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Effect of outdoor exposure and accelerated ageing on textile materials used in aerostat and aircraft arrester barrier nets

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The degradation behaviour of polyurethane (PU) coated nylon fabric and woven webbings made of nylon and polyester fibres when exposed to outdoor environment has been studied. The degradation behavior of these materials has also been studied under accelerated ageing using xenon lamp. The degradation behavior of the samples has been studied in terms of increase in gas permeability (for PU coated nylon fabric only), loss in breaking strength, work of rupture and extension-at-break. In PU coated fabrics, even though the tensile strength loss after outdoor exposure is acceptable, the gas retention property of PU coatings deteriorates sharply and material becomes unusable. It is observed that in case of polyester webbing, the outdoor exposure and xenon arc exposure data correlate quite well, however no such finding is observed for nylon webbing. It also emerges out that during outdoor weathering, although the strength loss in polyester webbing is less than that of nylon, the loss in work of rupture is higher. The UV resistant (UVR) finish has been found to be quite effective on both nylon and polyester webbings.

Keywords: Aerostat, Arrester barrier, Nylon, Outdoor weathering, Polyester, Polyurethane coated fabric, UVR finished, Webbing, Xenon arc exposure

1 Introduction

Aerostats, based on 'lighter-than-air technology', are used as raised platforms for various electronic payloads. Arrester barrier net is used to engage fighter aircrafts during emergency landing/take off. Estimation of service life of materials is an essential input for users of systems such as aerostats and aircraft arrester barrier nets to preempt system failures through periodic replacements of materials. These systems are essentially exposed to outdoor environment during their intended service life. A wide range of textile items is used in such systems. The life estimation entails knowledge of design load on materials, factors of safety, margins of safety and the rate of deterioration in strength of materials during usage/service. There are various environmental factors contributing towards the degradation of these textile items during their service life such as sunlight, heat, humidity and acid rain, primarily being the sunlight. A number of studies have been carried out on different textiles, ranging from fibres to yarn to made-up assemblies such as fabrics and narrow fabrics to know the extent of degradation during exposure to sunlight and accelerated ageing environments[1-20]. However, none of the literature referred gave conclusive idea of the degradation of textile materials used in such systems because of differences in climatic conditions, time of exposure, textile assemblies (a thicker made up textile degrades lesser than a thinner one), finishes, raw materials, etc.

Hence, it is required to generate near real time data on the textile materials used in such systems. In the present work, an attempt has been made to study degradation behavior in terms of increase in gas permeability (for PU coated fabric only) and loss in breaking strength, work of rupture and extension-at-break of PU coated nylon fabric and woven nylon and polyester webbings. This was done by subjecting the materials to outdoor environment on the institute rooftop and time-to-time withdrawals were conducted to find the loss in strength w.r.t. time. As a parallel approach, the materials were subjected to accelerated ageing using xenon arc lamp and results were compared. The correlation between the two exposures to estimate the real time degradation in short duration using accelerated ageing has also been reported. Further, it was also desired to find the efficacy of UVR finish on woven nylon and polyester webbings. Hence, both untreated and UVR finished webbings were used in the study.

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2 Materials and Methods

The following samples were used for the study:

(i) Polyurethane (PU) coated nylon fabric

(ii) Nylon and polyester webbings, as given below:

(a) Nylon, control (coded as N)

(b) Nylon, UVR finished (coded as N1)

(c) Polyester, control (coded as P)

(d) Polyester, UVR finished (coded as P1)

The details of the samples used are given in Tables 1 and 2. The nylon and polyester webbings were UVR finished by impregnating carbon black using butyral resin and butyl recinoleate.

From the preliminary trends of the degradation during outdoor exposure, the degradation was found to be higher during the initial phase. Keeping this in view, the outdoor exposure plan was made in such a manner that the degradation data was obtained initially for first month, then third month followed by every three-month interval for the one complete year on at least ten specimens of each textile item, starting from November 2002 for tensile specimens of PU coated nylon fabric and April 2003 for seam shear strength (SSS) specimens of PU coated nylon fabric and tensile specimens of nylon and polyester webbings. The mounting of specimens for outdoor exposure was done on specially designed MS frames in such a way that the materials were kept at 1.5 m above the surface of roof in a horizontal manner. For tensile testing of PU coated fabric, the fabric of 130 cm width was exposed and then tested from time to time from inner zones at least 5 cm away from edges. Care was taken so that nearly same set of warp threads was tested in one strip. For determining BS, 30 cm × 5 cm specimen is subjected to tensile load, gauze length is 20 cm, at constant traverse speed of 100 mm/min as per IS 7016, part II. For determining SSS of coated fabric, specimens were first prepared (with exact width of 5 cm) and then exposed. SSS specimens are made by making a lap joint (using adhesive) of overlap of 5 cm × 5 cm of two fabric specimens (15 cm × 5 cm). In case of tensile testing of seam shear specimens, if the joints remain intact and fabric fails, then it can be taken as a measure of tensile strength of fabric. The outdoor weather for exposure of materials is generally such that April to June is peak summers; July to September is rainy and December to February is peak winters.

It is found[20] that the average radiant exposure per year in New Delhi is around 180 kLy (kilo-Langley). However, the xenon arc exposure was given for slightly higher energy (190 kLy) taking into cognizance of the fact that apart from the outdoor environmental factors, the stress in the system and abrasion also add to the degradation of these textile materials. The temperature was taken as 65 ± 3°C, the reason being that the surface temperature of the materials rises ~17-33°C higher than the ambient temperature[2]. Remaining conditions of ISO 4892 were followed that includes 18 min rain cycle for every 102 min of dry cycle. For finding loss in tensile properties after xenon arc exposure a particular strip (warp-wise) along the entire length was used for specimen preparation so that only the same set of

Table 1—Test parameters and test methods for PU coated nylon fabric

Parameter	Value	Test method
Mass (maximum)	350 gsm	IS 7016 Part I
Breaking strength (minimum) (Warp and Weft)	250 kgf/5 cm	IS 7016 Part II
Hydrogen permeability (maximum) at 25 cm water column	2.5 L /m²/day	ASTM D-1434 or equivalent
Coating adhesion / peel strength for RF sealing & adhesive joints (minimum)	2 kgf /2.5 cm	IS 7016 Part V

Table 2—Physical and chemical parameters and test methods of nylon and polyester webbings

Parameter	Nylon webbing		Polyester webbing		Test method
	Control (N)	UVR finished (N1)	Control (P)	UVR finished (P1)	
Breaking strength, kgf	5651.5	5972.2	5673.3	5931.8	IS : 4227 (Appendix C)
Extension-at-break, %	24.7	31.2	14.0	19.4	IS : 4227 (Appendix C)
Width, mm	41.6	40.0	40.5	40.5	IS : 1954
Thickness, mm (at 200 g/cm^2 pressure)	3.97	3.64	3.95	3.55	IS : 7702
Mass, g/m^2	109.8	124	115.1	128.8	IS : 4227 (Appendix B)
MEK extraction, % (add-on of UVR finish)	-	8.1	-	6.5	IS : 4727 (Appendix E)

warp yarns is subjected to exposure and the effect of exposure alone is only reflected, not the variability of the specimen.

3 Results and Discussion

The results of the outdoor exposure are shown in Figs 1- 6. It is observed that, in general, initially the rate of degradation in outdoor environment is higher and it shows some leveling over a period of time. This may be due to the fact that the outer yarns face the brunt of the exposure and more reduction in strength takes place in these outermost yarns as compared to the yarns embedded in the inner structure. This suggests that the outer yarns have a shielding effect on the inner structure. Further, the degradation is relatively higher during peak summer from April to June, which is expected since the intensity of sunlight is highest during this period of exposure.

The effect of outdoor weathering and accelerated ageing is discussed on different textile items, viz. PU coated textiles as well as nylon and polyester webbings, both before and after UVR finish, in the following section.

3.1 PU Coated Nylon Fabric

The degradation behavior is shown in Figs 1 & 2 and Table 3. Figures 1 and 2 show the effect of outdoor exposure on breaking strength, work of rupture and extension-at-break of PU coated nylon fabric of tensile specimens and seam shear specimens respectively.

It appears that this material is sufficiently resistant to outdoor weathering initially. Even on exposure of one year the tensile strength (BS) loss is 8.6%. Surprisingly, the strength seems to increase between third month to nine month exposure, after an initial decline in first three months. This may be interpreted by the fact that during the initial three months due to the presence of moisture, accumulation of water condensate of mist on the upper fabric surface (daily in the early morning hours), hydrolysis takes place and this exhibits predominance over photo-tendering, resulting in strength loss. It is commonly known that the hydrolysis resistance of polyester grade PU, which is used as outer side (facing sun) coating of fabric, is inferior to that of polyether grade PU, which is used in inner side (facing gas). Further, almost no influence of sunlight is observed in another six months. This suggests that humidity also plays a major role in the degradation of this material apart from UV radiations of the sunlight alone. This trend is also evident by the enormous strength loss i.e. 34.8% (Table 3) of this material during xenon arc exposure. This may again be attributed to the spray cycle in the xenon arc chamber.

Table 3—Loss in breaking strength, extension-at-break and work of rupture of different textile materials after xenon arc exposure (4600 MJ/m^2 at 300 – 800 nm)

Sample	Breaking strength, %	Extension-at-break, %	Work of rupture, %
PU coated nylon fabric			
BS specimen	34.8	4.2	50.4
SSS specimen[a]	36.5	4.3	48.8
Nylon webbing (Control) (N)	28.3	-1.6	34.1
Nylon webbing (UVR finished) (N1)	2.8	-5.8	-9.3
Webbing polyester (Control) (P)	34.2	1.6	-
Webbing polyester (UVR finished 5.5%) (P1)	10.3	1.4	-

[a] Since the failure of joint did not take place at any conditions of exposure during application of load on specimen, seam shear strength (SSS) can be taken as a measure of BS.

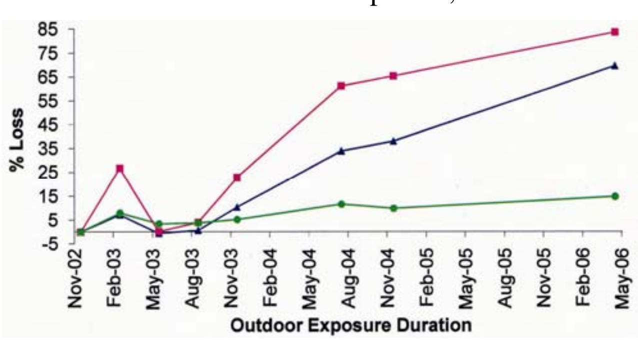

Fig.1—Effect of outdoor exposure on breaking strength, extension-at-break and work of rupture of PU coated nylon fabric (BS specimens) [-▲- Breaking strength, -■- Work of rupture and -●- Extension-at-break]

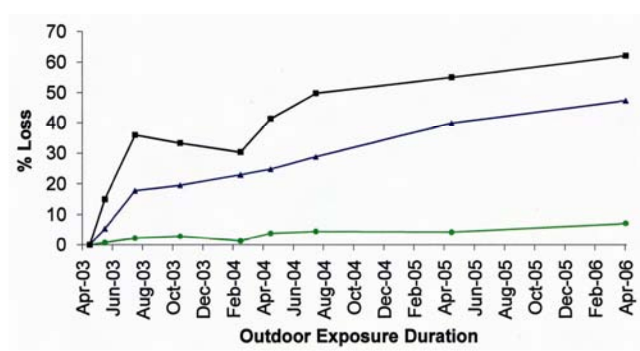

Fig.2—Effect of outdoor exposure on seam shear strength (BS), extension-at-break and work of rupture of PU coated nylon fabric (SSS specimens) [-▲- Breaking strength, -■- Work of rupture and -●- Extension at break]

Figure 1 shows that initially the coating polymer is sufficiently resistant to outdoor weathering but once it has been subjected to a critical duration of exposure, the strength loss increases linearly with time. It is also observed that the trend of loss in work of rupture (WOR), which is a measure of the energy absorbing capacity of the material, is similar to that of loss in BS. However, the loss in WOR in absolute terms is higher in comparison with loss in BS, since the extension-at-break also decreases as the time of outdoor exposure increases (Fig. 1).

Table 3 shows that there is considerably higher loss in the tensile strength of the PU coated specimens when subjected to xenon arc exposure (34.8% loss) for one year equivalent irradiance in comparison with the actual outdoor exposure of one year (10.5% loss). This suggests that the moisture, due to spray cycles of 18 min for every 2 h, during xenon arc exposure has played an important role for bringing about higher degradation to the material.

The data for effect of outdoor exposure (Fig. 2) on seam shear strength (SSS) suggest that there is a significant strength loss in the material (24.8%) in one year. Surprisingly, in this case the trend of degradation is in line with other materials (nylon and polyester webbings), i.e. the strength loss is appreciably higher during peak summer. It may be noted that no specimen joint failure/seam failure (adhesion slip, etc.) occurred in SSS specimens; hence SSS is basically the measure of BS in all the seam shear specimens. This higher strength loss in SSS specimens (24.8% in one year) as compared with BS specimens (10.5% in one year) (Fig. 1) may be attributed to the difference in mounting of these specimens. The BS specimens were prepared from exposed full-width fabric while SSS specimens were first prepared (with exact width of 5 cm) and then exposed. It seems that in SSS specimens the transport of moisture is relatively easier (may be due to capillary action) in comparison to BS specimens and hence the difference in strength loss. The hypothesis that moisture plays a crucial role in degradation of this material is also supported by a nearly similar strength loss in BS (34.8%) and SSS (36.5%) specimens during xenon arc exposure under identical conditions. From Fig. 2, it is also observed that the loss in WOR is higher in comparison with loss in BS, which is similar to the trend as observed with BS samples.

Figure 1 also shows that extension-at-break, except for one aberration, seems to go down with the duration of exposure. Since WOR is area under stress – strain curve, the loss in WOR is higher than that in BS at all points in time.

An important finding of this study is that the hydrogen permeability (HP) of the material increases significantly on account of exposure. The HP increases from 1.87 L/m^2/24h to 3.18 L/m^2/24h after exposure of one year. However, it increases drastically to 627.24 L/m^2/24h (negligible resistance to permeability) after exposure of approximately nineteen months. This may be due to some critical limit, which the coating layer has reached on account of exposure after which its properties degrade sharply, as discussed during the explanation of abrupt decrease in BS after one year. This suggests that permeability rather than tensile strength is a critical input for estimating the useful life of Aerostat system.

3.2 Nylon and Polyester Webbings

The degradation during outdoor exposure and xenon arc exposure is shown in Figs 3-5 and Table 3 respectively. Figure 6 is drawn based on data from Figs 3 and 5 of control nylon and polyester webbings for comparison of loss in tensile strength and work of rupture.

It can be observed from Fig. 3 that the nylon webbing (control) shows drastic strength loss on exposure to outdoor weathering. The strength loss after the initial exposure period (i.e. after the first month) is 24%. The strength loss plateaus later, perhaps due to the shielding effect of outer layer to the inner layers that prevents the entire material from degrading to similar extent. Also, the effect of weathering is harsh in summers as compared to other months in the entire year. This is evident from the slope of the curves during the period April'03-May'03 and April'04-July'04.

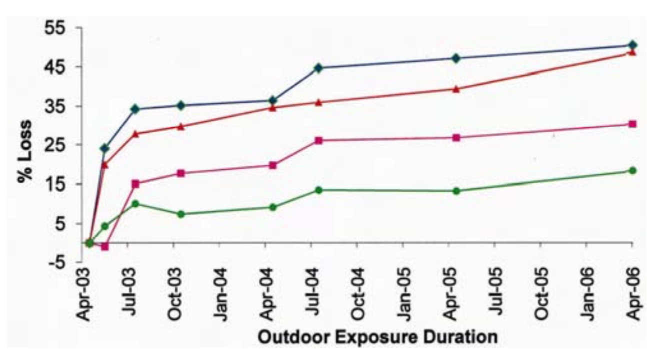

Fig.3—Effect of outdoor exposure on breaking strength of nylon and polyester webbings [-♦- Nylon control, -■- Nylon UVR finished, -▲- Polyester control, -●- Polyester UVR finished]

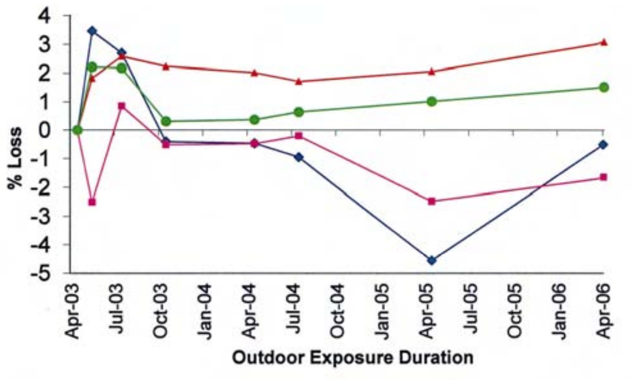

Fig.4—Effect of outdoor exposure on extension-at-break of nylon and polyester webbings [-◆-Nylon control, -■- Nylon UVR finished, -▲- Polyester control and -●- Polyester UVR finished]

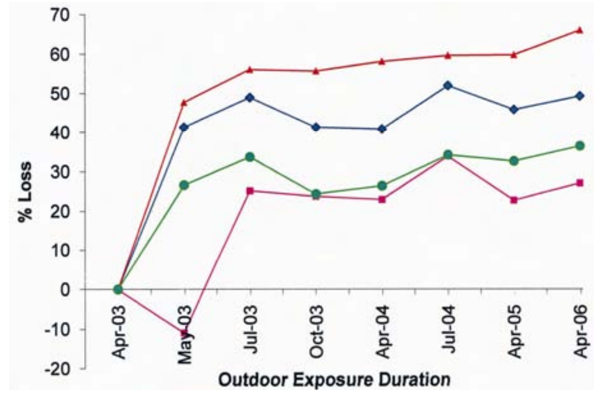

Fig.5—Effect of outdoor exposure on work of rupture of nylon and polyester webbings [-◆- Nylon control, -■- Nylon UVR finished, -▲- Polyester control and -●- Polyester UVR finished]

It can be seen from Fig. 4 that there is no specific trend in extension-at-break of nylon webbing. Initially there is some loss, however after some duration of exposure it appears to increase. At the same time, some loss in extension-at-break is always observed in polyester webbings.

From Fig. 3, it can be seen that surprisingly in the nylon webbing (UVR finished) (N1), there is a slight increase in its strength after one month exposure. This trend has been observed in other UVR finished polyester webbings as well. A few possible explanations may be that (i) there may be no real change in the breaking strength in such a short duration exposure, (ii) some cross-linking might have occurred within the polymeric chains on account of UV exposure during this period which has marginally increased the strength, and (iii) due to temperature some strains might have been reduced that develops during weaving of such compact structure and this might have led to uniform sharing of loads within yarns when these webbings are subjected to tensile testing . However, on prolonged exposure after one month, the strength has decreased substantially although not to the extent as that of the untreated webbing. Similar to untreated webbing, the strength loss is higher in summers as compared to other months during the entire exposure period, as is evident from the slope of the curves during the period April’03-July’03 and April’04-July’04.

Figure 5 shows that in all nylon and polyester webbings, the maximum loss in work of rupture (WOR) has occurred during the initial months of exposure. Thereafter, the WOR loss in nylon webbings is insignificant while there is some loss observed in polyester webbings.

The loss in strength due to xenon arc exposure, which is nearly equivalent to one year outdoor exposure in nylon webbing (control) is found to be ~28% (Table 3). This is less in comparison to the strength loss of 36.5 % (Fig. 3) during actual outdoor weathering of one year. Similarly, the loss in strength of nylon webbing (UVR finished) after xenon arc exposure is just 2.8% (Table 3). On the other hand, the strength loss of the same webbing under actual outdoor weathering of one year is 19.7% (Fig. 3). This suggests that there is no correlation of xenon arc and outdoor weathering in nylon webbings.

To compare the degradation behaviour of nylon and polyester, polyester webbings (without UVR and with UVR finish) were subjected to outdoor and xenon arc weathering. The results shown in Table 3 and Figs 3-6 are discussed hereunder.

It is observed that the trends of degradation of nylon and polyester webbings are not different. Both of these materials show a high loss in strength initially followed by a plateau region. It can also be seen that the trends of degradation of polyester control and UVR finished webbings are nearly same, although the strength loss in UVR finished webbing is significantly lower than that of the untreated webbing. Further, similar to nylon webbing, it appears that in a certain interval the strength increases somewhat on account of outdoor exposure for the probable reasons cited above. However, there is marginal loss in the overall extension-at-break of the material during the entire exposure period.

Further, it can be inferred from the results of breaking strength that polyester is better than nylon in terms of outdoor exposure since at all the intervals the loss in strength of polyester is less vis-à-vis nylon. This is in line with the findings reported in the literature[1].

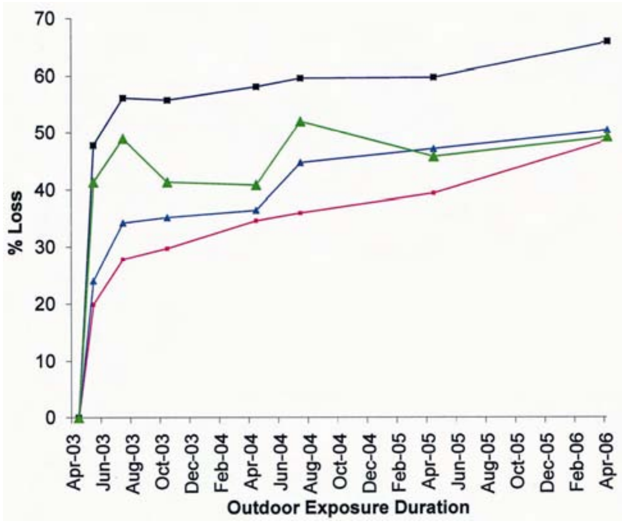

Fig.6—Effect of outdoor exposure on breaking strength (BS) & work of rupture (WOR) of control nylon & polyester webbings [-▲- BS nylon, -▲- WOR nylon, -■- BS polyester and -■- WOR polyester]

However, a very surprising finding of the study can be observed from Fig. 6, where the trends of loss in WOR of nylon and polyester webbings are contradictory to the trends of loss in breaking strength after outdoor exposure. It is observed that at any point of time the loss in WOR of polyester webbings is more than that of nylon webbings. This finding raises doubt over the fact that polyester is better than nylon in applications where the materials are exposed to sunlight.

3.3 Comparison of Outdoor and Accelerated Ageing

Student's t-test, two-sample equal variance, has been applied on the BS and WOR data (the parameters of primary concern) for one year of outdoor exposure and one year equivalent xenon arc exposure to find out correlation between the two.

3.3.1 PU Coated Nylon Fabrics

From Table 3 and Figure 1, it is observed that although the data for xenon arc exposure do not correlate to outdoor exposure to a great extent, some degree of correlation has been arrived, as described hereunder.

On applying t-test on BS data for outdoor weathering of PU coated nylon fabric for 20 months and xenon arc weathering of one-year-equivalent-irradiance, good correlation between the two is found, i.e. the 'probability that the means are same (Pr. 0.69). However, no such correlation is found between their WOR values. Similarly, the difference between SSS data for outdoor weathering of PU coated nylon fabric for 24 months and xenon arc weathering of one-year-equivalent-irradiance is not significant (Pr. 0.3). Although the WOR of 15 months outdoor exposure data correlates well with xenon arc exposure of one-year-equivalent-irradiance (Pr. 0.71), there is no such correlation between their SSS (Pr. 0.02). This difference between correlation of WOR and BS of xenon arc data arises because of the fact that at any time period of exposure, the loss in WOR is higher than the loss in BS (Fig. 1). Therefore, good correlation between outdoor exposure for 15 months is observed for WOR values while for SSS (actually measure of BS in this case) fair correlation is observed for 24 months outdoor exposure.

From the above findings, it can be inferred that xenon arc exposure of one-year-equivalent-irradiance is nearly equal to 15-20 months of outdoor exposure on PU coated nylon fabrics. Therefore, by controlling the amount of irradiance energy or moisture in xenon arc weather-o-meter, a reasonable correlation with outdoor weathering may still be found out.

3.3.2 Nylon and Polyester Webbings

On applying t-test on nylon webbings (both untreated and UVR finished), no correlation is found between outdoor and xenon arc weathering (Pr. is 0 for both) for BS, extension-at-break and WOR values.

It appears that the correlation between xenon arc and outdoor weathering data is quite good in case of polyester webbing (Table 3 and Figs 3-5). This is further confirmed by the application of t-test on the breaking strength values which reveals that for polyester webbing (untreated) (coded as P), Pr. is 0.77 and for polyester UVR finished webbing (coded as P1) the Pr. is 0.60. However, there appears partial correlation with breaking extension values with Pr. of 0.05 and 0.01 and WOR values with Pr. of 0.00 and 0.04 for P and P1 webbings respectively.

4 Conclusion

4.1 PU coated nylon fabric used in aerostats is sufficiently resistant to outdoor weathering of one year (10.5% loss). However, its strength falls rapidly thereafter, and the strength loss after 20 months is 36.5%. The hydrogen permeability is affected significantly in one year of outdoor exposure (3.18 against 1.87 L/m^2/24h of control) and increases abruptly to 627.24 L/m^2/24h after 20 months exposure, suggesting unsuitability of this material after prolonged exposure. Therefore, the loss in gas impermeability is critical input for life estimation of these materials. Further, apart from UV radiations, the moisture also plays a crucial role in the degradation of this material. There appears to be fairly good correlation between the strength loss after 20 months outdoor and one-year-equivalent-irradiance xenon arc exposure.

4.2 In case of both nylon and polyester webbings, the UVR finish is very effective. The strength loss in untreated nylon webbing after one year is 36.5%, whereas that in UVR finished nylon webbing is 19.7%. Similarly, the strength loss in untreated polyester webbing after one year is 34.7%, whereas that in UVR finished polyester webbing is 9.2%.

4.3 Further, there is fairly good correlation between one year outdoor weathering and equivalent xenon arc exposure in case of polyester webbings. However, no such correlation is observed for nylon webbings.

4.4 Also, the degradation behavior for three years outdoor exposure suggests that in terms of breaking strength retention polyester is better than nylon. However, converse is true as it emerges out from the trends of work of rupture. Summarily, for applications involving energy-to-break considerations and outdoor exposure, nylon appears better than polyester. The caveat is that the authors are unaware of the additives added in the polyester and nylon yarns and whether that has resulted in such difference. Further study in this regard is recommended.

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