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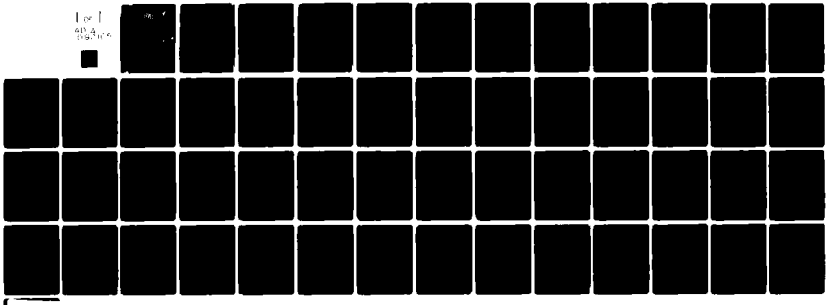

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THE WEATHERING OF PLASTICS MATERIALS IN THE TROPICS

5. POLYPHENYLENE OXIDE AND NORYL

Report by

Procurement Executive, Ministry of Defence/British Plastics Federation Joint Committee on the Behaviour of Plastics Materials under Tropical Conditions

"The material Noryl referred to in this report is no longer available. Present grades of Noryl have not been tested and may behave differently."

Issued by

Procurement Executive, Ministry of Defence
Propellants, Explosives and Rocket Motor Establishment
Waltham Abbey

PROCUREMENT EXECUTIVE, MINISTRY OF DEFENCE

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SUMMARY

The report describes the effect of long term weathering on polyphenylene oxide (PPO) and Noryl (a polystyrene modified PPO). Both natural and carbon black containing samples of each were exposed for up to 4 years at two tropical and one temperate site. Visual appearance, weight, tensile and flexural strength and electrical properties were recorded and used to monitor the effects of weathering. PPO embrittled within 6 months temperate exposure. The performance of Noryl was superior to PPO, but it could not be expected to retain acceptable mechanical properties after a prolonged exposure.

1 INTRODUCTION

The aims of this trial were to determine the extent to which certain mechanical and electrical properties of polyphenylene oxide (PPO) and of the related thermoplastic Noryl were retained on weathering. In addition the degree to which the addition of carbon black affected the weathering resistance of each material was examined.

PPO was introduced as a transparent engineering thermoplastic having good high temperature performance, exceptional resistance to creep and high toughness and rigidity. Noryl is a polystyrene modified PPO containing titanium dioxide and although it has a lower temperature ceiling than PPO, also has useful mechanical properties. However there was no information on the weathering performance of either material.

Specimens were exposed for periods up to four years at two tropical sites in Australia and on a temperate site in the United Kingdom.

The trial schedule appears in Appendix 1.

During this trial PPO was withdrawn from the market. However the carbon black pigmented material as well as the two types of Noryl exposed are still commercially available.

2 EXPERIMENTAL

2.1 Materials

Polyphenyl oxide is a product of General Electric Co and in this trial it was used in the natural transparent state (CT1002) and containing 1% carbon black (C1001). In the report the natural material will be referred to as PPO and the carbon black containing material as black PPO. In addition the related thermoplastic Noryl (a mixture of polystyrene (approx 50%) and PPO with about 1% titanium dioxide) was exposed in the natural state (807) and containing 1% carbon black (703). The former material will be referred to as Noryl and the latter as Noryl black.

2.2 Specimens

Four types of mouldings were produced, all nominally 3.2 mm thick, under conditions recommended by the material suppliers.

a Tensile specimens: Dumb-bells (BS 2782, Method 301.11)

b Flexural specimens: 102 mm x 12.7 mm rectangular bars

c Weight and dimensional change specimens: 102 mm diameter discs

d Electrical properties specimens:

(i) Loss tangent and Permittivity 50.8 mm discs (BS 2782 Method 207A)

(ii) Volume and Surface Resistivity 102 mm discs (BS 2782 Method 204C)

2.3 Exposure

2.3.1 Temperate

The site is at PERME, Waltham Abbey, which is 1°W 51°N in Southern England and is semi-rural in character. Specimens were mounted in wooden frames facing south and at 45° to the horizontal.

2.3.2 Hot/Wet (Clearing)

The hot/wet cleared site is situated at the Joint Tropical Trials and Research Establishment, Innisfail, Australia (146°E 17°S). The site comprises an area of some 3500 m^2 jungle clearing, sloping down towards north and clear of trees so that specimens are exposed to the full effect of the sun, wind and rain in addition to the heat and humidity characteristic of the forest itself. The ground cover consists of grass which is regularly cut. Specimens were mounted in light alloy frames inclined at 45° to the horizontal facing north. Meteorological instruments are mounted within the cleared area.

2.3.3 Hot/Dry (Desert)

This is situated at Cloncurry in 140°E, 21°S and comprises 18000 m^2 enclosed by a fence on level ground at the edge of a small airfield. Specimens are exposed to intense sunlight, long periods of low relative humidity, sparse rainfall and abrasion by windblown sand. The meteorological instruments are mounted about 1 km to the south without intervening obstructions. Specimens were mounted as in 2.3.2.

2.4 Control Specimens

Sets of control specimens were stored in a conditioned room (23°C, 50% rh) at JTTRE and at PERME for testing at the beginning and end of the trial and at each withdrawal.

2.5 Conditioning of Specimens before Laboratory Testing

Specimens were conditioned for 28 days at 20 ± 2°C and 65 ± 2% Relative Humidity prior to testing.

2.6 Test Methods

2.6.1 Visual Assessment

At each withdrawal specimens were maintained in the dark under conditions as in 2.5. Changes in appearance were classified as chalking, cracking, crazing, erosion, microbiological growth, colour and staining, using a scale of increasing severity of 0 to 3.

2.6.2 Weight Changes

Conditioned specimens were weighed to the nearest mg before exposure. Weights were approximately 32 g. On withdrawal, loosely adherent matter was removed with a camel-hair brush and more strongly adherent matter (generally from areas shaded by the mounting channels) was wiped off with a soft tissue. Specimens were then conditioned as in 2.5 and reweighed. Changes in weight were calculated as percentages of the original weight.

2.6.3 Dimensional Changes

Conditioned specimens were measured to 0.025 mm with vernier callipers before and after exposure and changes expressed as percentages of the initial dimensions.

2.6.4 Mechanical Properties

Measurements were generally made on five replicates. Sectional areas were determined by measuring dimensions to 0.025 mm and testing was carried out under a controlled atmosphere as in 2.5. Details of the test methods are given in Appendix 2.

2.6.5 Electrical Properties

Details of the test methods for the measurement of loss tangent, permittivity and volume and surface resistivities are summarised in Appendix 2.

3 RESULTS

Detailed results of the trial are given in Appendix 3. The main results are summarised below.

3.1 Changes in Appearance

The changes in the appearance observed for PPO and Noryl as a result of weathering are given in Tables 1 and 2 respectively.

It was apparent from the above observations that the onset of degradation of the materials occurred prior to the first assessment after 6 months exposure. Therefore JTTRE exposed fresh specimens of each type of material and attempted to follow changes in surface breakdown at intervals between one and twenty-six weeks. It was noted that all the materials showed definite signs of surface change after six weeks exposure and thereafter surface breakdown continued, being similar, in each material, to that previously observed after six months exposure. The results are summarised in Table 3.

TABLE 1

PPO, Changes in Appearance

Material	Exposure Site	Duration of Exposure (Years)	Chalking	Discolouration	Colour Change (1)		Loss of Gloss (1)		Cracking		Crazing		Microbiological Growth	Other Observations
					X	Z	X	Z	X	Z	X	Z		
PPO	Hot Wet Cleared	½	2	3	1	1	2	2	0	0	0	1*	1	
		1	2	3	1	1	2	2	0	0	2*	2*	0	Micro-pitting (1)
		2	2	3	1	1	2	2	2	2	2	2	2	Pitting (2)
		4	1	2	1	1	3	2	2	2	3	3	1	Pitting (2)
	Hot Dry	½	1	2	1	1	1	1	0	0	0	1*	0	
		1	1	2	1	1	1	1	0	0	1*	1*	0	Pitting (2)
		2	1	2	1	1	1	1	1	1	1*	1*	0	Pitting (2)
		4	1	1	1	2	2	1	2	2	2*	2*	0	Pitting (2)
BLACK PPO	Hot Wet Cleared	½	2	1	1	1	3	3	0	0	0	0	0	
		1	3	2	1	1	3	2	0	0	0	0	0	
		2	3	2	1	1	3	2	0	0	0	0	1	
		4	3	2	1	1	3	2	0	0	0	2*	1-2	
	Hot Dry	½	1	1	1	1	3	3	0	0	0	0	0	
		1	1	1	1	2	2	2	0	0	0	0	0	
		2	3	1	1	2	2	2	0	0	0	0	0	
		4	3	1	1	2	3	2	0	0	3*	2*	0	

Key: Ratings 0 = no change 1 = slight change 2 = moderate change 3 = severe change

Note (1) colour change and loss of gloss assessed after washing

X = upper surface Z = lower surface

*microcrazing

TABLE 2

Noryl, Changes in Appearance

Material	Exposure Site	Duration of Exposure (Years)	Chalking	Discolouration	Colour Change (1)		Loss of Gloss (1)		Cracking		Crazing		Microbiological Growth	Other Observations
					X	Z	X	Z	X	Z	X	Z		
NORYL	Hot Wet Cleared	½	0	2	3	3	3	3	0	0	0	0	0	**Peeling (1)
		1	0	2	2	2	3	3	0	0	0	0	2	**Peeling flaking (3)
		2	0	1	2	2	3	3	0	0	0	0	2	**Peeling flaking (3)
		4	1	2 (2)	2	2	3	2	0	0	2*	2*	1	**Peeling flaking (3)
	Hot Dry	½	0	2	3	3	3	3	0	0	0	0	0	**Peeling (2)
		1	0	3	2	2	2	2	0	0	0	0	0	**Peeling flaking (2)
		2	0	3	3	3	2	2	0	0	0	0	0	**Peeling flaking (3)
		4	1	3	3	3	1	1	0	0	1*	1*	0	**Peeling flaking (3)
BLACK NORYL	Hot Wet Cleared	½	1	1	1	1	3	3	0	0	0	0	0	**Peeling (1)
		1	2	1	1	1	2	2	0	0	0	0	0	**Peeling flaking (1)
		2	2-3	1	1	1	2	2	1	1	0	0	3	**Peeling flaking pitting (1)
		4	3	1	1	1	3	2	0	0	2*	2*	2	**Peeling flaking pitting (1)
	Hot Dry	½	1	1	1	1	3	3	0	0	0	0	0	**Peeling (1-2)
		1	1	1	1	1	2	1	0	0	0	0	0	**Peeling flaking (1)
		2	2	1	1	1	2	1	1	1	0	0	0	**Peeling flaking pitting (1)
		4	2	1	2	1	3	2	0	0	3*	2*	0	**Peeling flaking pitting (1)

Key: Ratings 0 = no change 1 = slight change 2 = moderate change 3 = severe change

Note (1) colour change and loss of gloss assessed after washing

Note (2) colour change from beige to yellow

*microcrazing **isolated areas

X = upper surface Z = lower surface

TABLE 3

Visual Surface Break-down of Polyphenylene Oxide and Styrene Modified Polyphenylene Oxide (Noryl)

Material	Period of Exposure (Weeks)					
	1	2	3	6	8	10, 12, 15, 21, 26
PPO	0*	0	0	Isolated areas of micro-cracking; slight roughness	As 6 weeks, slight micro-crazing particularly near low mounting position.	Degradation slowly increasing. 26 weeks - some microcrazing, extensive only in area of lower mounting position. Remainder of surface showed moderate surface erosion.
BLACK PPO	0	Slight dulling of surface	As 2 weeks	Dulling increased; microscopically surface less uniform	Surface dull. Microscopically surface roughness very slight.	Degradation slowly increasing. Chalking test performed at 12 weeks showed slight and at 26 weeks moderate chalking. 26 weeks - severe loss of gloss with uniform chalking. Microscopically the exposed surface showed slight roughness.
NORYL	0	Yellowing commenced	As 2 weeks	Darkening and yellowing; slight roughness	Area along lower mounting position showed cracking, flaking and peeling. Microscopically other areas surface showed start of break-down particularly along "flow lines".	Degradation slowly increasing. At 15 weeks microscopic examination showed extensive peeling and flaking, and at 26 weeks this was estimated to cover 60 - 70% surface.
BLACK NORYL	0	0	0	Patchy dullness	Type of degradation similar to Noryl 807, 8 weeks but not so advanced.	Degradation slowly increasing. Chalking tests performed at 12 weeks and 26 weeks were very slight and slight respectively. Throughout the observations the type of surface break-down appeared similar to material Noryl 807, but the degree of peeling and flaking was less. Associated areas of flaking with "flow lines".

0* = no change

3.2 Weight and Dimensional Changes

The changes in weight observed for control and exposed samples are given in Tables 4 and 5. No significant changes in the dimensions of the samples occurred during outdoor exposure (Appendix 3).

TABLE 4

PPO, Weight Changes

(% of Original Weight)

Type	Exposure Time (Years)	Tropical Control	Hot/Wet	Hot/Dry
PPO	½	<0.1	-0.75	-0.15
	1	"	-1.90	-0.23
	2	"	-4.20	-0.74
	4	"	-9.30	-2.60
BLACK PPO	½	<0.1	-0.45	-0.36
	1	"	-1.00	-0.51
	2	"	-1.68	-1.15
	4	"	-3.20	-2.60

TABLE 5

Noryl, Weight Changes

(% of Original Weight)

Type	Exposure Time (Years)	Tropical Control	Hot/Wet	Hot/Dry
NORYL	½	<0.1	-0.40	-0.22
	1	"	-1.30	-0.44
	2	"	-2.70	-1.10
	4	"	-6.0	-2.90
BLACK NORYL	½	<0.1	-0.36	-0.30
	1	"	-1.0	-0.49
	2	"	-1.94	-1.17
	4	"	-3.60	-3.0

3.3 Mechanical Properties

3.3.1 Tensile Properties

The results of tensile tests are summarised in Tables 6 to 9 inclusive. Results are given as mean values. Detailed results are shown in Appendix 3. Changes in mean values are plotted in Figs 1 to 4.

TABLE 6

PPO, Yield Strength and Breaking Strength (MPa)

Property	Type	Exposure Time (Years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Exposed
Yield Strength	PPO	0	81.0	-	-	-
		½	76.9	No yield	No yield	No yield
		1	79.6	"	"	"
		2	82.4	"	"	"
		4	82.5	"	"	"
	BLACK PPO	0	71.3	-	-	-
		½	68.8	67.9	67.9	66.7
		1	71.1	70.7	70.9	No withdrawal
		2	82.0	71.9	76.7	72.7
		4	72.2	71.7	73.4	73.4
Breaking Strength	PPO	0	57.9	-	-	-
		½	53.1	67.8	66.7	69.3
		1	56.1	61.1	71.0	No withdrawal
		2	62.4	34.7	61.7	64.4
		4	58.0	28.6	41.7	46.4
	BLACK PPO	0	57.7	-	-	-
		½	56.7	51.9	51.5	51.7
		1	58.2	54.1	54.1	No withdrawal
		2	59.4	54.9	55.2	56.4
		4	57.7	54.3	54.2	50.4

TABLE 7

Noryl, Yield Strength and Breaking Strength (MPa)

Property	Type	Exposure Time (Years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Exposed
Yield Strength	NORYL	0	65.1	-	-	-
		½	62.5	No yield	No yield	No yield
		1	66.4	"	"	No withdrawal
		2	65.6	"	"	No yield
		4	66.2	"	"	"
	BLACK NORYL	0	60.6	-	-	-
		½	58.2	No yield	No yield	58.7
		1	60.3	60.4	"	No withdrawal
		2	60.8	No yield	"	54.0
		4	62.6	"	"	No yield
Breaking Strength	NORYL	0	54.0	-	-	-
		½	49.8	60.3	57.4	60.6
		1	53.0	58.3	57.7	No withdrawal
		2	52.5	53.9	53.0	62.3
		4	54.4	46.0	43.6	58.7
	BLACK NORYL	0	51.9	-	-	-
		½	45.9	58.1	59.2	55.7
		1	50.9	60.1	59.7	No withdrawal
		2	54.2	61.8	60.0	53.6
		4	52.5	61.4	57.6	61.6

TABLE 8

PPO, Yield Strain and Breaking Strain (%)

Property	Type	Exposure Time (Years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Exposed
Yield Strain	PPO	0	12	-	-	-
		½	6.0	No yield	No yield	No yield
		1	6.3	"	"	No withdrawal
		2	Not measured	"	"	No yield
		4	5.9	"	"	"
	BLACK PPO	0	12	-	-	-
		½	6.1	6.2	6.1	5.7
		1	6.2	6.5	6.3	No withdrawal
		2	Not measured	Not measured	Not measured	7.0
		4	6.3	5.3	5.2	5.1
Breaking Strain	PPO	0	53	-	-	-
		½	46	4.0	3.6	3.9
		1	12.2	2.9	3.6	No withdrawal
		2	Not measured	Not measured	4.3	12
		4	26.7	1.2	1.7	2.1
	BLACK PPO	0	291	-	-	-
		½	144	110	85	26
		1	122	54	42	No withdrawal
		2	Not measured	Not measured	9.5	71
		4	"	26.9	15.6	11

Necking occurred with many of the specimens resulting in a wide range of breaking strains being obtained.

TABLE 9

Noryl, Yield Strain and Breaking Strain (%)

Property	Type	Exposure Time (Years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Exposed
Yield Strain	NORYL	0	10.7	-	-	-
		½	5.7	No yield	No yield	No yield
		1	5.3	"	"	No withdrawal
		2	Not measured	"	"	No yield
		4	4.9	"	"	"
	BLACK NORYL	0	10	-	-	-
		½	6.5	No yield	No yield	5.5
		1	5.8	"	"	No withdrawal
		2	Not measured	"	"	5.2
		4	5.1	"	"	No yield
Breaking Strain	NORYL	0	61	-	-	-
		½	48	4.0	3.1	3.8
		1	34	3.1	3.2	No withdrawal
		2	Not measured	3.0	4.2	15
		4	43	2.0	1.7	2.9
	BLACK NORYL	0	79	-	-	-
		½	55	8.7	6.0	163
		1	42	6.1	5.1	No withdrawal
		2	Not measured	7.8	5.1	22
		4	48	4.1	3.0	5.4

3.3.2 Flexural Properties

Flexural strength and flexural modulus results are given in Tables 10 to 13 inclusive. Detailed results are shown in Appendix 3. Mean values are plotted in Figs 5 and 6.

TABLE 10

PPO, Flexural Strength (MPa)

Type	Exposure Time (Years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Exposed
PPO	0	117+	-	-	-
	½	95.8*	89.7	89.8	95.7+
	1	96.8*	74.6	86.9	No withdrawal
	2	95.5+	56.1	92.6	85.6
	4	107.4+	27.1	51.4	73.3
BLACK PPO	0	109.5+	-	-	-
	½	87.0+	85.8+	88.3+	88.5+
	1	87.5+	87.6+	88.6+	No withdrawal
	2	89.2+	89.5+	91.3+	95.2+
	4	95.5+	103	97.4	106

+Indicates that the specimens did not break and the figure represents the mean stress at a deflection of 6.35 mm.

*Indicates that at least one of the specimens did not break.

TABLE 11

Noryl, Flexural Strength (MPa)

Type	Exposure Time (Years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Exposed
NORYL	0	111.6+	-	-	-
	½	91.2+	89.9	82.3	81.9
	1	91.2+	77.0	76.6	No withdrawal
	2	90.8+	81.5	79.3	82.1
	4	97.9+	53.7	54.1	74.0
BLACK NORYL	0	107.3+	-	-	-
	½	87.3+	86.6+	83.4	87.1+
	1	90.9+	85.4	81.0	No withdrawal
	2	89.6+	86.3	93.9	91.2*
	4	94.9+	77.5	75.7	87.1

+Indicates that the specimens did not break and the figure represents the mean stress at a deflection of 6.35 mm.

*Indicates that at least one of the specimens did not break.

TABLE 12

PPO, Flexural Modulus (GPa)

Type	Exposure Time (Years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Exposed
PPO	0	2.53	-	-	-
	½	2.39	2.41	2.34	2.44
	1	2.36	2.39	2.43	No withdrawal
	2	2.37	2.36	2.43	2.49
	4	2.62	2.21	2.36	2.63
BLACK PPO	0	2.35	-	-	-
	½	2.29	2.31	2.32	2.43
	1	2.25	2.23	2.25	No withdrawal
	2	2.26	2.21	2.31	2.58
	4	2.46	2.53	2.49	2.68

TABLE 13

Noryl, Flexural Modulus (GPa)

Type	Exposure Time (Years)	Tropical Control	Hot/Wet	Hot/Dry	Temperate Exposed
NORYL	0	2.42	-	-	-
	½	2.29	2.50	2.52	2.35
	1	2.21	2.38	2.44	No withdrawal
	2	2.27	2.50	2.58	2.45
	4	2.48	2.69	2.82	2.61
BLACK NORYL	0	2.31	-	-	-
	½	2.23	2.31	2.36	2.31
	1	2.19	2.22	2.34	No withdrawal
	2	2.19	2.25	2.34	2.34
	4	2.47	2.38	2.56	2.46

3.4 Electrical Properties

Results from the measurement of Loss Tangent, Permittivity and Volume and Surface Resistivities are summarised in Appendix 3.

4 DISCUSSION

4.1 Visual Changes and Weight Measurements

The visual assessments of PPO and Noryl, with and without carbon black, for periods of up to 4 years outdoor exposure on the hot/wet and hot/dry sites are summarised in Tables 1 and 2.

With PPO, the most significant changes in chalking, loss of gloss and discolouration occurred during the first six months of exposure, these changes were usually more severe on the hot/wet site than on the hot/dry site. Slight surface microcrazing and micropitting of the PPO specimens was observed on both sites after six months exposure, which eventually became severe on the hot/wet site and moderate on the hot/dry site. Slight to moderate cracking, which was confined to a thin surface layer, was observed at both sites between two and four years exposure. The black PPO did not show cracking or pitting at either site, but moderate to severe surface microcrazing was observed between two and four years exposure. Chalking was more severe on the black materials.

With Noryl, the most significant difference between the behaviour of the natural and the black material was the greater discolouration of the unfilled material which occurred during the first six months of exposure. On the other hand, black Noryl showed considerably more chalking especially on the hot/wet site. Both types of material showed significant losses of gloss after six months exposure, which was generally rather more severe on the hot/wet site. Neither material showed any significant cracking although both types showed isolated areas of peeling and flaking after six months exposure, which became more severe with Noryl as exposure progressed.

All specimens developed surface microcrazing between two and four years exposure, this was rated as moderate on the hot/wet site for both filled and unfilled Noryl, and slight for the unfilled Noryl and moderate/severe for the black Noryl on the hot/dry site.

Microbiological growth at the hot/wet site was rated as slight on Noryl and moderate on black Noryl.

From the weight change measurements which were only made at the tropical sites it can be seen that for all the materials exposed there was a continuous loss in weight over the whole of the trial. As with the visual changes, the hot/wet site measurements show a greater change than those from the hot/dry site, even the PPO black showed more change at the hot/wet site than the PPO natural at the hot/dry site. The measurements of weight loss at the hot/dry site showed little distinction between the materials whereas at the hot/wet site there was a marked gradation in the degree of weight loss; PPO > Noryl > Black PPO > Black Noryl. After four years the relative degrees of weight loss were approximately 3:1.5:1.1:1.

The weight changes at the hot/wet site were more severe than the hot/dry site, even although it has been shown by using PPO film, that the level of UV radiation is higher at the hot/dry site, probably because the heavy rainfall at the hot/wet site would favour erosion processes and would also help keep the surfaces free from dust etc. The gradual collection of dust on specimens at the hot/dry site was probably the reason why the various materials differ little in their degree of weight loss.

4.2 Tensile Properties

At all three sites black PPO fared reasonably well. Specimens yielded and showed very little change in their stress at yield and stress at break even after four years exposure. On the other hand black Noryl showed no yield after a year's tropical exposure or four years at the temperate site. At all three sites however the breaking stress of black Noryl showed little change.

The tensile properties of PPO and Noryl were significantly affected at all three sites. After six months' exposure at any site both materials had become brittle, ie showed no yield. Regarding breaking stress, the biggest changes were shown by PPO and Noryl at the hot/wet site where this property fell by about 50% and 20% respectively after four years exposure. This tendency for PPO to weather less well than Noryl can be detected in the results from the other two sites.

The elongation at break results for the control specimens for each material showed evidence of ageing. Allowing for this, the elongation at break results (like the yield and breaking stress results) indicate the loss in ductility

suffered by PPO and Noryl at each site in six months. The results in Tables 8 and 9 also suggest that PPO black was slightly less affected than Noryl black.

4.3 Flexural Properties

After an initial drop, control specimens of all materials tended to show an increase in flexural strength with time. Black PPO showed the same tendency but (in general) the black materials showed little change in flexural strength and flexural modulus throughout the trial, irrespective of the exposure site. On the other hand PPO and Noryl suffered losses in flexural modulus at all sites. As with breaking stress, the biggest changes occurred at the hot/wet site; where PPO showed a continuous drop until, after four years, only about 25% of the original flexural strength remained, whereas with Noryl, while it exhibited the same gradual change, the loss was only half as much. There was little to distinguish between the behaviour of PPO and Noryl at the hot/dry and temperate sites, the effects being less severe than those at the hot/wet site.

4.4 Electrical Properties

The overall changes in the electrical properties were generally slight to moderate. The greatest changes in the electrical characteristics for all materials appeared to take place during exposure in temperate conditions. This is probably due to higher industrial pollution levels of the atmosphere in the United Kingdom compared with the sites in Australia.

The greatest change found for any material was for PPO, black at the hot/dry site where the surface resistivity had reduced considerably after 12 months but then recovered with further ageing. This does not tie in with any other property change so definite conclusions cannot be drawn. Otherwise nothing outstanding or alarming is shown by the electrical characteristics.

4.5 General

The results of this trial indicate that PPO is unsuitable for applications which involve long periods of outdoor exposure. Inside six months' temperate exposure PPO embrittled; a fact which suggests that its impact strength was drastically reduced. The overall performance of Noryl was superior to that of PPO but it also should not be expected to retain its mechanical properties to any high degree after prolonged periods of exposure.

The black materials performed reasonably well at all three sites with the black PPO appearing the more weather resistant. Thus, while Noryl is superior to PPO the addition of carbon black reverses their order of stability. A possible explanation is that uniform and effective incorporation of the carbon black is more difficult in the heterogeneous Noryl (PPO/styrene/titanium dioxide) than in the homogeneous PPO.

Exposure at the hot/wet site proved the most severe and at the temperate site the least severe for both natural and pigmented materials. The intermediate position of the hot/dry site requires an explanation because it has been shown independently that PPO films exposed for periods of a few days degrade somewhat faster at the hot/dry site than the hot/wet site. The probable explanation is that dust affords some level of protection to specimens at the hot/dry site.

It has been shown that the PPO weathers primarily by a photolytic process which is caused by the UV portion of the solar spectrum.

The colour changes in PPO resulting from photolytic degradation have been related quantitatively to the UV dose and have been made the basis of a sample method of UV monitoring which is currently being used to monitor continuously solar UV at more than twenty sites throughout the world.

APPENDIX 1

TRIAL SCHEDULE

Subject: Plastics - Polyphenylene Oxide and Noryl

1 Sponsor: Joint Services Research and Developments Committee on Plastics

Manufacturers: Granules from Vereniyd Plastic - Holland
Injection moulded by PERME (Waltham Abbey)

2 Purpose of Trial: To study the rates of degradation as shown by changes in physical properties of polyphenylene oxide and Noryl when exposed to tropical and temperate outdoor climates

3 Scope of Trial:

Number of types	- 16		
Number of replicates	- 5 of types 1A to D, 2A to D and 3A to D		
Number of withdrawals	- 4		
Number of sites	- 2 tropical, 1 temperate		
Number of specimens			
on sites	- 576 tropical,	288	temperate
controls	- 360	360	
totals	- 936	648	

4 Exposure:

Sites - Hot/wet, clearing) Hot/dry) tropical
Rural temperate

Types - See Appendix 2

Specimens - Test pieces see Appendix 2

Method - Specimens held at edges in aluminium channel on stands at 45° facing north in Australia and south in UK

Controls - One set stored in conditioned room at JTTRE and at PERME for testing at beginning of trial and at each withdrawal

5	Assessment:	Visual on site Tensile strength and elongation of types 1A to D (5 replicates) Flexural strength on types 2A to D (5 replicates) Weight and dimensions on types 3A to 3 (2 replicates) Volume and Surface Resistivity on types 3A to D (3 replicates) Loss Tangent and Permittivity on types 4A to D (3 replicates) See Appendix 2
6	Withdrawal Programme:	6 months 12 months 24 months 48 months
7	Met Data:	Routine
8	Reports:	At each withdrawal Final
9	Estimated Exposure:	1968

APPENDIX 2

TYPES OF SPECIMENS AND METHODS OF TEST

1 Types of Specimens

Each specimen in this trial is a test piece made by combining the variants in materials:

(A) Polyphenylene oxide Grade CT1002, natural transparent (PPO)

(B) Polyphenylene oxide Grade C1001, carbon black filled (Black PPO)

(C) Noryl Grade 807, beige (Noryl)

(D) Noryl Grade 703, carbon black filled (Noryl black)

and in mouldings (1) 216 mm x 19 mm shaped as BS 2782, 301.11

(2) 102 mm x 12.7 mm rectangle

(3) 107 mm disc

(4) 50.8 mm dia disc

Number of specimens required:

Type	Tropical		Temperate	
	2 Sites	Controls	1 Site	Controls
1A to D) 2A to D) 3A to D)	40	25	20	25
4A to D	25	15	12	15

2 Methods of Test

Tensile Strength and Elongation

Apparatus

The testing machine shall be capable of applying a load in tension to a test piece gripped in wedge-type self-aligning grips. Provision shall be made for making simultaneous measurements of both load on the test piece to within 2% and the distance between reference lines on the test piece to within 5% of the true values and preferably recording these values automatically on a load extension curve throughout the test.

Test Pieces

Five replicates shall be used for each test. The pieces shall be moulded shapes to BS 2782/1965, 301.11. When the test pieces have been selected to be the specimens for exposure, they shall not be cut or sanded in any way between withdrawal and testing.

Procedure

Before testing, the test pieces shall be conditioned for at least 28 days at 65 ± 5% rh and 20 ± 2°C. The test shall be carried out at 20 ± 2°C immediately after removal from the conditioning atmosphere.

Reference lines shall be marked 50.8 mm apart on the central parallel portion of the test pieces as shown in Fig 301.11 in BS 2782 and described in method 301J.

The width and thickness of the test pieces shall be measured at three points between the reference lines to the nearest 0.03 mm and the mean width and thickness calculated.

Each test piece shall be gripped with a fixed distance of 115 mm between grips and the load applied at a rate to give a rate of separation of the jaws of 25 mm per minute to break.

Calculations

The tensile strength of each test-piece shall be calculated from the maximum load sustained and the original area of cross section and shall be expressed in Pascals. The elongation of each test piece at yield and at break shall be expressed as a percentage of the original distance between the reference lines. Both tensile strength and elongation shall be reported respectively as the arithmetic means of the five readings.

Report

The report shall state:

1 The individual test results
2 The test pieces which broke at the grips
3 The tensile strength of the material
4 The elongation and stress at yield*
5 The elongation at break

*if obtainable (weathered specimens may not exhibit a yield)

Flexural Strength and Elastic Modulus in Flexure

Apparatus

The testing machine shall be capable of applying a bending load by means of a loading block parallel to and exactly mid-way between two parallel supporting

blocks placed 30.8 mm ± 0.75 mm apart. Provision shall be made for making simultaneous measurements of both load on the test piece and its deflection at its midpoint to within 2% of the true values, and for recording these values automatically on a load/deflection curve. The contact edges of the supporting and loading blocks shall have a radius of 1.6 mm and shall be not less than 25.4 mm long.

Test Pieces

Five replicates shall be used for each test. The dimensions shall be nominally 102 mm x 12.7 mm x 3.2 mm, the larger surfaces, 102 mm x 12.7 mm being called the faces. When the test-pieces have been selected to be the specimens for exposure, they shall not be cut or sanded in any way between withdrawal and testing.

Procedure

Before testing, the test pieces shall be conditioned for at least 28 days at 65 ± 5% rh and 20 ± 2°C. The test shall be carried out at 20 ± 2°C immediately after removal from the conditioning atmosphere.

The width and thickness of the test pieces shall be measured at three points along the length to the nearest 0.25 mm and the mean width and thickness calculated. The points of measurement shall not be within 25 mm of either end of the test piece.

The test piece shall be placed symmetrically across the two supporting blocks with the face which was uppermost on the exposure rack, ie the weathered face, resting on the two supports. After having ensured that a suitable load-measuring scale is in use, the load shall be applied by moving the loading block relative to the supports at a substantially constant rate of approximately 5 mm per minute.

The load and deflection shall be recorded continuously until the test piece breaks or until the deflection is 6.3 mm.

Calculations

1 If the test piece breaks, the flexural strength of the specimens shall be calculated as follows:

$$= \frac{1.5\ WL}{BD^2}$$

where W = force at fracture
L = distance between supports
B = width of test piece
D = thickness of test piece

2 If the test piece does not break, the force at 6.3 mm deflection

$$= \frac{1.5\ WL}{BD^2}$$

where W = force at 6.3 mm deflection
L = distance between supports
B = width of test piece
D = thickness of test piece

3 Elastic modulus in flexure

$$= \frac{WL^3}{4BD^3e}$$

where W = load
e = deflection

as read from the load/deflection curve at a point to be agreed.

Report

The report shall state:

1 The number of test pieces which fractured and the individual results of cross-breaking strength.

2 The number of test pieces which deflected to 6.3 mm and the individual results of load at 6.3 mm deflection.

3 The individual results of elastic modulus in flexure if required.

APPENDIX 2

ELECTRICAL PROPERTIES

Volume and Surface Resistivity

The test pieces, discs 102 mm diameter and 3.2 mm thick, shall be tested according to BS 2782, Part 2, 1965, Method 204C, except that the pieces shall not be dried and then immersed in water but tested after conditioning for 28 days at 65 ± 5% rh and 20 ± 2°C. Three replicates of each type of specimen shall be tested and the mean of the logarithms of the readings reported.

Loss Tangent and Permittivity

The test pieces, discs 50.8 mm diameter and 3.2 mm thick, shall be tested according to BS 2782, Part 2, 1965, Method 207A at 1 MHz.

Three replicates of each type of specimen shall be tested and the arithmetic mean of the readings reported.

APPENDIX 3

MECHANICAL AND ELECTRICAL PROPERTIES OF CONTROL AND EXPOSED SPECIMENS

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
TROPICAL CONTROLS	(A) PVC	0				81.3 81.3 80.6 81.3 80.6	11.8 11.5 11.7 11.6 12.2	57.6 56.3 56.8 56.0 58.0	55 53 53 53 53	118.5* 117.8* 120.0* 115.0* 114.0*	2.57 2.54 2.60 2.47 2.47				
		Mean				81.0	12.0	57.9	53	117.0*	2.53	2.62	0.00211	>15.273	15.930
		6				77.5 76.5 76.5 77.2 76.8	6.0 6.0 5.6 6.0 6.4	53.4 49.6 53.8 52.8 53.8	42 36 52 50 52	95.8* 95.1* 95.8 95.8* 95.6*	2.40 2.38 2.40 2.38 2.40				
		Mean	< +0.1	Nil	Nil	76.9	6.0	53.1	46	95.8*	2.39	2.37	0.0009	>15.273	>16.0645
		12				80.6 80.3 79.2 78.2 79.6	6.1 6.3 6.0 6.4 6.5	58.5 55.2 55.2 57.4 56.9	7.0 11.5 6.5 7.5 28.5	96.1* 94.7 97.8* 96.1* 99.2*	2.32 2.36 2.40 2.36 2.36				
		Mean	< 0.1	< -0.01	< -0.01	79.6	6.3	56.1	12.2	96.8*	2.36	2.49	0.00205	>14.573	13.24
		24				82.9 81.9 80.5 81.4 83.3	Not Measured	61.9 56.3 71.5 59.7 62.6	Not Measured	68.7* 66.6* 56.5* 65.6* 69.6*	1.61 1.60 1.57 1.59 1.59				
		Mean	< 0.1	< 0.01	< 0.01	82.4		62.4		65.4*	1.59	2.48	0.0019	>15.573	>16.055
		48				82.6 82.0 83.0 81.9 82.9	5.4 5.5 7.3 5.5 5.7	56.3 57.5 61.1 57.5 57.6	9.7 37.8 15.3 27.3 43.3	108.0* 105.0* 110.0* 108.0* 106.0*	2.68 2.60 2.59 2.64 2.61				
		Mean	< 0.1	+0.02	+0.01	82.5	5.9	58.0	26.7	107.4*	2.62	2.68	0.0022	>15.573	15.775

*Did not break, strength at 6.3 mm deflection

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
TROPICAL CONTROLS	(B) BLACK PPO	0				71.6 70.9 71.6 70.9 70.9	12.1 12.0 11.6 12.2 11.7	55.2 55.6 62.6 59.3 55.8	155 290 370 350	107.5* 107.5* 107.5* 113.0* 111.6*	2.29 2.32 2.31 2.44 2.40				
		Mean				71.2	12.0	57.7	291	109.5*	2.35	2.42	0.00078	>15.573	>16.0645
		6				69.7 68.1 68.3 68.9 68.9	6.2 6.0 6.0 6.1 6.2	55.1 52.0 63.4 58.4 54.6	94 74 216 194 142	87.1* 85.2* 88.9* 86.4* 87.5*	2.42 2.19 2.26 2.32 2.26				
		Mean	< +0.1	Nil	Nil	68.8	6.1	56.7	144	87.0*	2.29	2.50	0.00242	>15.573	>16.0719
		12				70.9 71.7 70.9 71.3 71.3	6.0 6.1 6.3 6.3 6.6	58.2 55.2 61.7 60.6 55.2	174 58 196 96 88	87.5* 87.5* 87.5* 87.5* 87.5*	2.23 2.27 2.23 2.23 2.27				
		Mean	< -0.1	< -0.01	< -0.01	71.1	6.2	58.2	122	87.5*	2.25	2.46	0.00066	>14.535	15.77
		24				72.1 72.1 71.7 71.6 72.5	Not Measured	56.4 64.5 57.4 62.2 56.5	Not Measured	61.2* 51.4* 62.1* 62.3* 63.6*	1.47 1.49 1.45 1.47 1.49				
		Mean	< -0.1	< -0.01	< -0.01	72.0		59.4		60.1	1.47	2.47	0.00040	>15.573	>16.078
		48				72.8 72.7 72.6 72.1 71.2	5.4 5.5 7.5 5.3 7.6	63.0 57.5 56.8 55.6 55.4	Not Measured	95.5* 94.6* 95.6* 96.5* 95.2*	2.48 2.41 2.53 2.44 2.48				
		Mean	< -0.1	+0.02	Nil	72.2	6.3	57.7		95.5*	2.46	2.67	0.0010	>15.573	15.351

*Did not break, strength at 6.3 mm deflection

APPENDIX 3

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
TROPICAL CONTROLS	(C) NORYL	0				64.8 64.6 65.2 64.8 65.7	10.9 10.5 10.5 10.0 10.5	52.8 54.4 54.2 53.8 54.5	68 72 55 65 33	115.8* 115.8* 106.1* 110.2* 110.2*	2.51 2.51 2.29 2.36 2.40				
		Mean				65.1	10.7	54.0	61	111.6*	2.42	2.40	0.00113	>15.573	>16.0828
		6				63.0 62.6 62.7 61.5 62.6	5.4 5.8 5.9 5.7 5.7	50.5 49.3 49.9 49.3 50.3	44 56 46 50 48	91.5* 93.2* 90.6* 90.2* 90.6*	2.30 2.31 2.32 2.29 2.20				
		Mean	< 0.1	Nil	Nil	62.5	5.7	49.8	48	91.2*	2.29	2.44	0.0093	>15.573	>16.0899
		12				67.1 66.2 64.8 68.2 65.6	5.3 5.3 5.4 5.0 5.6	54.2 53.5 53.5 53.1 51.5	30 38 38 30 38	92.0* 92.0* 90.3* 90.3* 92.0*	2.20 2.27 2.20 2.24 2.30				
		Mean	< 0.1	< -0.01	< -0.01	66.4	5.3	53.0	34	91.2*	2.24	2.43	0.00116	>14.573	>15.045
		24				65.6 64.9 65.8 66.1 65.6	Not Measured	52.4 52.9 52.8 52.4 52.3	Not Measured	52.6* 65.2* 65.2* 63.7* 63.9*	1.49 1.51 1.51 1.77 1.77				
		Mean	< -0.1	< -0.01	< -0.01	65.6		52.5		62.1*	1.61	2.43	0.00110	>15.573	>16.0800
		48				65.1 66.5 65.5 66.7 66.1	4.9 4.9 4.9 4.9 4.9	52.9 53.5 53.4 57.6 54.6	37 57 66 30 27	97.0* 98.6* 97.0* 99.1* 97.2*	2.48 2.46 2.51 2.53 2.42				
		Mean	< -0.1	-0.01	-0.01	66.2	4.9	54.4	43	97.9*	2.48	2.64	0.00150	>15.573	15.781

*Did not break, strength at 6.3 mm deflection

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
TROPICAL CONTROLS	(D) BLACK NORYL	0				62.1 59.9 59.7 61.9 59.7	))) 10))	54.0 50.2 51.5 52.4 51.3	85 90 68 62 90	104.7* 110.2* 108.2* 110.2* 103.4*	2.24 2.36 2.34 2.36 2.25				
		Mean				60.6	10	51.9	79	107.3*	2.31	2.49	0.00078	>15.573	>16.0228
		6				59.3 57.7 58.4 57.3 58.5	6.8 6.6 6.8 6.1 6.6	43.3 48.9 43.7 47.7 45.8	60 52 56 62 46	87.8* 88.2* 88.9* 87.3* 88.9*	2.27 2.20 2.24 2.20 2.22				
		Mean	Nil	Nil	Nil	58.2	6.5	45.9	55	87.3*	2.23	2.44	0.00091	>15.573	>16.0864
		12				59.9 60.5 59.9 59.9 61.5	6.0 6.0 5.4 5.7 5.7	49.3 54.1 50.0 50.0 50.6	64 50 40 26 28	90.6* 92.0* 90.6* 90.6* 90.6*	2.19 2.23 2.22 2.16 2.16				
		Mean	Nil	Nil	Nil	60.3	5.8	50.9	42	90.9	2.19	2.42	0.00066	>14.573	>15.077
		24				61.2 59.6 60.4 62.2 60.7	Not Measured	57.9 50.9 57.5 51.9 52.9	Not Measured	61.3* 61.9* 61.4* 62.2* 61.7*	1.43 1.44 1.43 1.45 1.44				
		Mean	< 0.1	Nil	Nil	60.8		54.2		61.7*	1.44	2.48	0.00090	>15.572	>16.081
		48				61.4 62.4 62.5 63.0 63.7	5.1 5.2 5.1 5.1 5.1	51.5 51.9 53.1 52.5 53.6	50 77 32 32 47	94.6* 95.0* 95.5* 95.1* 94.2*	2.55 2.49 2.47 2.45 2.41				
		Mean	< 0.1	Nil	Nil	62.6	5.1	52.5	48	94.9*	2.47	2.64	0.0010	>15.573	15.573

*Did not break, strength at 6.3 mm deflection

APPENDIX 3

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
HOI/WET	(A) PPO	0				81.3 81.3 80.6 81.3 80.6	11.8 11.5 11.7 11.6 12.2	57.6 56.3 56.8 56.0 58.0	55 53 53 53 53	118.5* 117.8* 120.0* 115.0* 114.0*	2.57 2.54 2.60 2.47 2.47				
		Mean				81.0	12	57.9	53	117.0*	2.53	2.62	0.0021	>15.573	15.9340
		6				Did not yield		63.1 66.0 68.0 70.2 71.7	3.3 3.4 3.6 4.0 4.2	94.4 93.0 85.4 91.6 84.0	2.45 2.35 2.42 2.38 2.43				
		Mean	-0.75	Nil	Nil			67.8	4.0	89.7	2.41				
		12				Did not yield		68.7 50.0 64.1 62.4 67.5	3.5 2.1 3.1 3.1 2.9	65.7 71.6 73.7 76.5 85.4	2.37 2.37 2.42 2.37 2.43				
		Mean	-1.90	-0.01	-0.01			61.1	2.9	74.6	2.39	2.51	0.00225	>14.573	15.06
		24				Did not yield		25.4 31.9 45.5 42.1 29.1	Not Measured	87.6 39.2 41.3 42.6 30.6	1.66 1.56 1.61 1.60 1.57				
		Mean	-4.2	< -0.01	Nil			34.8		38.3	1.58	2.53	0.0019	>15.573	>16.069
		48				Did not yield		38.5 31.2 33.8 14.8 24.6	1.7 1.3 1.4 0.5 1.0	30.0 25.1 23.4 27.8 29.3	2.33 2.28 2.07 2.21 2.17				
		Mean	-9.3	< 0.01	Nil			28.6	1.2	27.1	2.21	2.81	0.0042	14.751	15.351

*Did not break, strength at 6.3 mm deflection

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
HOT/WET	(8) BLACK PPO	0				71.6 70.9 71.6 71.0 71.0	12.1 12.0 11.6 12.2 11.7	55.2 55.6 62.6 59.3 55.8	155 290 370 350 -	107.5* 107.5* 107.5* 113.0* 111.6*	2.29 2.32 2.31 2.44 2.40				
		Mean				71.3	12.0	57.7	291	109.4*	2.35	2.42	0.00078	>15.573	>16.0645
		6				68.1 68.2 67.3 68.1 68.0	6.1 6.3 6.1 6.2 6.1	50.9 51.8 53.5 52.3 51.2	92 84 174 130 74	85.8* 86.3* 85.4* 86.1* 87.5*	2.24 2.29 2.31 2.33 2.36				
		Mean	-0.45	Nil	Nil	67.9	6.2	51.9	110	86.2*	2.31				
		12				70.9 70.6 70.6 70.6 70.6	6.5 6.4 6.5 6.5 6.4	54.2 53.5 54.4 54.1 54.2	60 40 66 38 64	87.2* 87.2* 88.8* 87.5* 87.2*	2.23 2.23 2.23 2.19 2.26				
		Mean	-1.0	< -0.01	Nil	70.7	6.5	54.1	54	87.6*	2.23	2.49	0.00107	13.775	15.016
		24				72.0 71.7 71.4 71.9 72.7	Not Measured	57.6 53.9 54.9 54.4 53.9	Not Measured	58.9* 62.2* 61.7* 62.4* 62.1*	1.45 1.46 1.49 1.54 1.46				
		Mean	-1.68	Nil	Nil	71.9		54.9		61.3*	1.48	2.52	0.0011	12.965	15.925
		48				71.55 72.00 71.48 71.3 72.0	5.2 5.3 5.2 5.3 5.3	54.3 54.8 54.1 54.1 54.0	30.0 25.7 32.6 25.7 20.5	102.8 102.0 103.9 103.6 103.0	2.55 2.51 2.55 2.50 2.52				
		Mean	-3.20	Nil	Nil	71.7	5.3	54.3	26.9	103.0	2.53	2.70	0.0019	14.751	>16.095

*Did not break, strength at 6.3 mm deflection

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
HOT/WET	(C) NORYL	0				64.8 64.6 65.2 64.8 65.7	10.9 10.5 10.5 10.0 10.5	52.8 54.4 54.2 53.8 54.5	68 72 55 65 33	115.8* 115.8* 106.1* 110.2* 110.2*	2.51 2.51 2.29 2.36 2.40				
		Mean				65.1	10.7	54.0	61	111.6*	2.42	2.40	0.00113	>15.573	>16.0828
		6				No yield		61.0 61.1 60.4 60.1 59.3	4.2 4.1 3.8 4.0 3.6	90.3 90.3 91.6 87.5	2.49 2.41 2.48 2.58 2.51				
		Mean	-0.40	Nil	Nil			60.3	4.0	89.9	2.50				
		12				No yield		57.2 57.2 59.3 58.6 59.4	3.0 3.0 3.2 3.0 3.2	74.4 77.8 77.8 78.5 76.5	2.47 2.35 2.29 2.43 2.34				
		Mean	-1.3	-0.01	Nil			58.3	3.1	77.0	2.38	2.48	0.00113	14.396	14.959
		24				No yield		52.1 52.6 53.3 56.5 55.0	3.0 3.0 3.0 4.0 4.0	51.9* 55.5* 53.8* 55.5* 57.3*	1.67 1.65 1.73 1.69 1.69				
		Mean	-2.7	-0.02	-0.01			53.9	3.0	55.8*	1.68	2.41	0.0012	>15.573	15.541
		48				No yield		47.2 45.4 45.6 44.9 46.4	2.0 2.0 2.0 2.0 2.0	53.5 54.1 54.5 52.9 53.7	2.62 2.64 2.72 2.76 2.73				
		Mean	-6.0	Nil	Nil			46.0	2.0	53.7	2.69	2.65	0.0021	14.901	15.172

*Did not break, strength at 6.3 mm deflection

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
HOT/WET	(D) BLACK NORYL	0				62.1 59.9 59.7 61.9 59.7	))) 10))	54.0 50.2 51.5 52.4 51.3	85 90 68 62 90	104.7* 110.2* 108.2* 110.2* 103.4*	2.24 2.36 2.34 2.36 2.25				
		Mean				60.6	10	51.9	79	107.3*	2.31	2.49	0.00078	>15.5729	>16.0828
		6				No yield		58.4 57.7 57.5 57.9 59.0	12.8 6.8 9.6 6.4 8.0	88.2* 87.2* 86.8* 85.4* 85.4*	2.34 2.29 2.32 2.32 2.29				
		Mean	-0.36	Nil	Nil			58.1	8.7	86.6*	2.31				
		12				No yield 60.3 60.5	 5.5 5.7	60.3 60.4 61.0 59.0 59.8	5.4 5.4 6.1 7.0 6.5	84.1 86.8 86.8 84.1	2.23 2.20 2.18 2.26				
		Mean	-1.0	< -0.01	< -0.01	60.4	5.6	60.1	6.1	85.4	2.22	2.40	0.00103	>14.573	>15.044
		24				No yield		59.6 61.7 62.3 63.2 62.0	5.0 8.0 9.0 8.0 6.0	62.7* 52.8* 62.7* 54.0* 63.4*	1.54 1.53 1.48 1.50 1.52				
		Mean	-1.94	< -0.01	< -0.01			61.8	7.8	59.1*	1.51	2.44	0.0013	>15.372	15.584
		48				No yield		60.7 62.3 61.8 60.8 61.4	4.2 3.8 4.6 4.5 3.7	78.6 75.7 75.5 78.2 79.6	2.40 2.40 2.36 2.38 2.34				
		Mean	-3.6	Nil	Nil			61.4	4.1	77.5	2.38	2.57	0.0014	14.805	15.578

*Did not break, strength at 6.3 mm deflection

APPENDIX 3

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
HOT/DRY	(A) PPO	0				81.3 81.3 80.6 81.3 80.6	11.8 11.5 11.7 11.6 12.2	57.6 56.3 56.8 56.0 58.0	55 53 53 53 53	118.5* 117.8* 120.0* 115.0* 114.0*	2.57 2.54 2.60 2.47 2.47				
		Mean				81.0	12	57.9	53	117.0*	2.53	2.62	0.0021	>15.573	15.9340
		6				Did not yield		71.6 63.1 65.0 63.4 70.3	4.1 3.2 3.3 3.3 3.9	85.4 84.0 88.9 88.9 102.0	2.41 2.57 2.19 2.19 2.32				
		Mean	-0.15	Nil	Nil			66.7	3.6	89.8	2.34				
		12				Did not yield		73.0 70.9 70.9 68.6 66.3	4.2 3.6 3.6 3.4 3.2	83.4 86.8 77.2 91.9 95.0	2.40 2.46 2.41 2.51 2.36				
		Mean	-0.23	Nil	-0.01			71.0	3.6	86.9	2.43	2.5[illegible]	0.00260	14.105	14.83
		24				Did not yield		57.9 61.9 57.9 65.3 65.3	4.3 4.3 4.3 4.3 4.3	66.3 62.2* 64.7* 61.1*	1.59 1.65 1.65 1.62				
		Mean	-0.74	< -0.01	Nil			61.7	4.3	63.6	1.63	2.47	0.0018	>15.573	>16.055
		48				Did not yield		30.3 56.4 35.9 26.1 59.6	1.2 2.3 1.4 1.0 2.6	57.2 52.8 53.3 49.4 44.3	2.39 2.43 2.37 2.39 2.32				
		Mean	2.60	< +0.01	+0.01			41.7	1.7	51.4	2.36	2.70	0.0033	14.131	15.834

*Did not break, strength at 6.3 mm deflection

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
HOT/DRY	'8) BLACK PPO	0				71.7 70.9 71.7 71.0 71.0	12.1 12.0 11.6 11.2 11.7	55.2 55.6 62.6 59.3 55.8	155 290 370 350 -	107.5* 107.5* 107.5* 113.0* 111.6*	2.29 2.32 2.31 2.44 2.40				
		Mean				71.3	12.0	57.7	291	109.4*	2.35	2.42	0.00078	>15.573	>16.0645
		6				68.5 67.5 68.5 68.2 67.5	6.1 6.0 6.2 6.0 6.0	52.6 50.4 50.8 50.6 50.7	104 50 74 134 61	88.9* 87.5* 88.5* 87.9* 88.5*	2.38 2.31 2.29 2.32 2.32				
		Mean	-0.36	Nil	Nil	67.9	6.1	51.5	85	88.3*	2.32				
		12				70.6 70.6 71.3 70.6 71.3	6.6 6.1 6.4 6.2 6.4	54.3 53.8 54.4 53.4 54.7	38 33 40 40 56	88.9* 88.9* 88.9* 88.9* 87.5*	2.23 2.24 2.26 2.26 2.24				
		Mean	-0.51	Nil	Nil	70.9	6.3	54.1	42	88.6*	2.25	2.50	0.00144	8.437	>14.909
		24				71.9 72.2 73.1 73.1 73.1	Not measured	53.8 55.0 55.9 55.5 65.5	8.8 12.0 9.3 8.8 8.8	62.8* 62.8* 63.9* 61.4* 61.6*	1.55 1.55 1.55 1.55 1.52				
		Mean	-1.15	< -0.01	< -0.01	72.7		55.2	9.5	62.5*	1.55	2.51	0.0033	12.307	15.101
		48				72.3 72.2 72.2 72.1 72.8	5.30 5.25 5.13 5.11 5.23	54.12 54.77 54.22 54.97 54.87	15.0 16.6 14.6 16.5 15.7	95.4 97.7 97.4 98.0 98.6	2.55 2.37 2.51 2.50 2.54				
		Mean	-2.60	Nil	Nil	73.3	5.2	54.6	15.6	97.4	2.49	2.70	0.0031	1..909	>16.083

*Did not break, strength at 6.3 mm deflection

APPENDIX 3

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
HOT/DRY	(C) NORYL	0				64.8 64.6 65.2 64.8 65.7	10.9 10.5 10.5 10.0 10.5	52.8 54.4 54.2 53.8 54.5	68 72 55 65 33	115.8* 115.8* 106.1* 110.2* 110.2*	2.51 2.51 2.29 2.36 2.40				
		Mean				65.1	10.7	54.0	61	111.6*	2.42	2.40	0.00113	>15.573	>16.0828
		6				No yield		57.5 57.3 57.3 57.5	3.2 3.1 2.9 3.2	82.6 82.6 82.6 80.6 82.0	2.56 2.58 2.45 2.49 2.49				
		Mean	-0.22	Nil	Nil			57.4	3.1	82.3	2.52				
		12				No yield		56.8 57.3 57.0 58.9 58.3	3.0 3.2 3.2 3.0 3.5	75.1 76.5 75.1 76.5 79.9	2.35 2.48 2.38 2.47 2.44				
		Mean	-0.40	Nil	Nil			57.7	3.2	76.6	2.44	2.42	0.00145	>14.573	>15.074
		24				No yield		53.5 56.0 49.2 53.9 52.3	4.3 4.3 3.6 4.3 4.3	54.4* 53.1* 54.4* 55.2* 54.4*	1.72 1.74 1.75 1.69 1.72				
		Mean	-1.1	-0.02	< 0.01			53.0	4.2	54.3*	1.73	2.42	0.0019	>15.573	15.769
		48				No yield		46.0 41.3 42.3 44.4 44.2	1.8 1.6 1.7 1.75 1.6	53.3 57.0 53.2 52.8 54.3	2.88 2.75 2.89 2.83 2.77				
		Mean	-2.9	Nil	Nil			43.6	1.7	54.1	2.82	2.65	0.0022	13.440	15.241

*Did not break, strength at 6.3 mm deflection

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
HOT/DRY	(D) BLACK NORYL	0				62.1 59.9 59.7 61.9 59.7	))) 10))	54.0 50.2 51.5 52.4 51.3	85 90 68 62 90	104.7* 110.2* 108.2* 110.2* 103.4*	2.24 2.36 2.34 2.36 2.25				
		Mean				60.6	10	51.9	79	107.3*	2.31	2.49	0.00078	>15.273	15.930
		6				No yield		59.2 58.7 59.0 59.1 59.7	6.2 6.0 6.6 4.9 4.5	82.0 82.0 80.3 86.5 86.5	2.33 2.33 2.45 2.33 2.33				
		Mean	-0.30	Nil	Nil			59.2	6.0	83.4	2.36				
		12				No yield		60.4 59.7 59.1 59.7 59.9	4.8 4.3 5.4 6.1 4.8	82.7 81.3 77.2 82.7 81.3	2.33 2.30 2.30 2.30 2.33				
		Mean	-0.49	< -0.01	Nil			59.7	5.1	81.0	2.32	2.44	0.00116	>14.573	>15.066
		24				No yield		60.4 58.2 60.3 60.1 60.7	5.7 5.0 5.0 5.0 5.0	64.8 63.1 64.8 63.9 64.6	1.56 1.54 1.57 1.57 1.60				
		Mean	-1.17	0.01	0.01			60.0	5.1	64.3	1.57	2.45	0.0010	14.972	15.486
		48				No yield		55.8 57.8 58.3 58.6	2.7 3.1 3.1 3.0	78.9 72.2 75.8 - 75.8	2.57 2.54 2.63 2.56 2.49				
		Mean	-3.0	Nil	-0.01			57.6	3.0	75.7	2.56	2.66	0.0014	14.848	15.315

*Did not break, strength at 6.3 mm deflection

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
TEMPERATE	(A) PPO	0				81.3 81.3 80.6 81.3 80.6	11.8 11.5 11.7 11.6 12.2	57.6 56.3 56.8 56.0 58.0	55 53 53 53 53	118.5* 117.8* 120.0* 115.0* 114.0*	2.57 2.54 2.60 2.47 2.47				
		Mean				81.0	12	57.9	53	117.0*	2.53	2.62	0.00211	>15.573	14.9340
		6				Did not yield		63.9 72.3 68.8 70.3 71.3	3.6 4.0 3.5 4.5 4.0	96.8* 95.1* 95.8* 95.1* 95.8*	2.45 2.45 2.40 2.37 2.51				
		Mean	-0.06	Nil	Nil			69.3	3.9	95.7*	2.44	2.41	0.00074	>15.573	>16.0569
		12	No withdrawal												
		Mean													
		24				Did not yield		63.3 65.3 64.5 66.4 62.4	12 12 12 10	82.0 85.4 89.6 89.6 81.3	2.48 2.48 2.52 2.52 2.46				
		Mean						64.4	12	85.6	2.49	2.60	0.0019	13.271	14.3700
		48				Did not yield		49.8 48.4 48.4 39.8 45.6	2.2 2.1 2.2 2.1 2.0	76.5* 71.5* 71.1* 72.1* 75.1*	2.59 2.70 2.58 2.64 2.62				
		Mean						46.4	2.1	73.3*	2.63	3.21	0.0071	>15.573	16.108

*Did not break, strength at 6.3 mm deflection

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
TEMPERATE	(B)	0				71.7 70.9 71.7 71.0 71.0	12 12.0 12 11.0 12.0	55.2 55.6 62.6 59.3 55.8	155 290 370 350 -	107.5* 107.5* 107.5* 113.0* 111.6*	2.29 2.32 2.31 2.44 2.40				
		Mean				71.3	12	57.7	291	109.4*	2.35	2.42	0.00078	>15.573	>16.0645
		6				65.5 65.5 67.5 68.2	5.9 5.3 5.5 5.9	51.6 50.9 57.6 52.3	16 38 12 36	90.2* 84.1* 90.2* 85.4* 92.3*	2.38 2.48 2.43 2.48 2.38				
		Mean	-0.06	Nil	Nil	66.7	5.7	51.7	26	88.5*	2.43	2.47	0.00118	12.644	15.730
	BLACK PPO	12	No withdrawal												
		Mean													
		24				75.4 71.2 71.6 72.3 72.7	6 6 7 7 7	57.1 53.6 55.4 61.3 54.4	150 56 88 24 40	93.0* 93.0* 91.6* 103.4* 95.0*	2.34 2.34 2.32 3.53 2.40				
		Mean				72.7	7	56.4	71	95.2*	2.58	2.60	0.0030	13.0916	14.502
		48				74.3 73.5 73.4 73.4 73.5	5.0 5.2 5.1 5.1 5.2	49.8 50.4 49.9 51.5 50.6	12.0 24.0 7.7 5.7 5.8	105.5 106.5 107.5 107.0 106.5	2.67 2.69 2.68 2.65 2.73				
		Mean				73.4	5.1	50.4	11.0	106.6	2.68	3.04	0.0045	>15.573	16.084

*Did not break, strength at 6.3 mm deflection

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
TEMPERATE	(C) NORYL	0				64.8	10.9	52.8	68	115.8*	2.51				
						64.6	10.5	54.4	72	115.8*	2.51				
						65.2	10.5	54.2	55	106.1*	2.29				
						64.8	10.0	53.8	65	110.2*	2.36				
						65.7	10.5	54.5	33	110.2*	2.40				
		Mean				65.1	10.7	54.0	61	111.6*	2.42	2.40	0.00113	>15.573	>16.0828
		6				No yield		60.5	4.0	79.9	2.39				
								60.1	3.3	76.5	2.29				
								59.5	3.7	79.9	2.39				
								61.6	4.3	96.5	2.39				
								61.1	4.1	79.9	2.29				
		Mean	-0.06	Nil	Nil			60.6	3.8	81.9	2.35	2.51	0.00214	>15.573	15.8762
		12	No withdrawal												
		Mean													
		24				No yield		61.3	14	83.4	2.41				
								63.9	14	79.9	2.43				
								62.1	16	82.0	2.50				
								61.8	14	82.0	2.54				
								62.5	16	83.4	2.50				
		Mean		Nil	Nil			62.3	15	82.1	2.45	2.52	0.0027	14.463	15.150
		48				No yield		59.0	3.0	75.1	2.57				
								59.1	2.4	72.6	2.60				
								59.9	3.1	74.4	2.59				
								57.6	2.9	74.1	2.69				
								58.1	2.9						
		Mean		Nil	Nil			58.7	2.9	74.0	2.61	2.64	0.0022	>15.573	15.385

*Did not break, strength at 6.3 mm deflection

Exposure			Changes %			Tensile Properties				Flexural Properties		Electrical Properties at 1 MHz		Resistivity	
Site	Type	Months	Weight	Length	Breadth	S_y MPa	e_y %	S_b MPa	e_b %	S MPa	E_f GPa	K	tan δ	Surface	Volume
														Log_{10} AR/t	
TENNERATE	(D) BLACK NORYL	0				62.1 59.9 59.7 61.9 59.7	))) 10))	54.0 50.2 51.5 52.4 51.3	85 90 68 62 90	104.7* 110.2* 108.2* 110.2* 103.4*	2.24 2.36 2.34 2.36 2.25				
		Mean				60.6	10	51.9	79	107.3*	2.31	2.49	0.00078	>15.573	>16.828
		6				58.6 58.1 58.3 59.3 59.3	5.2 5.7 5.2 5.6 5.8	54.8 50.1 57.7 58.6 57.4	132 85 188 72 340	87.5* 87.5* 85.4* 87.5* 87.5*	2.34 2.36 2.29 2.36 2.36				
		Mean	-0.02	Nil	Nil	58.7	5.5	55.7	163	87.1*	2.31	2.46	0.00091	>15.573	>16.0828
		12	No withdrawal												
		Mean													
		24				54.1 53.9 53.9 53.9 54.1	4.7 5.2 5.3 5.4 5.4	53.9 52.4 53.9 53.9 54.1	18.0 24.0 20.0 22.0 26.0	90.2 88.8 85.4 93.0* 98.5	2.23 2.31 2.43 2.34 2.35				
		Mean				54.0	5.2	53.6	22	91.2	2.34	2.55	0.0032	14.386	15.000
		48				No yield		60.6 61.0 63.1	5.5 5.9 4.8	86.4 84.4 90.2 85.4 88.9	2.61 2.50 2.40 2.46 2.36				
		Mean						61.6	5.4	87.1	2.46	2.62	0.0012	>15.573	15.573

*Did not break, strength at 6.3 mm deflection

FIG 1 TENSILE YIELD STRENGTH

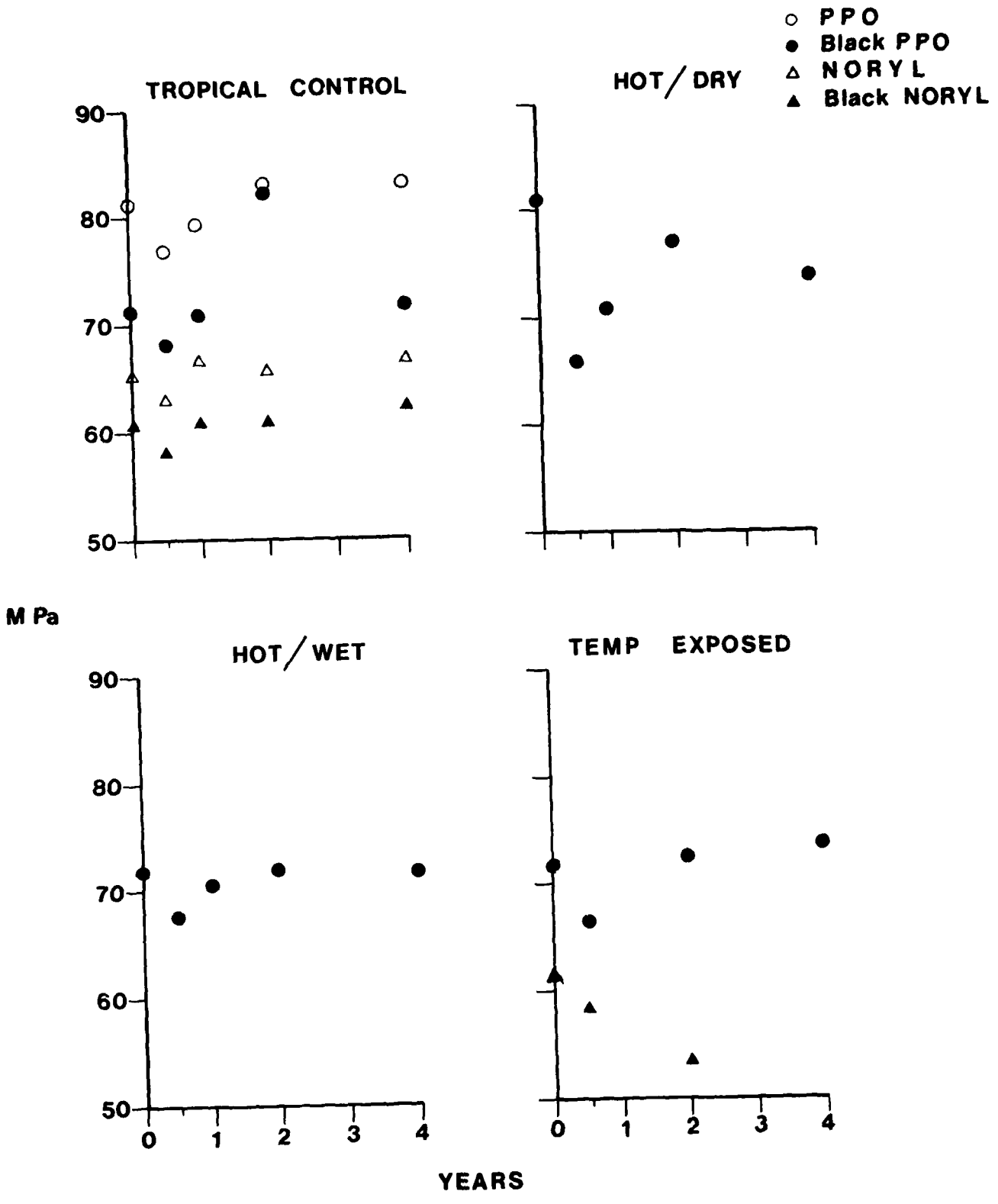


FIG 2 TENSILE BREAKING STRENGTH

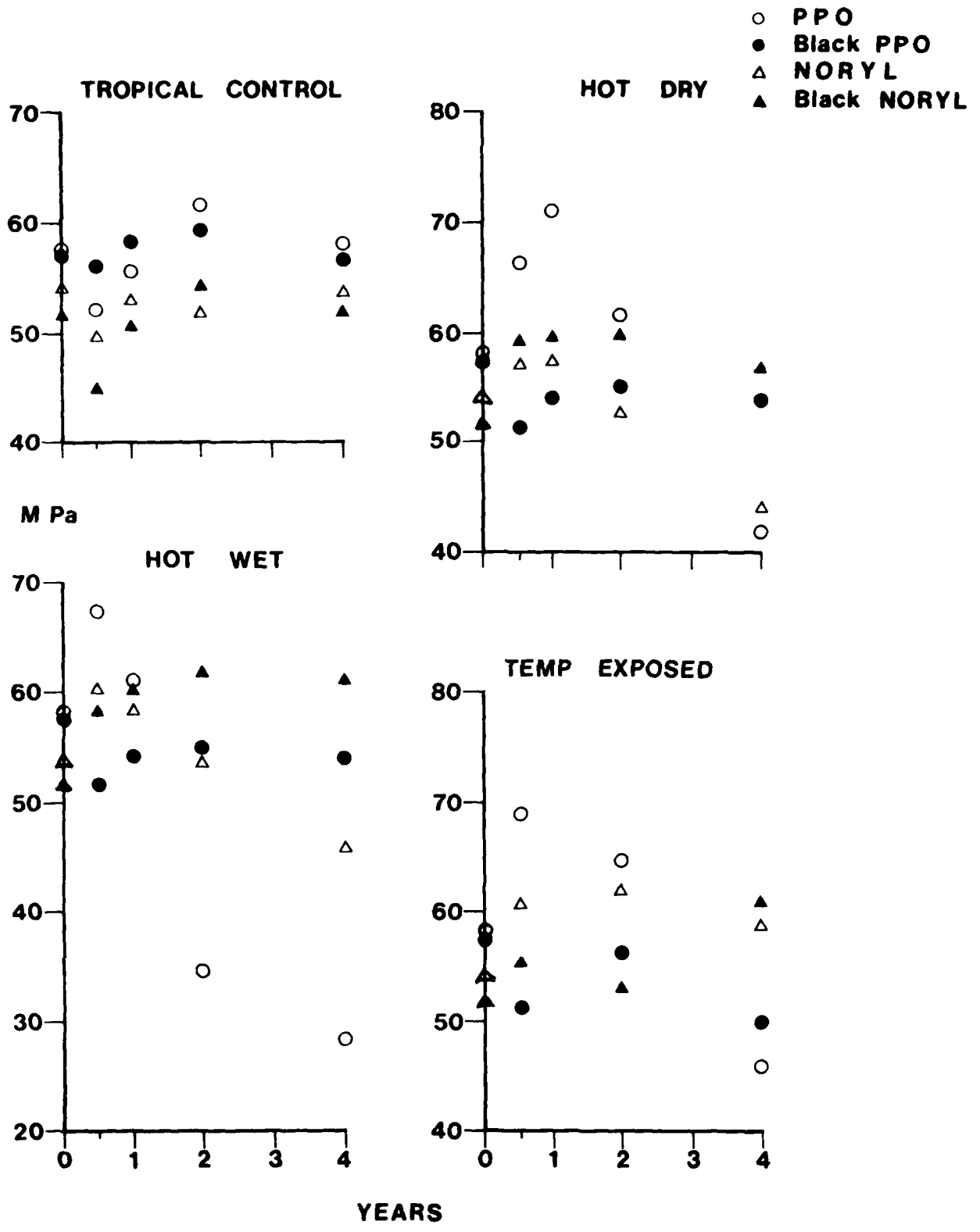


FIG 3 TENSILE YIELD STRAIN

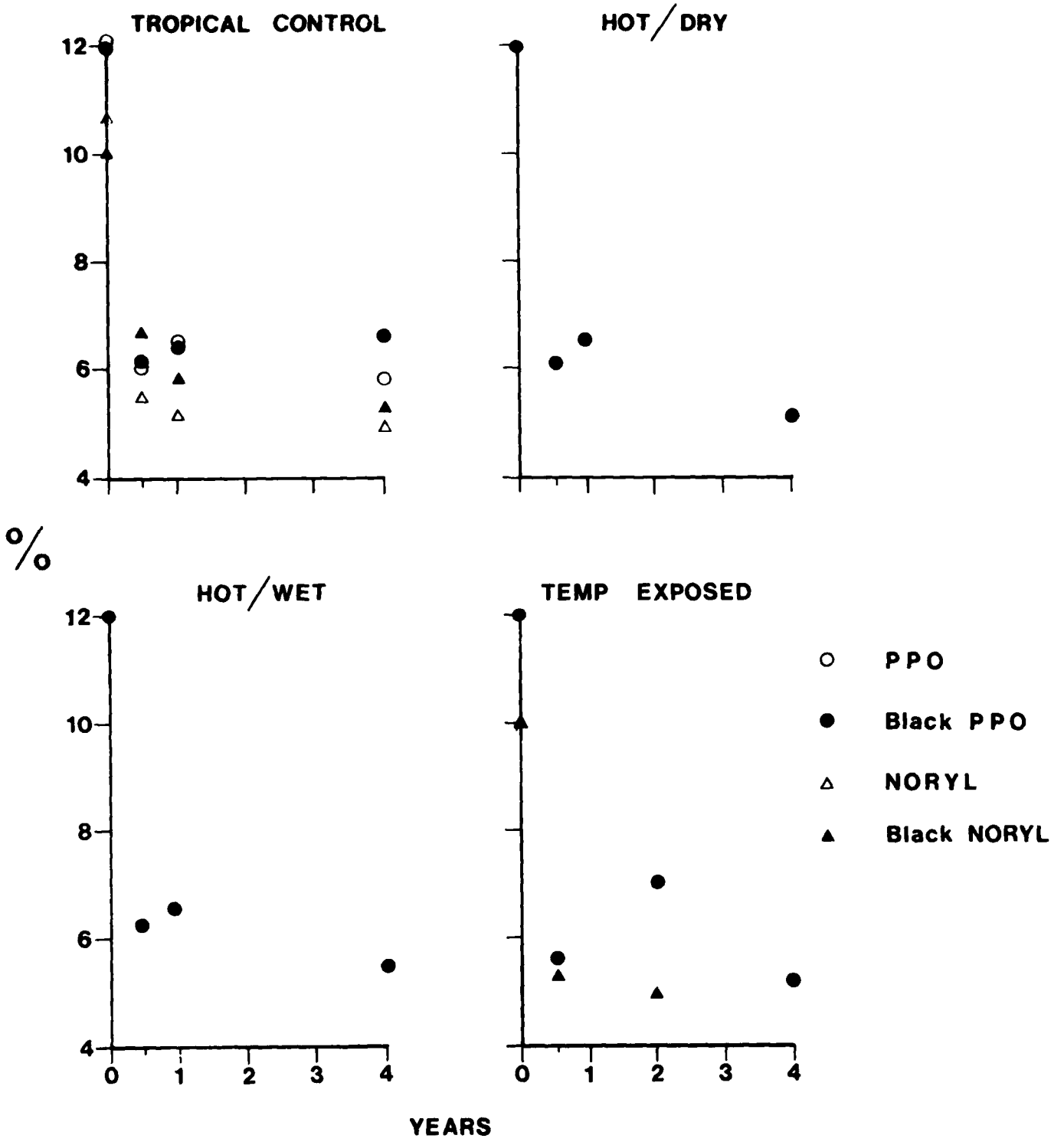


FIG 4 TENSILE BREAKING STRAIN

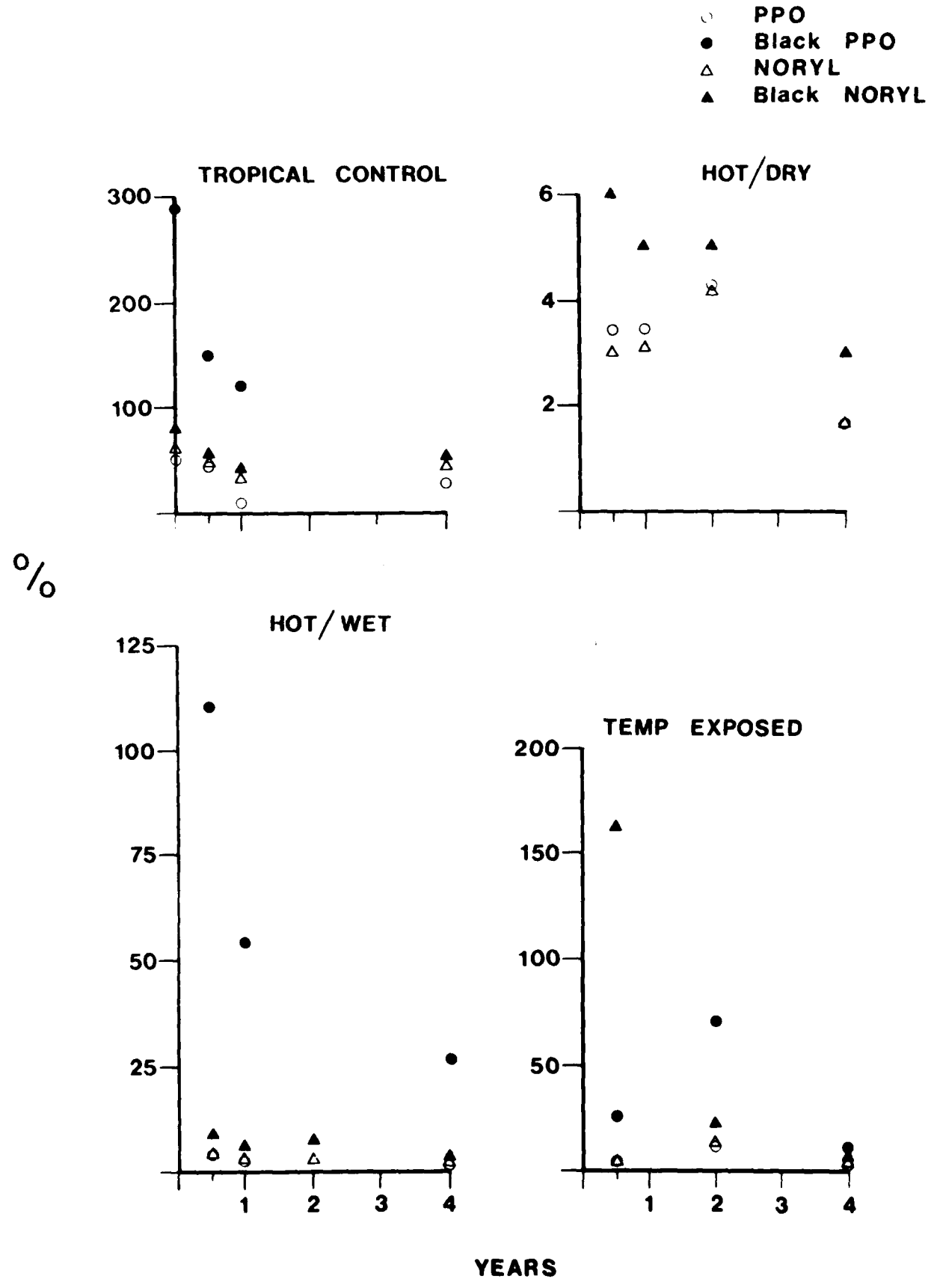


FIG 5 FLEXURAL STRENGTH

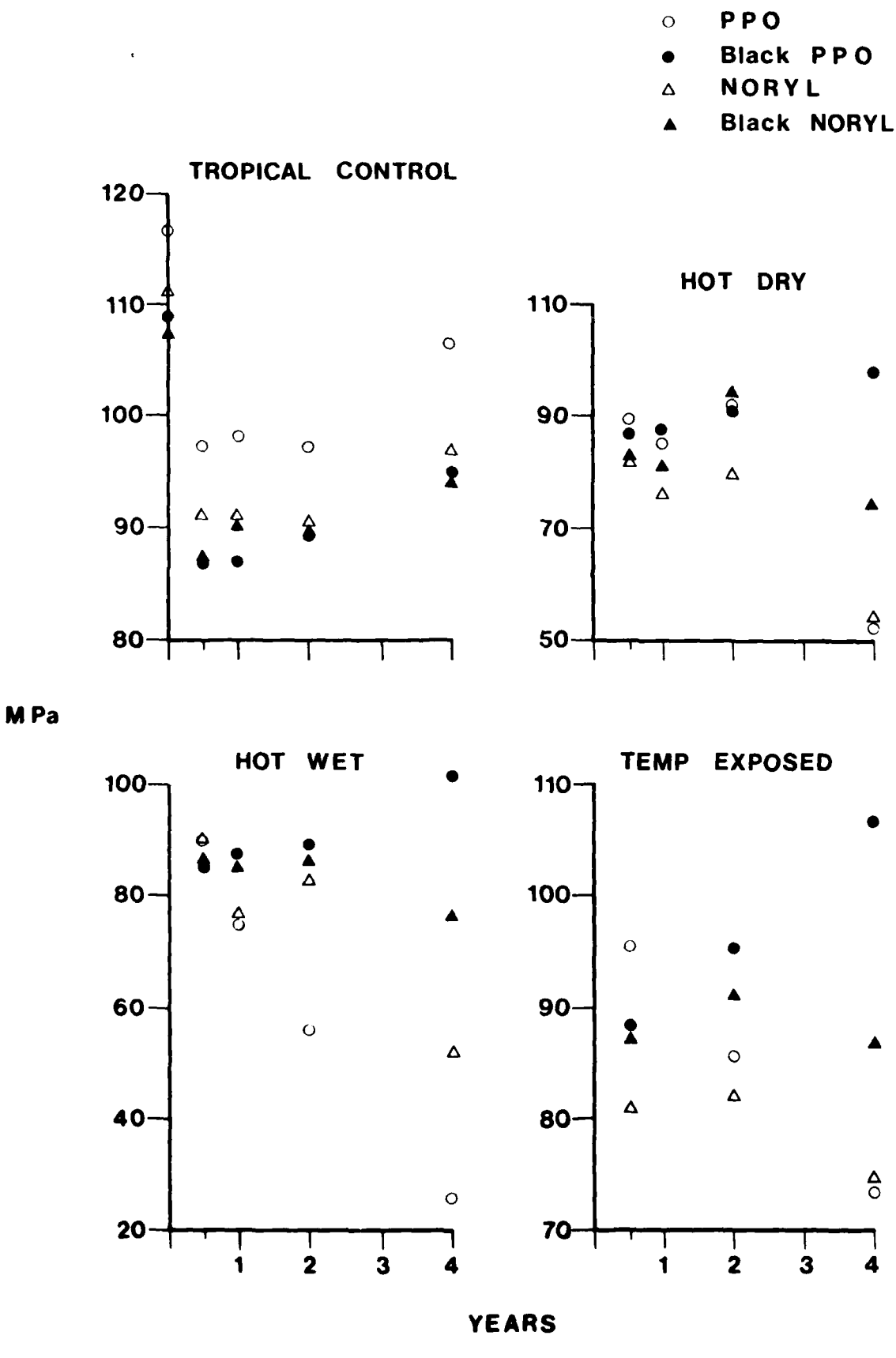
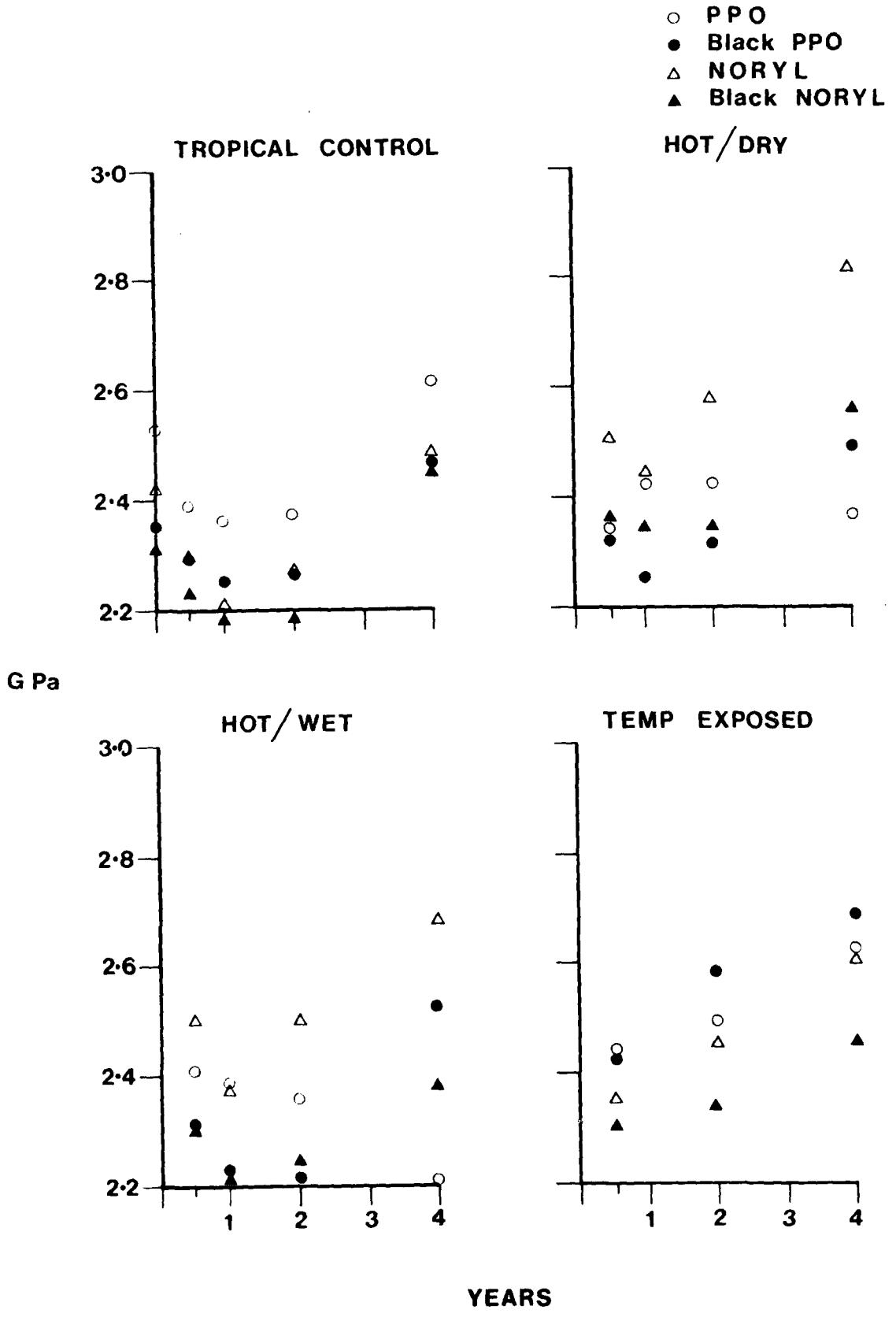


FIG 6 FLEXURAL MODULUS



REPORT DOCUMENTATION PAGE

(Notes on completion overleaf)

Overall security classification of sheet ..... Unlimited .....

(As far as possible this sheet should contain only unclassified information. If is is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R),(C) or (S)).

1. DRIC Reference (if known)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification
			Unlimited

5. Originator's Code (if known)	6. Originator (Corporate Author) Name and Location
7281400E	Propellants, Explosives and Rocket Motor Establishment Waltham Abbey Essex, England.
5a. Sponsoring Agency's Code (if known)	6a. Sponsoring Agency (Contract Authority) Name and Location

7. Title WEATHERING OF PLASTICS MATERIALS IN THE TROPICS
5 POLYPHENYLENE OXIDE AND NORYL

7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers). Title, place and date of conference

8. Author 1. Surname, initials	9a Author 2	9b Authors 3, 4...	10. Date	pp	ref
Procurement Executive, Federation Joint Committee on Behaviour under Tropical Conditions.	Ministry of Defence/British Plastics of Plastics Materials		1.1980	52	-

11. Contract Number	12. Period	13. Project	14. Other References

15. Distribution statement

Descriptors (or keywords)
Plastics, Weathering, Tropical tests, Mechanical properties, Noryl (C)

(TEST)

Abstract

The report describes the effect of long term weathering on polyphenylene oxide (PPO) and Noryl (a polystyrene modified PPO). Both natural and carbon black containing samples of each were exposed for up to 4 years at two tropical and one temperate site. Visual appearance, weight, tensile and flexural strength and electrical properties were recorded and used to monitor the effects of weathering.