (11) according to the effect of stabilization. The colour of PA film changed much after 6-month exposure to the value of 27. For films of PVC, PC, PET, PA, the colour difference increased with the exposure time, and after 12 months, the value reached 42, 19, 7, 8 respectively.

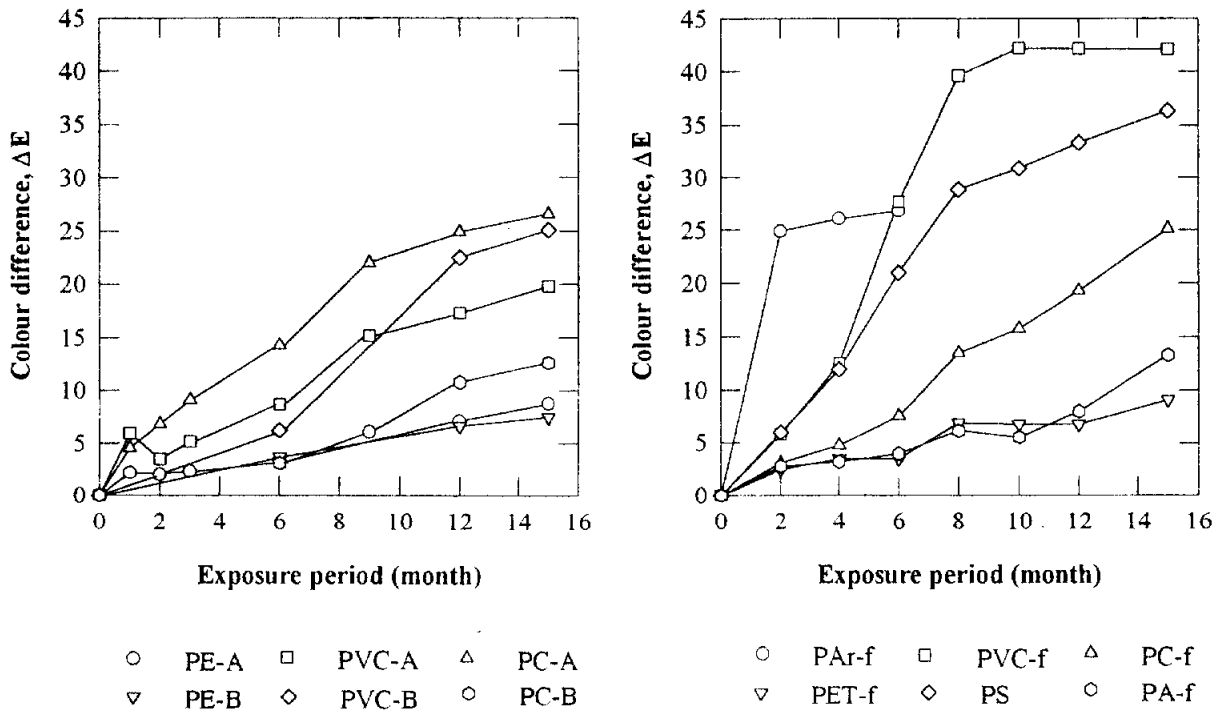


Figure 6. Change of colour difference of plastics.

3. Gloss measurement

The gloss retention data of the specimens after 1- year exposure are presented in Figure 7. The gloss retention of all specimens decreased with exposure time, followed by the exponential decay of plastics degradation. The gloss retention of unstabilized PE (20%) was lower than stabilized PE (55%) after 1 year. For PVC specimens, unstabilized PVC showed lower gloss retention than stabilized PVC. After 1 year, there was an effect of dirt collection on the surface. It was found that the gloss measurement of unstabilized PVC and stabilized PVC showed the same unexpected results as colour difference measurement. The gloss retention of unstabilized PC and stabilized PC was about 65% after 1 year. PAr showed decrease of gloss retention to 52% after 6 months. The gloss retention of PVC film, PC film, PET film and PS sheet was 62%, 57%, 65% and 22% respectively. The gloss retention decreased much during March to June which was in the period of high solar radiation, about 500 MJ/m².

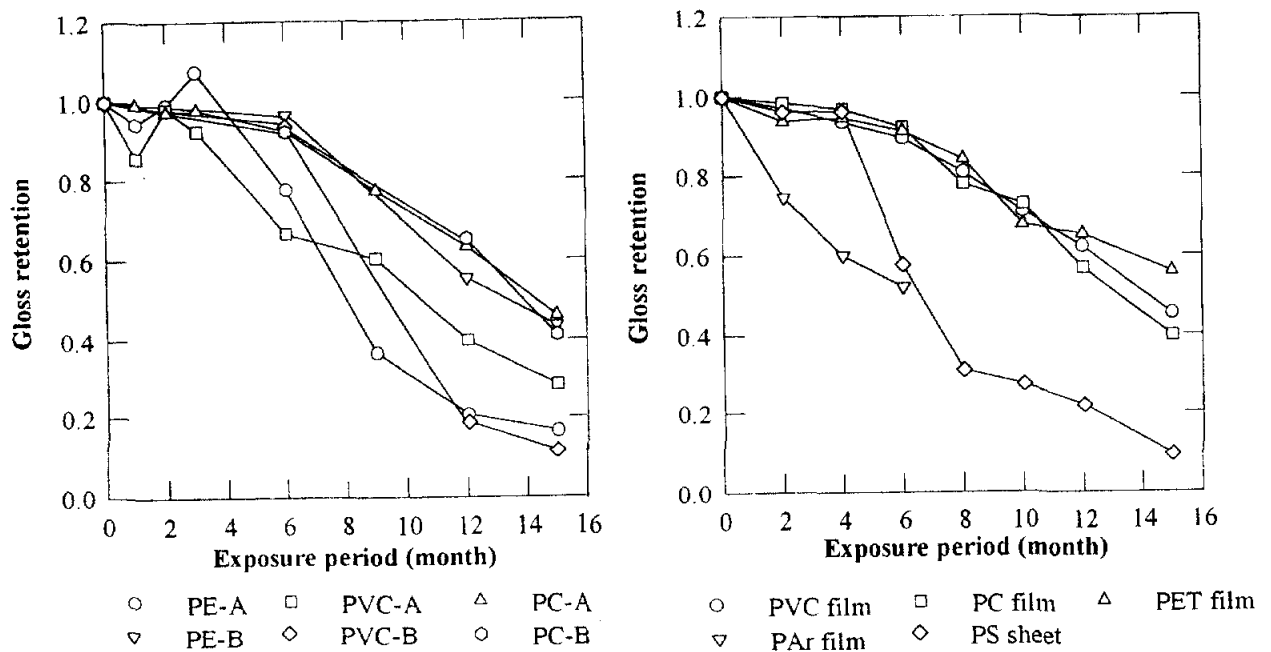


Figure 7. Change of gloss retention of plastics.

4. Tensile strength and elongation measurement

The tensile strength and elongation data of PE and PVC specimens are presented in Figures 8-13. The tensile strength and elongation at break of stabilized PE was higher than unstabilized PE after 6- month exposure. The breaking strength of unstabilized PE decreased to 60% (8 kPa) of an initial value (14 kPa), whereas elongation at break value decreased 50% (to 90% elongation). But after 6 months, the surface cracks of unstabilized PE could be observed along the horizontal direction of the exposed surface ; therefore, the strength and elongation decreased drastically. The strength and elongation at break of stabilized PE was about 14 kPa and 200 % elongation. For PVC, the breaking strength and elongation at break of unstabilized PVC and stabilized PVC did not decrease significantly, the value was about 25 kPa, 300% elongation.

5. Infrared spectroscopy

Figure 14 shows carbonyl index measured monthly at TISTR site. Carbonyl index expressed by the relative amount of carbonyl produced in PE and LDPE films can be used as a reference to the atmospheric aggressive to polymer. The carbonyl index of LDPE change more in the period of high temperature showing the sensitivity to a temperature change. Compared with the climatic data, the carbonyl index and solar radiation in summer were higher than those in rainy and low temperature seasons. This showed correlation of carbonyl index with solar radiation and temperature, indicating that the degradation of plastics was greatly influenced by solar radiation and temperature. After 20- month exposure, it was found that the carbonyl profile over the exposure period was similar. The IR absorption data of PVC film was shown in Figure 15. PVC film showed higher absorption at 1720 cm^{-1} and 3444 cm^{-1} than unexposed PVC film indicating carbonyl group and hydroxyl groups presented in the molecular structure and absorption value increased with exposure time. For PC film, PET film and PAr film, the absorption peaks at 3532 cm^{-1} , 3340 cm^{-1} , 3465 cm^{-1} respectively indicated the increases of hydroxyl groups in the structure after 6- month exposure.

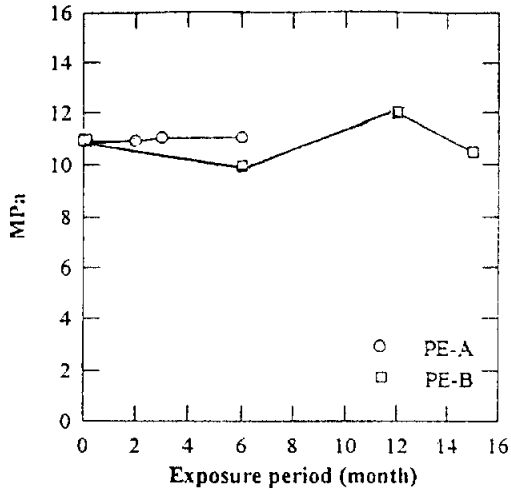


Figure 8. Change of yield strength of PE.

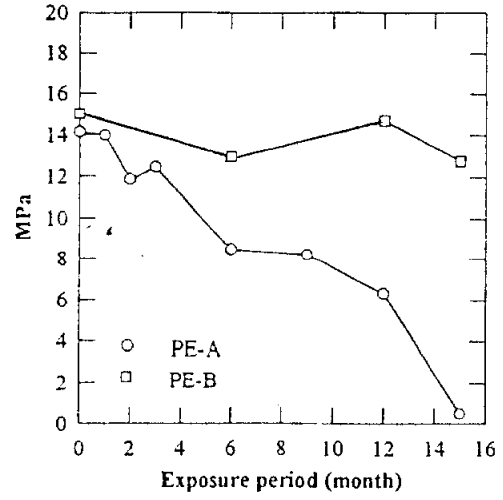


Figure 9. Change of breaking strength of PE.

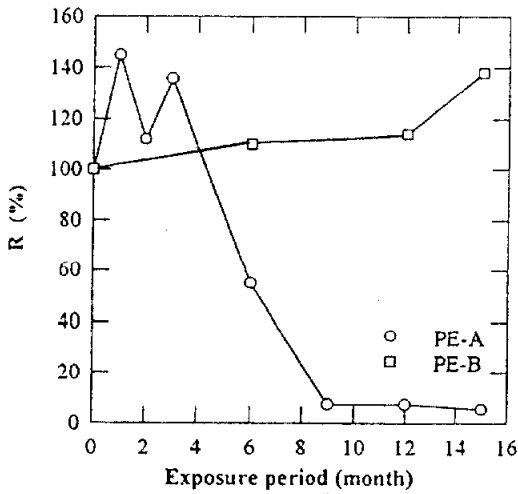


Figure 10. Change of breaking elongation of PE.

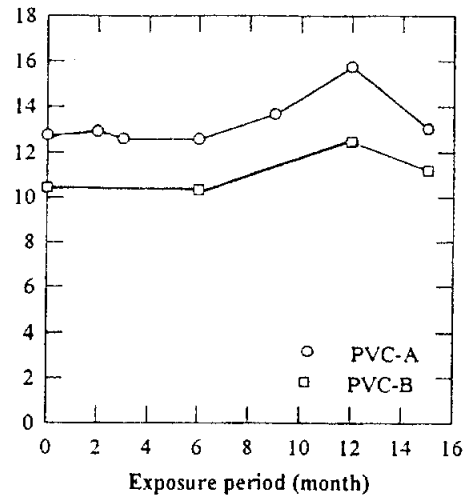


Figure 11. Change of nominal strain point of PVC.

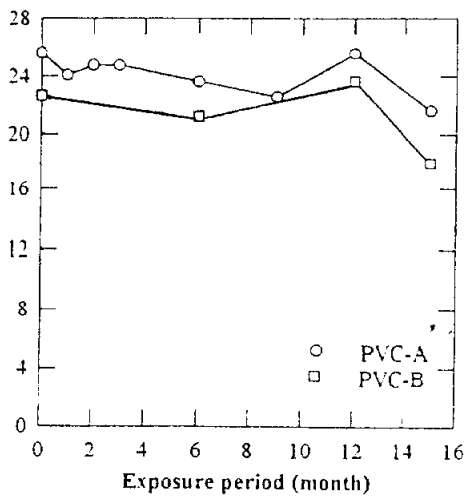


Figure 12. Change of breaking strength of PVC.

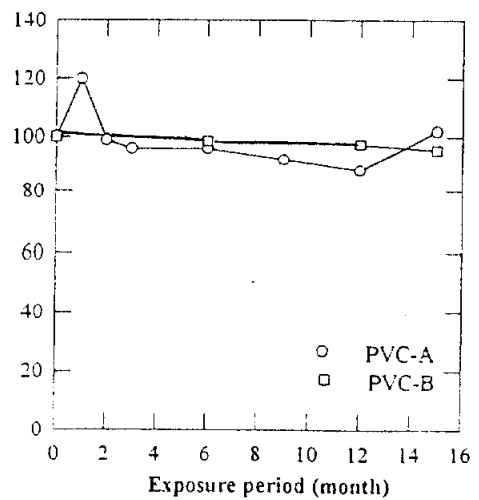


Figure 13. Change of breaking elongation of PVC.

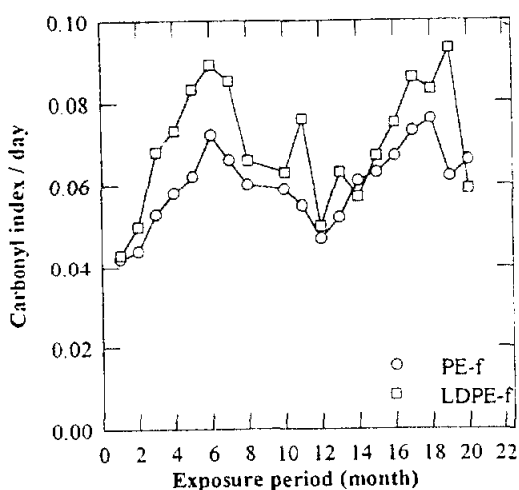


Figure 14. Seasonal change of carbonyl index at TISTR site (Dec. 96-Aug. 98).

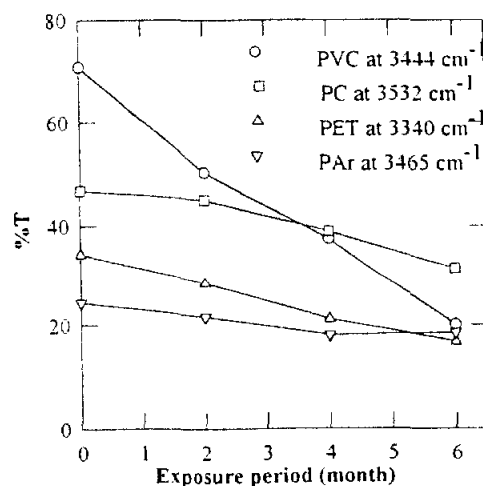


Figure 15. Change of IR transmittance of plastic films (Dec. 96-Jun. 97).

IR absorption results of PVC, PC, PA films according to the revised program, beginning in September 1997 are shown in Figures 16-18. The absorption of the exposed PVC film showed presence of carbonyl and hydroxyl groups. The growth of carbonyl groups correlated with solar radiation energy during 3- month exposure period. Absorption of 2- month exposed PVC was about twice that of 1 month exposed PVC. The IR absorption data of PA film did not show any change due to thickness of samples.

IR absorption of PC showed increases of hydroxyl group at 3490 cm^{-1} with exposure time. The extended exposure program indicated the correlation of climatic data with IR absorption data especially solar radiation and moisture content.

6. Ultraviolet spectroscopy

UV absorption data of plastic films are shown in Figure 19, indicating that UV absorbance of films increased with exposure time which may be due to the presence of oxidation products. PVC film absorbed UV in the region 290-400 nm in the direction that absorption decreased with longer wavelength. PC film, PA film, PET film and PS also followed the same absorption pattern except for exposed PAr film which completely absorbed all the UV range 290-400 nm in the early stage of exposure period.

UV absorption data of PVC film, PC film, PA film, PET film and PS following the revised exposure program (beginning in September 1997) are shown in Figure 20. It was found that the monthly change of UV absorption of each film was not significantly observed due to the exposure period which was in the rainy season with low temperature and solar radiation energy. However, the absorption seemingly tended to correlate with solar radiation energy. The data of 2- and 3-month exposed film showed the increasing UV absorption of films with exposure time. It was found that the UV absorption for each material increased with the highest solar radiation and temperature.

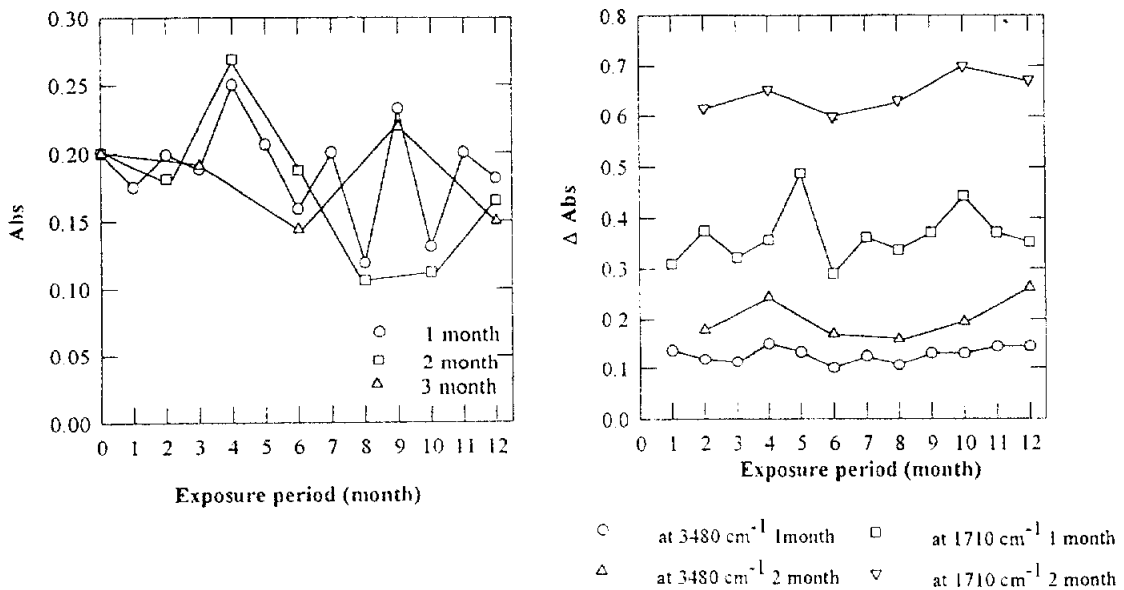


Figure 16. Change of IR absorbance at 2160 cm⁻¹ of PA film (Sep. 97 - Aug. 98). Figure 17. Change of difference in IR absorbance of PVC film (Sep. 97 - Aug. 98).

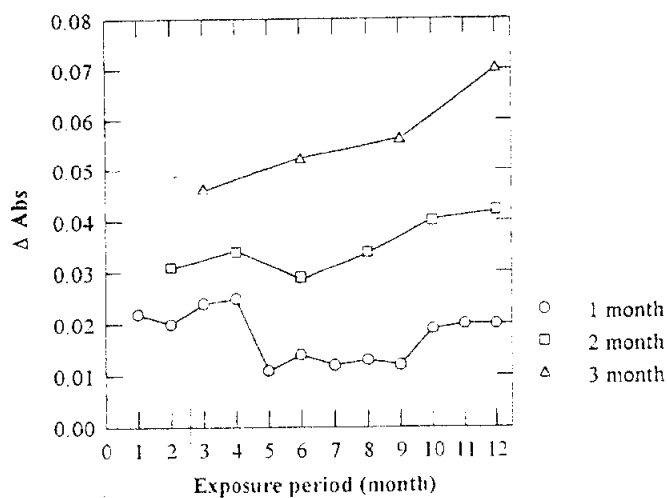


Figure 18. Change of difference in IR absorbance at 3490 cm⁻¹ of PC film (Sep. 97-Aug. 98).

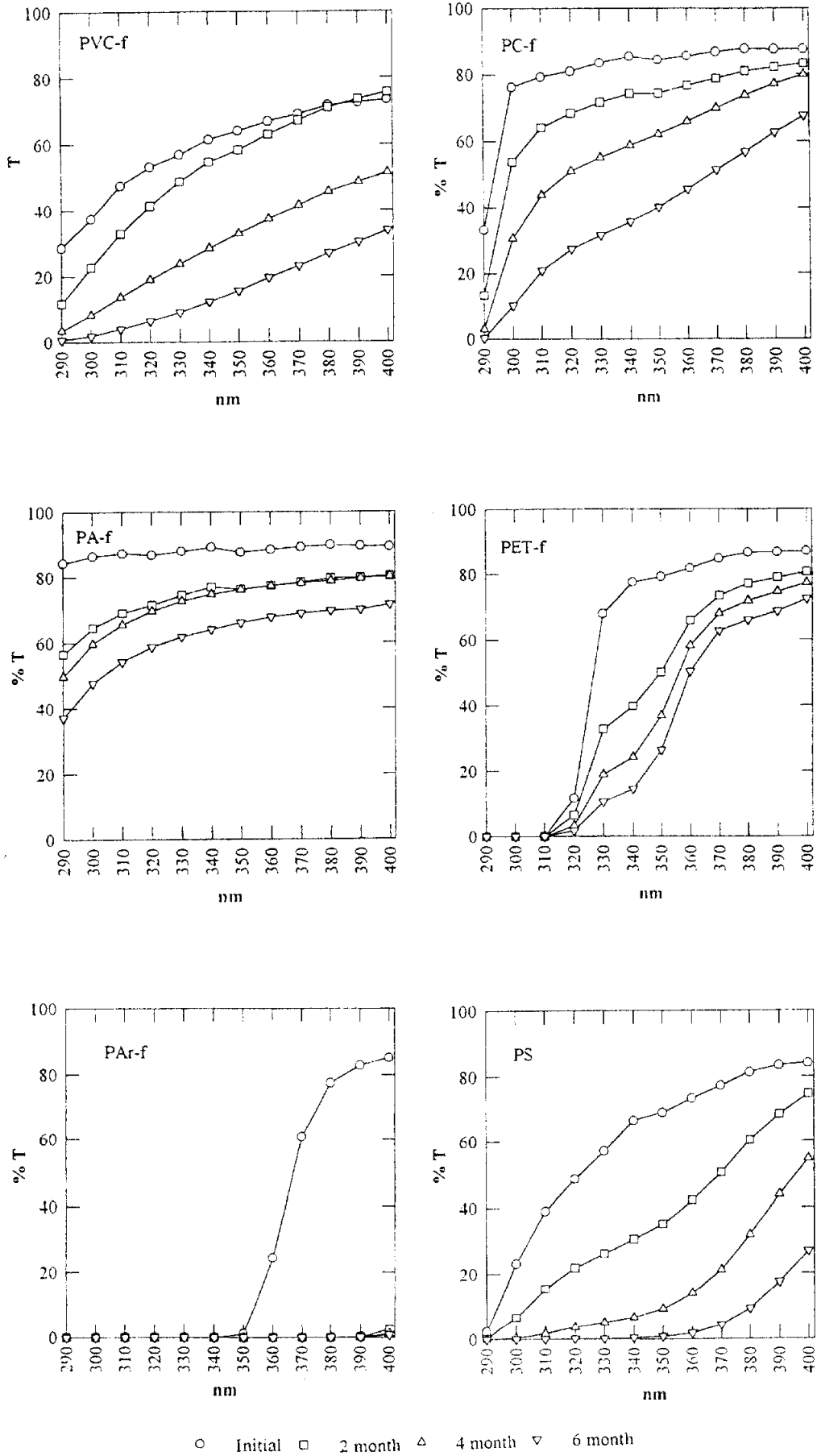


Figure 19. Change of UV transmittance of plastic films (Dec. 96 - Jun. 97).

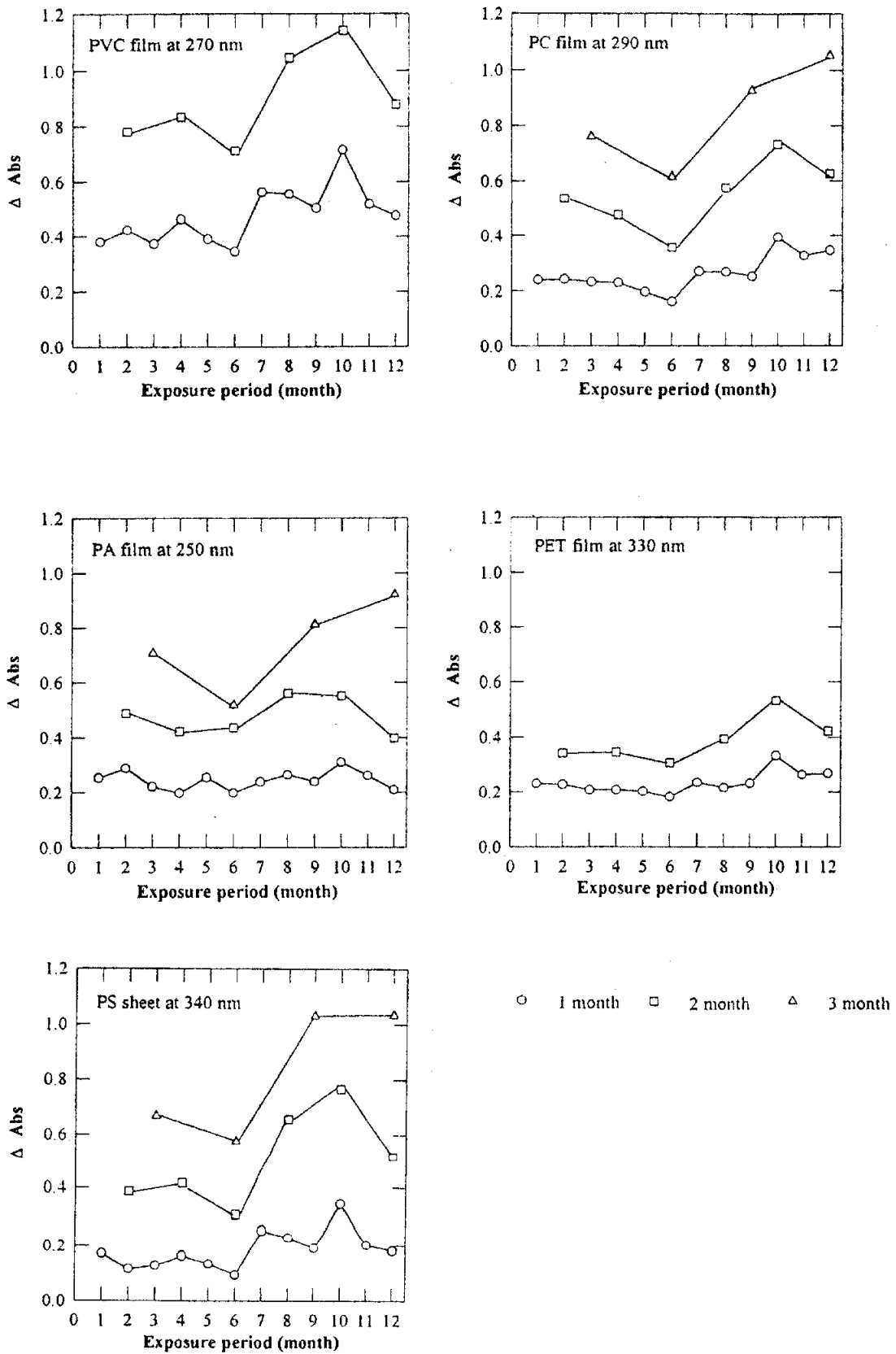


Figure 20. Change of difference in UV absorbance of plastic films (Sep. 97 - Aug 98).

7. Records of changes in appearance of the exposed samples

Samples on the exposure rack were observed every week during the exposure period. The records of changes in appearance are shown in Table 5.

Table 5. Records of changes in appearance of the exposed samples

Date	Any peculiarities in appearance	Loss	Discolouration	Crack	Mold, moss	Others
9 Dec'96			PAR-f : changed to greenish colour			
21 Jan'97			PC-A, PS : surface colour changed to yellow			
31 Mar'97	PA-f: film wrinkle due to expansion					
12 May'97	PVC-A,B: film surfaces easily catch dust due to slightly sticky surface					
19 May'97			PVC-f : colour changed to yellow			
29 Jul'97				PE-A:surface cracks occurred along the horizontal direction on the exposed side		

Conditions concerning the deterioration of plastic materials

General conditions concerning the deterioration of plastic materials at the exposure site by visual inspection were as follows:

1. Colour change - usually changed to yellow and became deepened as the exposure continued.
2. Gloss - loss of gloss due to surface degradation.
3. Discolouration - due to degradation process and dirt collection.
4. Cracking - occurred in unstabilized PE.
5. Dirt collection due to sticky surface occurred in stabilized and unstabilized PVC.
6. Dimensional change occurred in PA film due to expansion.

Examples of such changes of the exposed samples (prior to cleaning) were shown in Figures 21-26.

The degradation of PE caused by UV radiation led to cross-linking and broken main chain. Glossiness decreased gradually and significantly when a visible crack appeared on the surface. The gradual invisible growth of microcracks on the surface was caused by internal stress due to the structural change of the surface. Penetration of dust decreased glossiness and changed colour. The tensile characteristics showed decrease in the yield stress. The fracture occurred before the yield points was reached probably due to main chain. The tensile fracture elongation of unstabilized PE showed that estimated period when retention reached 50% was 6 months.

PVC degraded by UV breaking main chains, and cross-linking while dehydrochlorination reaction generated polyene structure and colouration. The colour changed to brown. A gradual rise in the tensile stress and no decrease in fracture elongation were assumed to be cross-linking occurred first. Glossiness of unstabilized PVC decreased significantly. The specimens surface of stabilized PVC grade became sticky probably due to migration of plasticizers. The glossiness of unstabilized grade decreased due to dirt which could not wash away. The surface change may reflect air pollutant. The stabilized grade changed more. This suggests that this stabilization method was not suitable in this environment. The estimated period when unstabilized PVC grade changed to brown was about 2 months based on the time when the value b^* changes from plus to minus (from blue to yellow) on a^*b^* coordinate in colour measurement.

The degradation of PC causes colouration by photo-Fries reaction. Breaking of main chain causes a decrease of molecular weight. The glossiness decreased and yellowness increased with exposure time. Yellowness in unstabilized PC increased more than stabilized grade. The period when the glossiness reached 90% was about 7 months.

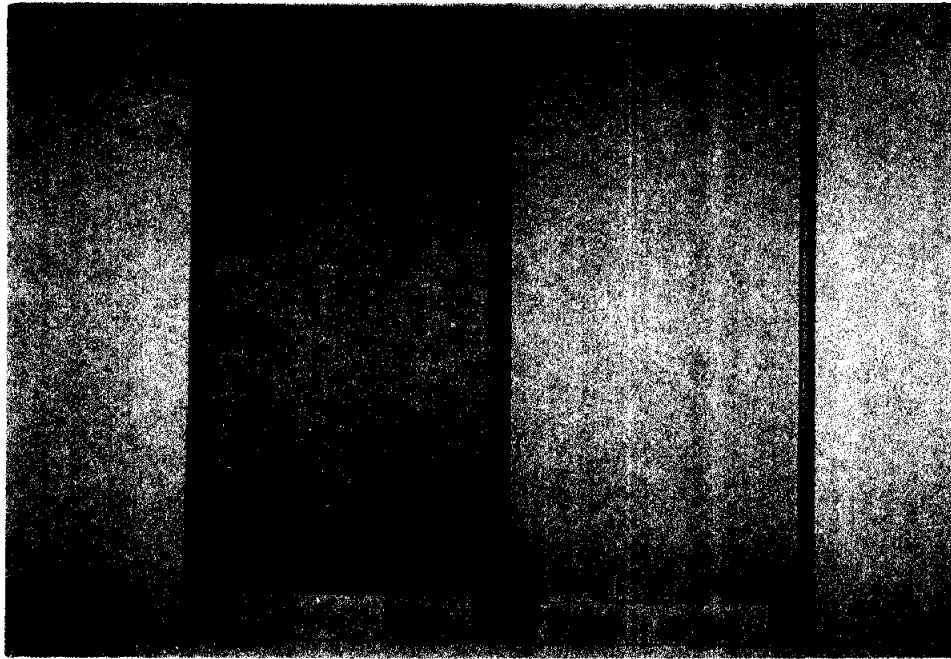


Figure 21. Discolouration of unstabilized PC after 1 - year exposure.

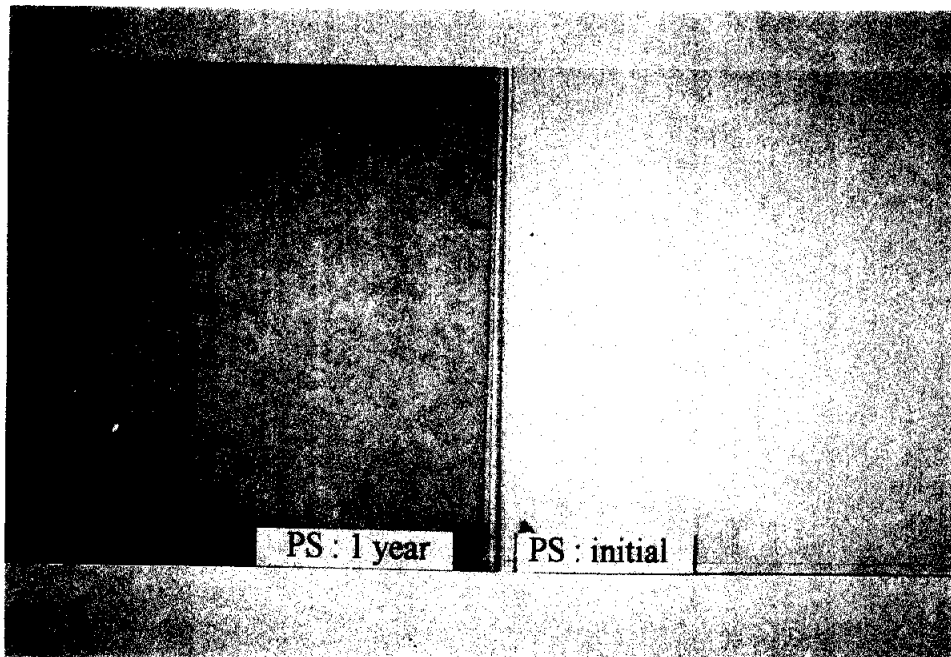


Figure 22. Discolouration of PS after 1 - year exposure.

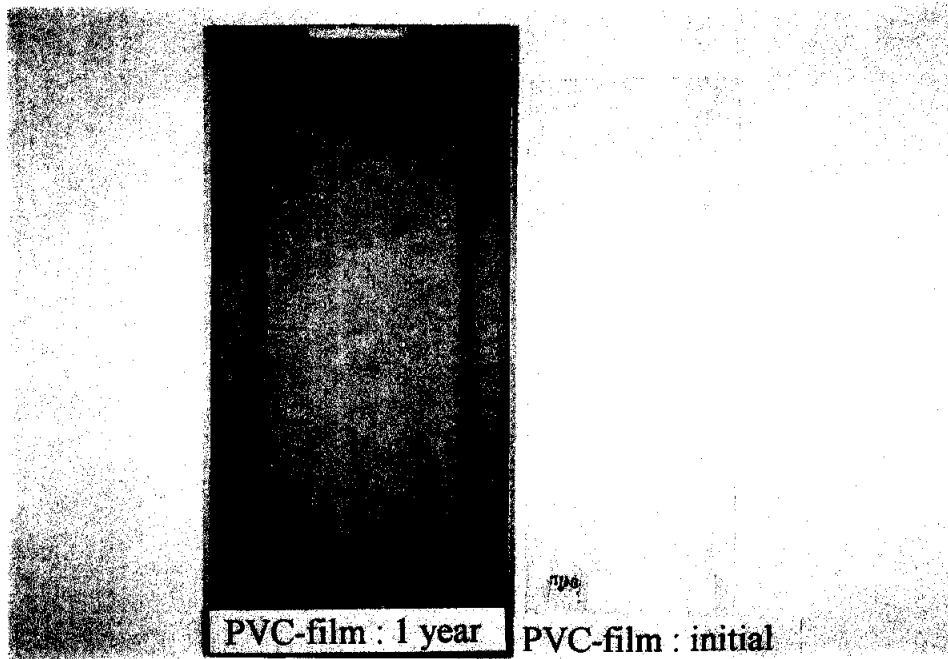


Figure 23. Discolouration of PVC after 1 - year exposure.

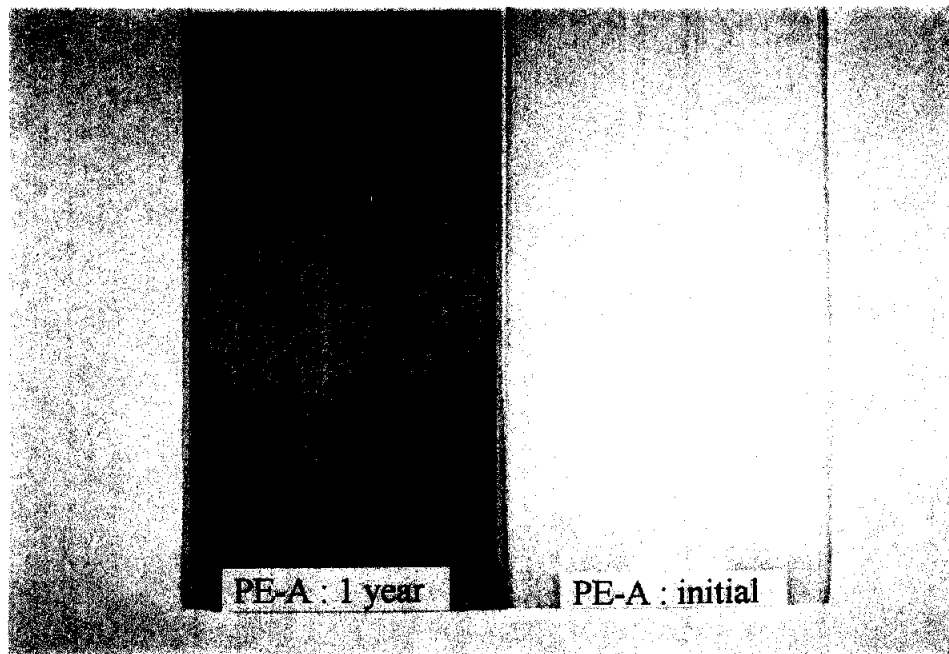


Figure 24. Surface cracking of unstabilized PE after 1 - year exposure.

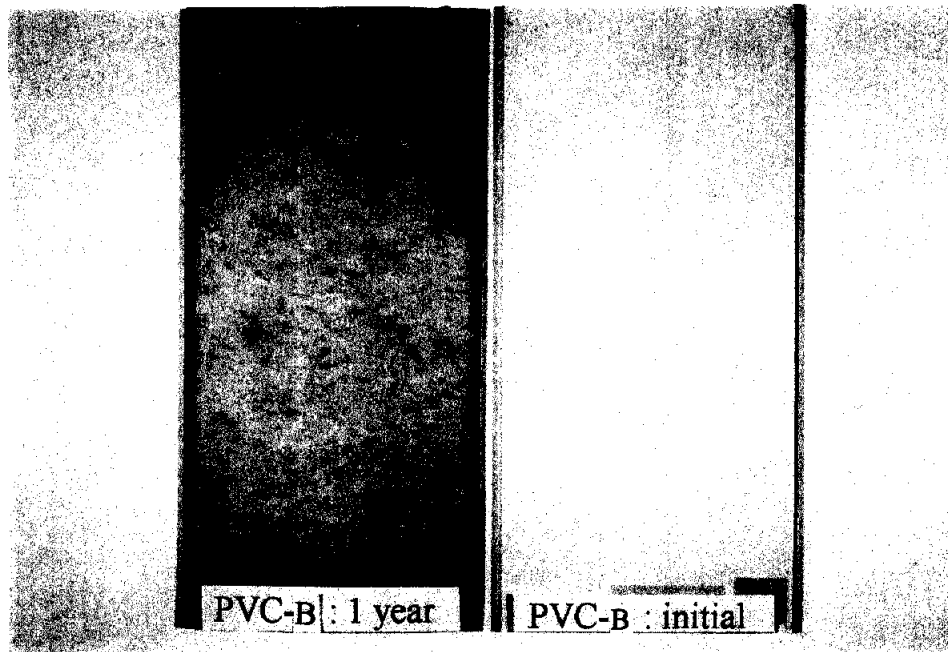


Figure 25. Dirt collection on stabilized PVC surface after 1 - year exposure.

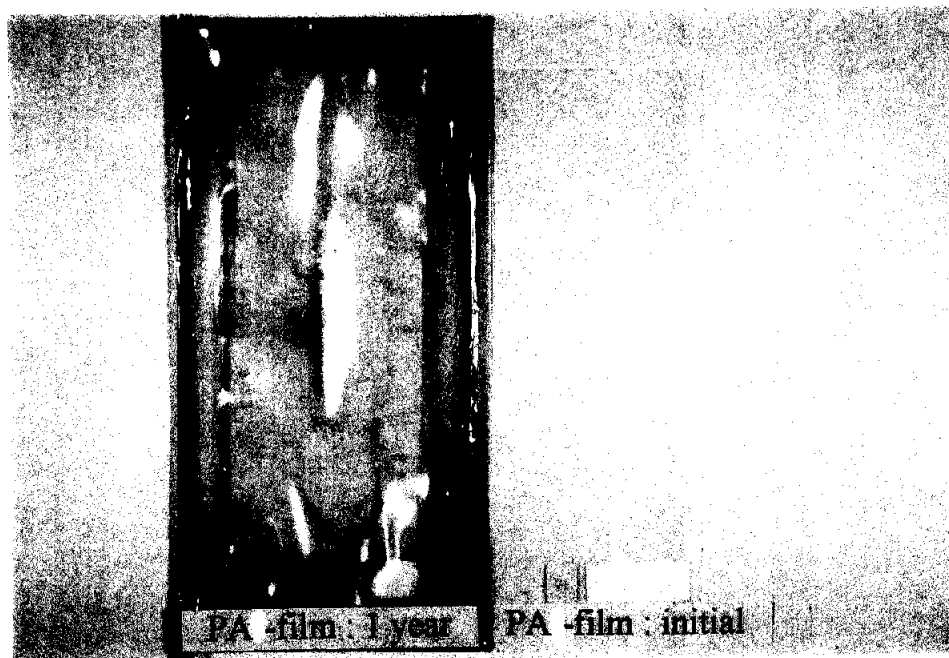


Figure 26. Dimensional change of PA film after 1 - year exposure.

Reference films

Light oxidation of PE film generated carbonyl groups. The carbonyl generation rate is positively correlated to the amount of solar radiation and temperature, thus expected to be an index to indicate the severity of exposure environment.

PP film is not suitable for correlating weathering condition because it did not change by short time exposure.

The reaction rate of LDPE was higher in high temperature than PE standard film, thus showing that the reaction is sensitive to high temperature.

PVC degradation generated conjugate double bond which caused colouration. Transmittance decreased significantly in the range from ultraviolet to visible light. The IR analysis showed a significant change near 1720 cm^{-1} and 3500 cm^{-1} , indicating generation of carbonyl group and hydroxyl group. The carbonyl peak had the positive correlation with solar and temperature. This may represent environmental conditions.

UV analysis of PC film showed a decrease of transmission in the short wavelength range. IR analysis showed slight change near 3500 cm^{-1} . It is suggested that an UV absorbance change may be due to oxidation products.

Light degradation of PA is said to be started by cleavage of CN bond in the amide group, generating various kinds of functional groups. The UV transmittance decreased due to oxidation products. The correlation with carbonyl index was not so good when compared with PVC and PC.

Degradation of PET is said to generate -COOH end groups and fluorescent substance and break main chain. Generation of -COOH is well correlated with UV absorbance.

Light degradation of PS sheet is said to be occurred by automatic oxidation which generates radicals by breaking C-H bond adjacent to benzene ring. A change of UV absorbance is well correlated with yellowing. Generally, there is positive correlation of UV absorbance at 340 nm with temperature and solar radiation and it may represent environmental condition.

CONCLUSIONS

1. The exposure site

The experimental site of this project is located in a tropical area. The monthly climatic data during the year 1997-1998 showed that the solar radiation varied in the range of 440-620 MJ/m² with the highest at about 620 MJ/m² in March 1998, whereas the rainy season covered the period during June-October. The average temperature was around 26-32°C with the maximum temperature of 36°C in May 1997, and the relative humidity was ranged from 62-74 %. The climatic profile over the exposure period seemed to be similar.

2. Colour and gloss retention data

The exposed plastics showed an increase of colour with exposure time, whereas gloss retention decreased with exposure time in all types of plastics. Dirt clinging on plastic surfaces interfered the gloss and colour measurement.

3. Tensile strength and elongation

The exposure time had some effects on the specimens, however, high stabilized PE and PVC showed some protective effect.

4. IR absorption data

There were some changes in the structure of plastics due to photo-oxidation which mainly produced carbonyl and hydroxy groups in the structure. By following these functional groups, the seasonal severity of the exposure site could be identified and the intensity of absorption of these groups increased with exposure time. Studies

on the use of reference plastic films with weathering tests, carbonyl index of PE and LDPE tended to look promising. Effect of seasonal change on other plastics could be considered.

5. UV absorption data

The experiment showed an increase of UV absorption of plastic films with exposure time. Difference in absorption of exposed films from initial ones tended to correlate with solar radiation energy.

6. Changes of specimens

The specimens showed some changes. appearance of the surface e.g. changes of colour and glossiness, discolouration, collection of surface dirt, cracking and dimensional changes after reaching certain exposure period. This would affect performance requirement of plastics to their applications.

RECOMMENDATION

1. Items which should be taken up in international standards on weatherability

- Elements should be defined e.g. climatic condition used in defining exposure site clearly and classification.

- Assessment after exposure especially for visual assessment should be clearly defined and reported by ratings.

- Control specimens should be specified for use as a comparative test during testing period.

2. Problems and suggestions to be taken up in the future

- Problems may arise from the selection of suitable tests for plastic materials having general and specific applications. The tests should be applicable to the material grade and correspond to expected modes of degradation and related to the expected performance requirements of applications.

- The effect of unit manufacturing processes and grade of plastic materials on weathering performance should be considered.

- Correlation between property change after exposure and product failure mode in service should be studied.

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