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DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
MATERIALS RESEARCH LABORATORIES
MELBOURNE, VICTORIA

REPORT

MRL-R-930

AGE LIFE PREDICTION OF NYLON 66 PARACHUTE MATERIALS.
PART-I. MECHANICAL PROPERTIES

G.T. Egglestone and G.A. George

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Tensile strength measurements done on suspension lines from used parachutes gave strength losses larger than those expected from storage temperature oxidation. This increased loss was considered to result from shearing of nylon filaments by accumulated abrasive material. Acoustic emission during line fracture supported this type of failure.

Low temperatures had a negligible effect on suspension lines. The energy absorbing characteristics of the lines remained reasonably constant over the temperature range of -40°C to 22°C.

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AGE LIFE PREDICTION OF NYLON 66 PARACHUTE MATERIALS.

PART-I. MECHANICAL PROPERTIES

1. INTRODUCTION

The safe service life of military personnel parachutes has traditionally been determined by periodic engineering evaluation of parachutes with known service and storage histories [1,2,3]. These investigations have been performed in the USA and the UK and have covered parachutes stored and used in both temperate and tropical zones. The results of these investigations, together with limited engineering evaluations of a sample of parachutes taken from service have been used to extend the service life of Australian Army parachutes. The present lifing requirement for personnel parachutes is a maximum age of 12 years [4] from the date of manufacture with the material having a maximum shelf life of three years prior to manufacture. The lifing requirements for cargo parachutes are not as stringent [4]. The heavy and medium cargo parachutes have a service life limitation of 20 years with a contingency lifetime of a further 10 years. Light cargo parachutes have a service lifetime of 25 years from procurement and a 10 year contingency lifetime. During their service life, (as a result of normal stock rotation procedures) all parachute types may be used for as few as 10 to 20 deployments. Consequently it is inevitable that most of the service life of both personnel and cargo parachutes is spent under storage conditions.

To date there has been no systematic study of the effects of Australian operating conditions on the mechanical properties of nylon components of parachutes. This is considered a necessary requirement for an adequate Australian lifing policy.

The object of this investigation was to examine a number of Australian Army personnel parachutes withdrawn from service and storage and also to perform accelerated ageing studies on nylon parachute materials to determine:

- (i) if there was any significant loss in mechanical properties of parachute canopies and suspension lines with age or service life;
- (ii) the rate of loss of mechanical properties of nylon 66 materials under accelerated service and storage conditions;
- (iii) if any changes in mechanical properties of the parachute components resulted from degradation of the material and ways this could be avoided.

These data were then to be used to assist in predicting the expected service life of the new range of T-10 materials.

In this report the mechanical properties of parachute components returned from service and subjected to accelerated ageing are studied. From these studies predictions of the changes in strength for the T-10 series of parachutes are made.

In Part-2 of this report, assessment of the chemical and physical changes in the nylon 66 parachute materials are made and any patterns of deterioration determined.

The parachutes and repair materials studied were of two basic types: the UK and Australian manufactured PX series and the US manufactured T-10 series. The PX series, being largely superseded, provided a wide range of storage and service histories. Repair materials for the PX and T-10 series were subjected to accelerated environmental ageing in order to obtain a comparison of predicted and actual strength changes.

2. EXPERIMENTAL

2.1 Materials

- (i) The types and ages of the parachutes studied are given in Table 1.
- (ii) The physical characteristics of the nylon 66 plain woven taffeta material (PX-Series) and the nylon 66 plain woven olive drab ripstop material (T-10 Series) are given in Table 2.
- (iii) The suspension lines tested were manufactured to specifications MIL-C-5040 and MIL-C-7515. Typical minimum specified breaking strengths for the lines were 2.4 kN.

2.2 Accelerated Ageing of Nylon 66 Materials

Thermal ageing was performed in a forced air oven at temperatures of 110°C, 100°C, 80°C and 65°C for the undyed taffeta material and at 120°C,

110°C, 100°C, 80°C and 70°C for the olive drab ripstop material. The time of ageing ranged from 14 days to 500 days depending on temperature.

The effect of solar radiation on canopy materials was determined by mounting samples outdoors at MRL under window glass facing north at an angle of 36° to the horizontal. Mechanical tests were performed at regular intervals. The incident radiation was measured by changes in optical density at 340 nm of poly(phenylene oxide) films [5].

2.3 Mechanical Measurements

Tensile strength determinations were performed using the following two instruments:

- (i) A Denison T41D tensile testing machine fitted with flatbook grips was used at a constant rate of extension of 100 mm/min, for testing canopy fabric. Bollard grips, 25 mm in diameter and a constant rate of extension of 200 mm/min was used for testing suspension lines.
- (ii) Breaking strength determinations on suspension lines were also performed using an Instron 1026 table model tensile testing machine, at a constant rate of extension of 200 mm/min using capstan grips.

3. RESULTS AND DISCUSSION

CHANGES IN MECHANICAL PROPERTIES OF PX-SERIES CANOPIES WITH AGE

The tensile strength and extension to break of canopy material from personnel parachutes are given in Table 1. The dates of manufacture of the service parachutes range from 1961 to 1975. The civilian parachute tested was manufactured in 1950. The trend as shown in Table 1 is for the older parachutes to have lower tensile strengths and elongations. Two PBI/MK6 parachutes (Parachute numbers 454708, 454715) 12 years old at test have tensile strengths above those expected. Although these parachutes appear to be out of character, no original tensile strength data are available. The data for change in the percentage extension at break are similar. Graphs showing the decrease in tensile strength and extension at break with increasing age are given in Figures 1 and 2 respectively.

COMPARISON OF UK AND AUSTRALIAN DATA FOR PX-1 CANOPIES

As the Australian lifing policy for the PX-series of parachutes was based largely on UK experience with these assemblies, it is of interest to compare the results of engineering evaluations of parachutes in service with the UK Army with those used by the Australian Army. In the study by Irvin Pty Ltd [1], any ageing effects are best recognized by a study of the data for the

reserve parachutes which will have had little or no usage. In the UK study, the average strength of canopy material from reserve parachutes in storage is reported as 227 N/25 mm width after 11 years. Material from Australian parachutes of the same age and also tested by Irvin Pty Ltd was reported to have a strength of 205 N/25 mm width. These results are compared with the data from this investigation in Figure 1 and it can be seen that the result for the parachutes in storage is in agreement with the results of this investigation, whereas the Australian parachutes measured by Irvin Pty Ltd appear to be lower in strength than those studied in this investigation. However, the overall trend in strength loss for both the UK and Australian studies appear to be consistent. What is of utmost importance in the development of a predictive capability for the safe storage life of a parachute assembly is the determination of the reasons for this strength loss with increasing age.

ACCELERATED AGEING OF NYLON 66 CANOPY MATERIALS

Nylon 66 fibres are known to be susceptible to thermal oxidation [6]. It is therefore possible that the strength loss observed from personnel parachutes during storage results from slow thermal oxidation. To test this, a series of accelerated ageing trials were performed by subjecting canopy repair material for PX-1 parachutes to temperatures from 65°C to 110°C in air and periodically measuring the strength retained by the material.

The results of these measurements are summarized in Figure 3 as graphs of % retained strength versus time of ageing. It can be seen that the effect of increasing the temperature is to reduce the strength at a faster rate i.e. the rate of degradation increases with temperature. The specific rate of degradation, k is given by the INITIAL slopes of the lines in Figure 3.

The rates of most chemical reactions, including the thermal oxidation of polymers, show an exponential increase with temperature - the Arrhenius relation [7,8]. If the strength losses on accelerated ageing result from thermal oxidation, the data of Figure 3 should also increase exponentially with temperature. This is confirmed in Figure 4 where it can be seen that over the range 65°C to 110°C there is an exponential relationship and the specific rate of degradation, k is given by

$$k = 1.16 \times 10^7 \exp \left(\frac{-8004}{T} \right) \quad (1)$$

where T is the temperature in degrees Kelvin.

EXTRAPOLATION OF ACCELERATED AGEING DATA TO STORAGE TEMPERATURES

While relation (1) has been shown to hold at temperatures between 65°C and 110°C, it is considered valid to extrapolate the relation to

temperatures that may be encountered in storage. The justification for this is based on chemical and physical measurements on nylon 66 over a wide range of temperatures as detailed in the second report (PART-2) of this investigation. This extrapolation is shown as the dotted line in Figure 4, and it enables values of the specific rate of degradation, k , to be estimated for temperatures from 20°C to 40°C, - the expected range of storage temperatures for nylon 66 parachutes.

In Figure 5 the estimated rates of degradation are plotted as % strength loss against time at 5°C intervals from, 20°C to 40°C. The time scale is from 5 to 30 years and strength losses predicted from Figure 5 can be compared with actual measurements made on the canopies of PX-1 parachutes as summarised in Figure 1 and Table 1. The results for the PX-1 parachutes are shown as triangles in Figure 5.

The fact that strength loss measurements for the PX-1 parachute canopies occur within the values for predicted strength losses at temperatures of 20°C and 30°C - a reasonable range for average storage temperature of parachute canopies in Australia - validates the use of accelerated ageing data to estimate rates of degradation at storage temperatures. This implies that this approach can be used to predict the safe storage life of new materials being introduced into service.

PREDICTION OF STRENGTH LOSSES ON STORAGE OF T-10

OLIVE DRAB RIPSTOP CANOPY MATERIALS FROM

ACCELERATED AGEING

To predict the strength losses from the olive drab ripstop material used in all T-10 parachutes, accelerated ageing trials on repair material were performed at temperatures from 70°C to 120°C. The initial changes in strength with time of ageing are shown in Figure 6. These plots are used to determine the rate of degradation of the material. Again it is found that the specific rate of strength loss k increases exponentially with temperature according to an Arrhenius relation as shown in Figure 7. This relation is given by:

$$k = 1.44 \times 10^9 \exp \left(\frac{-10137}{T} \right) \quad (2)$$

This relation is quite different from that obtained for the PX-1 repair material (Relation 1) and immediately indicates that the data obtained for the PX-series of parachutes cannot be used to predict the performance of the newer range of T-10 parachutes. The chemical and physical studies detailed in (PART-2) show that the process of strength loss is again one of thermal oxidation and that it is valid to extrapolate the accelerated ageing data to storage temperatures.

The rates of strength loss of olive drab ripstop material at storage temperatures calculated from these extrapolated data are plotted in Figure 8. This plot can be immediately compared with Figure 5 for the PX-1 white nylon taffeta material, and it can be seen that the rate of strength loss from the olive drab material used in the manufacture of T-10 parachutes presently in service is lower by a factor of ≈ 10 . Thus, all other factors being equal, a canopy constructed from the olive drab ripstop material might be expected to last 10 times as long as that from a PX-1 parachute.

To compare the predicted strength losses with time and temperature of ageing, six dyed T-10 parachutes have been stored for two years, in a controlled laboratory at 65% RH and 20°C. Using equation (2) established previously, the parachutes were theoretically expected to lose 0.1% strength at this temperature. Table 3 shows the parachutes have lost no strength. The determined increase in strength is considered to be within the experimental error as tensile specimens were taken from different gores when insufficient sample remained. At these very short exposure times, it is impractical to expect a confirmation of the relationship between predicted and practical strength losses. To confirm this relationship, further monitoring of these samples is required. These samples will therefore continue to be stored under the above conditions with regular monitoring of their physical properties.

CHANGES IN MECHANICAL PROPERTIES OF CANOPY

MATERIAL ON OUTDOOR EXPOSURE

The present parachute maintenance instructions clearly indicate that exposure of canopy materials to sunlight must be kept to a minimum [4]. This recognizes the extreme susceptibility of lightweight nylon 66 fabrics to solar degradation unless the material contains special additives such as ultraviolet absorbers. Much of the data upon which the present maintenance policy was based is several years old. As these may have been derived from studies of dull and semi-dull nylon containing the anatase form of titanium dioxide, a known photo sensitising agent for nylon (9), the repair materials for the PX-1 and T-10 series of parachutes were subjected to outdoor exposure.

The measured decrease in tensile strength with time of outdoor exposure of these materials is summarised in Table 4. It can be seen that losses in strength are less than 10% for up to two months outdoors, after which there is a rapid loss in strength. In addition it should be noted that the olive drab ripstop (T-10) material degrades faster than the undyed taffeta (PX-1). This is opposite to the result for the thermal oxidation of these two materials. Further experiments and possible reasons for this result are described in the second report (PART 2).

These data suggest that the outdoor exposure of the T-10 series of parachutes should also be kept to a minimum although short term exposure during field operations (eg. for drying) would not be expected to lead to large strength losses.

EFFECT OF SHOCK LOADING DURING OPERATION ON

RETAINED STRENGTH OF CANOPY MATERIALS

In addition to the age of a parachute, the number of jumps that the assembly receives has been considered to reduce the retained strength [1,2,3]. The shock loading that a canopy and suspension lines will receive can be calculated and a recent study of cargo parachutes has shown that a considerable safety margin is maintained for canopy material [10].

In this study only a limited number of parachutes with a verifiable jump history were available. A typical loss in strength after 45 jumps was 9% for the PX-1 series parachutes. The only data available for the T-10 series are from US studies [2,3] in which no strength loss was recorded that was attributable to jump history.

These data support the general conclusion that there should be no limitation to the number of jumps that a canopy may sustain in its service life.

MECHANICAL PROPERTIES OF PARACHUTE SUSPENSION LINES

The slow loss in tensile strength occurring in nylon 66 fibres due to thermal oxidation on storage will occur in the suspension lines at a rate comparable to that for the canopy materials. Detailed analysis of the material used in the suspension lines has shown it to be identical to that from the canopies and ageing affects should be similar.

It has been found, however, in studies in the US and UK that the suspension lines are more likely to suffer strength losses as a result of service use. This appears as a decrease in tensile strength with increased number of jumps [1,2,3]. While a large number of suitable parachutes was not available to determine if this was a general result for operation in Australia, a limited study has shown decreases in strength of up to 30% from suspension lines taken from PX-series parachutes with more than 40 jumps. These are summarized in Table 5 and compared with results from the UK study of similar parachutes.

Previous studies in these Laboratories [11] have shown strength losses in suspension lines of up to 25% due to abrasive salt particles trapped in the structure of the line after salt water immersion and incomplete washing. Siliceous matter would be expected to have a similar effect.

During tensile testing of suspension lines from these PX-series parachutes with a large number of jumps, premature failure of individual yarns in the lines was observed. This is shown in Figure 9 as a series of irregularities in the load-elongation curve. As a yarn suddenly fails the load momentarily drops until other yarns take up the load. The test is

accompanied by discernible acoustic emission from the point marked A.E. in Figure 9 which is further evidence for premature yarn failure. When individual yarns are removed from the suspension lines and tested, neither irregularities in the load-elongation curve nor acoustic emission events, are observed.

Studies in the USA by Natick Laboratories have shown that suspension lines from T-10 parachutes more than 15 years old show substantial accumulation of siliceous particles and other abrasive materials. The strength losses from these suspension lines have been attributed to internal abrasion by a mechanism matching that proposed here.

STRENGTH RETENTION OF SUSPENSION LINES AT LOW TEMPERATURES

In operations at very high altitudes the ambient temperature may be -35°C . It is therefore necessary to determine if there is any decrease in the tensile strength and energy to fracture of the material that could lead to premature failure during deployment under these conditions.

The mechanical properties of T-10 suspension lines at temperatures of -40°C and -20°C are compared with those measured at 22°C in Table 6 for a number of strain rates. It is seen that at low temperatures the breaking force is increased and the elongation at failure is decreased. The energy to fracture, which is a good measure of the energy absorbed by the suspension lines during loading, remains reasonably constant for the entire range of temperatures and strain rates. It is therefore concluded that operations at low temperatures will be unlikely to lead to premature failure.

4. CONCLUSIONS

A study of the life expired range of PX-personnel parachutes in storage and service in Australia shows that there is a pattern of strength loss analogous to that experienced with similar parachutes in the UK.

From accelerated ageing trials it is possible to predict the strength losses occurring in the canopy materials due to slow thermal oxidation while in storage. However it is not possible to apply data from the measurements made on the PX-series parachutes to the T-10 parachutes presently in service with the Australian Army.

It is found that the olive drab nylon ripstop canopy material used in the T-10 series is much more stable to thermal oxidation than the undyed nylon taffeta used in the PX-series, and this results in a predicted storage life of up to ten times longer. The use of these results for service life prediction should be supported by periodic testing of assemblies withdrawn from service or storage.

In contrast, the olive drab ripstop is more easily degraded by sunlight than the undyed taffeta. While both materials require continuous exposure of three months outdoors before strength losses of more than 10% are observed, it is still recommended that the exposure of parachute canopies to sunlight be minimized.

From an examination of life expired PX-series parachutes there appears to be no significant loss of strength of the canopy with increasing number of recorded jumps. However a study of a limited sample of PX-parachutes showed that suspension lines may sustain a loss in strength of up to 30% after only 45 recorded jumps. The unusual load-elongation behaviour of these low-strength lines suggests that the trapping of abrasive particles during service may be partly responsible for the strength loss.

This study has found that one of the greatest problems in determining changes in mechanical properties of parachute components when in service or in storage is the lack of reliable mechanical data for the original materials. Data from parachutes covering a wide range in age shows much greater scatter than the accelerated ageing data. This has been attributed to variability in the mechanical properties of the nylon materials which are procured to a specified minimum set of mechanical properties. This problem has also been recognized in the UK and the USA [1,2,3].

It is hoped that this will be overcome for the T-10 series as representative assemblies are now in controlled storage at Materials Research Laboratories. The original properties of the materials have been measured and periodic engineering and chemical evaluations of these parachutes will be performed for comparison with parachutes in service. This will further test the validity of the accelerated ageing method for predicting possible strength losses of a new material.

5. ACKNOWLEDGEMENTS

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TABLE 1

MECHANICAL PROPERTIES OF CANOPY MATERIALS FROM

PX-1 SERIES PARACHUTES OF DIFFERENT AGE

PARACHUTE NUMBER	AGE YEARS	TYPE	TENSILE STRENGTH N/25 mm WIDTH	EXTENSION AT BREAK (%)
380437	19	PR MK1	195.5	17.6
382241	16	PBI MK4	220.0	18.9
382242	16	PBI MK4	215.0	17.8
443537	15	X TYPE	215.5	21.5
436060	13	PR TYPE	213.0	21.1
454708	12	PBI MK6	250.5	24.7
454715	12	PBI MK6	246.5	24.1
7280025	5	PBI MK6	244.5	25.3
CIVILIAN	30	PX TYPE	174.0	18.2

TABLE 2

PHYSICAL CHARACTERISTICS OF CANOPY MATERIALS TESTED

TEST	PLAIN WOVEN UNDYED TAFFETA (PX-SERIES)	PLAIN WOVEN OLIVE DRAB RIPSTOP (T-10 SERIES)
weight (g/m ²)	44.5	34.7
ends	40	43
picks	39	43
Breaking Strength (N) per 25 mm width warp	231	217
Extension (%)	23.5	20.9
Filaments/yarn		
warp	12	10
weft	12	10
linear density		
warp	5.3	3.6
weft	5.2	3.5
Fibre diameter (μm)	21.2	20.1
Delustrant as TiO ₂ (%)	0.28	0

TABLE 3

PHYSICAL CHARACTERISTICS OF T-10 PARACHUTES STORED AT 65% RH AND 20°C

Description	Date of Manufacture	Physical Characteristics of canopy material as received		Physical Characteristics of canopy material after 2 Years	
		Breaking Force (N)	Elongation %	Breaking Force (N)	Elongation %
PARA COMMANDER S/N 777377	1977	342	32	348	32
SUPER STERABLE S/N 586133	1977	187	23	207	25
MC-1-2B-D-C S/N 86280	1977	183	29	201	29
TIO RESERVE S/N 16026	1980	206	23	209	23
MC 1-B-D S/N 15921	1980	208	28	210	29
TIO-B-D S/N 81087	1976	202	22	202	22

*Tensile Measurements made in warp direction.
Specimen 25 mm wide.

TABLE 4

TENSILE STRENGTH MEASUREMENTS FOR CANOPY MATERIALS

AFTER OUTDOOR EXPOSURE

DAYS EXPOSED	TOTAL DOSE GJ/m ²	PERCENTAGE TENSILE STRENGTH LOSS	
		OLIVE DRAB MATERIAL (T-10 SERIES)	UNDYED TAFFETA MATERIAL (PX-1 SERIES)
0	0	0	0
17	0.18	3.5	0
38	0.46	9.5	6.2
59	0.80	7.0	6.7
111	1.89	25.4	18.4
131	2.35	42.5	28.8
181	3.44	75.0	52.0

TABLE 5

EFFECT OF JUMP HISTORY ON SUSPENSION LINES

A. THIS INVESTIGATION

PARACHUTES: PBI/6 (1968, TYPE 2); PX1/32

JUMPS	STRENGTH (N)	% LOSS
0	1883	0
20 to 30	1657	12
45	1285	32
80	1451	23

EFFECT OF JUMP HISTORY

B. UK STUDY (1)

JUMPS	STRENGTH (N)	% LOSS
CONTROL (0)	2118	0
15	1893	6
35	1667	21
55	1598	25
75	1559	26
95	1559	26

TABLE 6

TENSILE STRENGTHS OF OLIVE DRAB PARACHUTE SUSPENSION LINE AT VARIOUS TEMPERATURES

RATE OF STRAIN (mm/min)	Temperature - 40°C				Temperature - 20°C				Temperature 22°C			
	Breaking Strength (kgf)	Extension %	Energy J	Breaking Strength (kgf)	Extension %	Energy J	Breaking Strength (kgf)	Extension %	Energy J	Breaking Strength (kgf)	Extension %	Energy J
5	155	23.5	24	140	25.5	24	133	25	23			
50	144	22.5	22	147	24.5	24	140	26.5	23.5			
200	153	24.5	25.5	151	26.0	26.5	149	28.0	27.0			
500	147	22.0	24	147	24.5	24	141	28.0	25.5			

All samples 150 mm in length.

The low result at high strain may be due to interfilament friction.

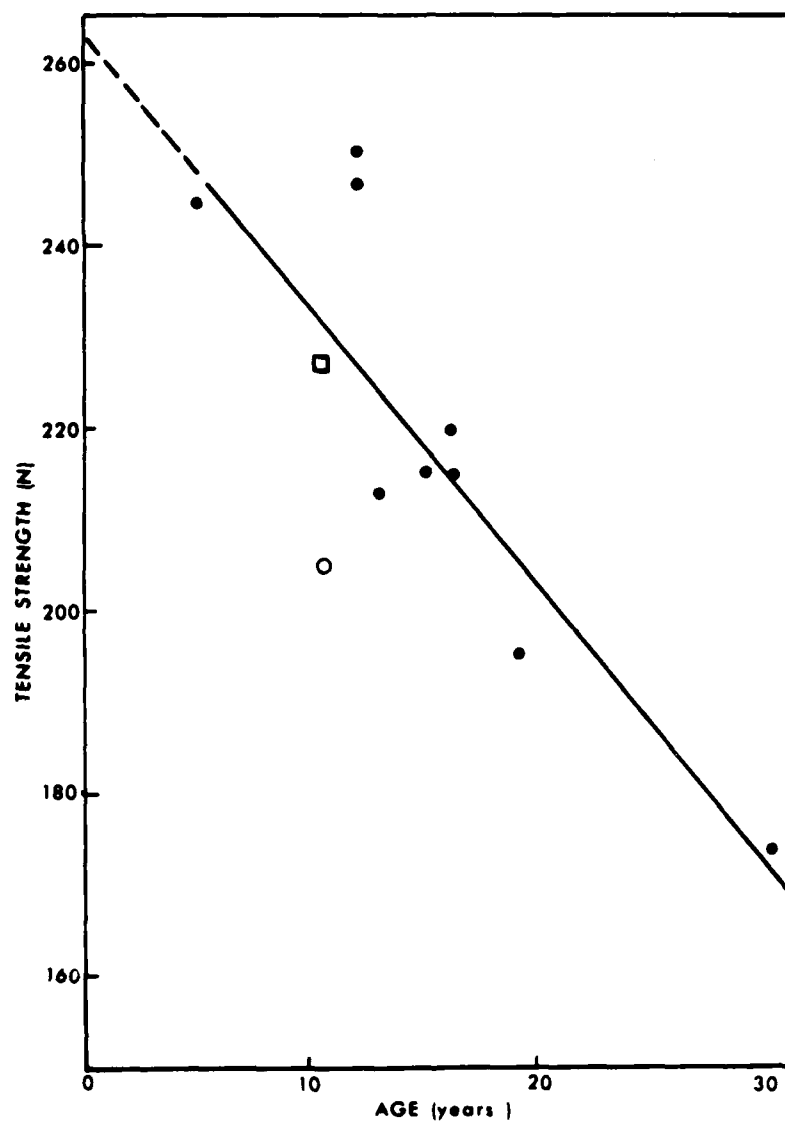


FIG. 1. Variation in breaking force (N) of canopy material from PX-series parachutes with age of the parachute.

● Data from this study

□ Data from Reference 1 for 10.5 year old reserve parachute used by U.K. Army.

○ Data from Reference 1 for 10.75 year old reserves used by Australian Army.

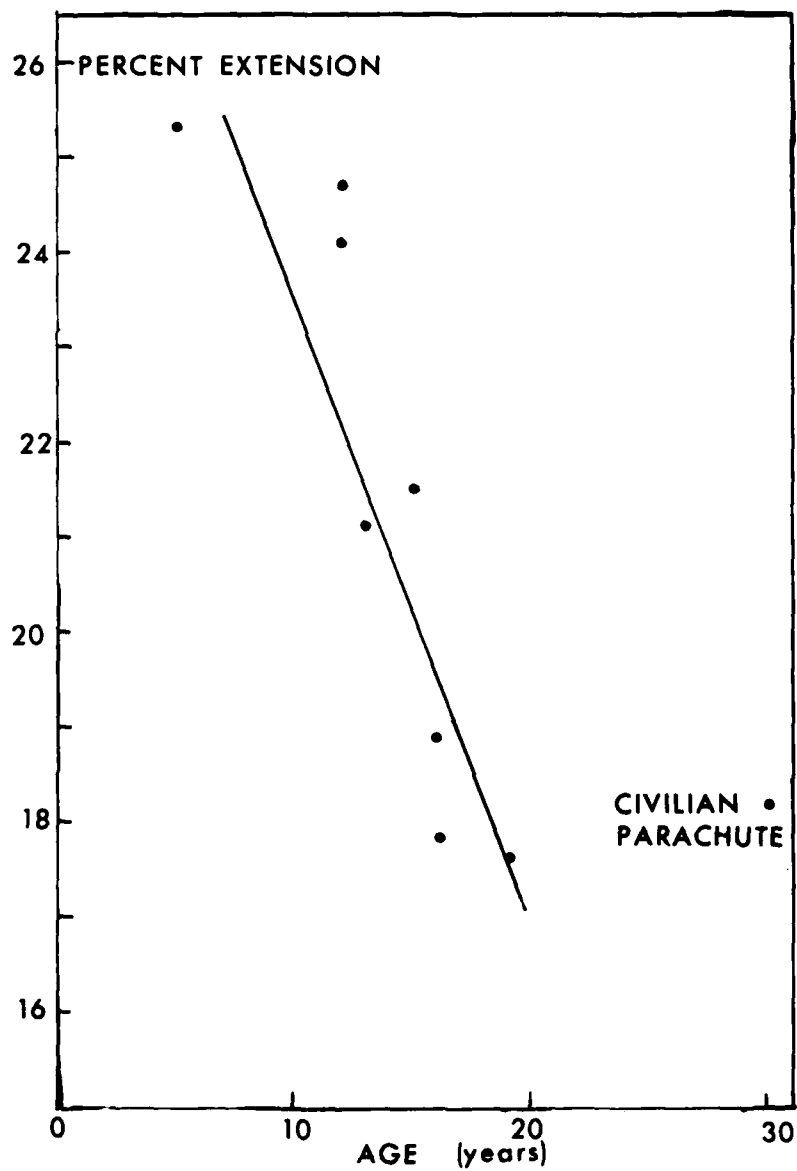


FIG. 2. Variation in extension with Parachute age for canopy material from PX-series Parachutes.

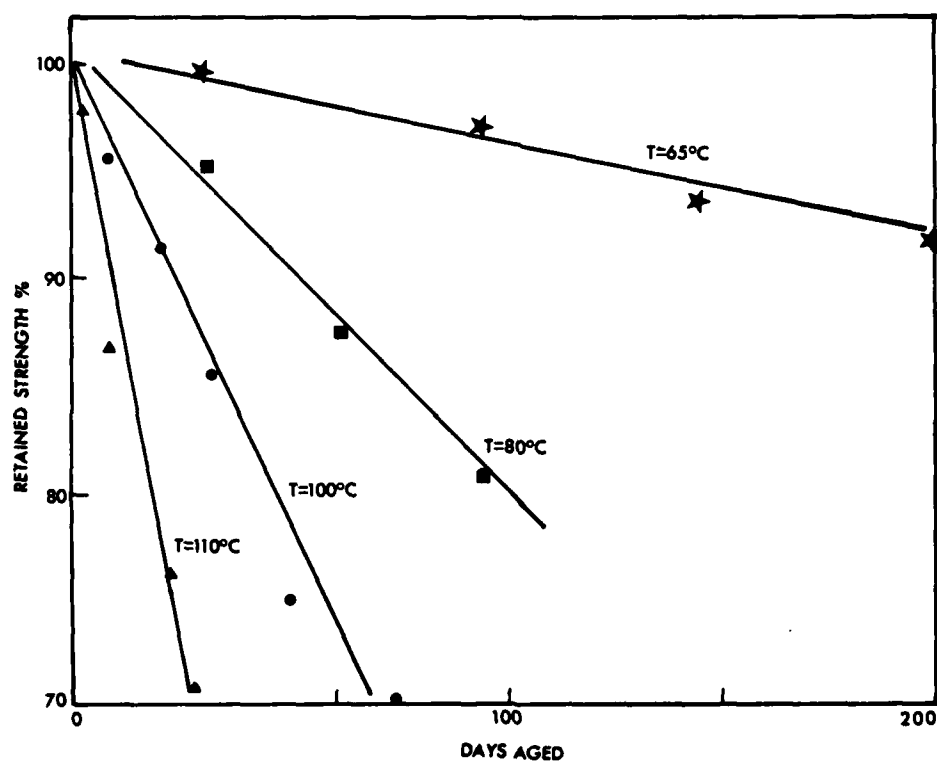


FIG. 3. Change in percent strength retained by nylon 66 taffeta canopy repair material with time of ageing.

- ★ T = 65°C
- T = 80°C
- T = 100°C
- ▲ T = 110°C

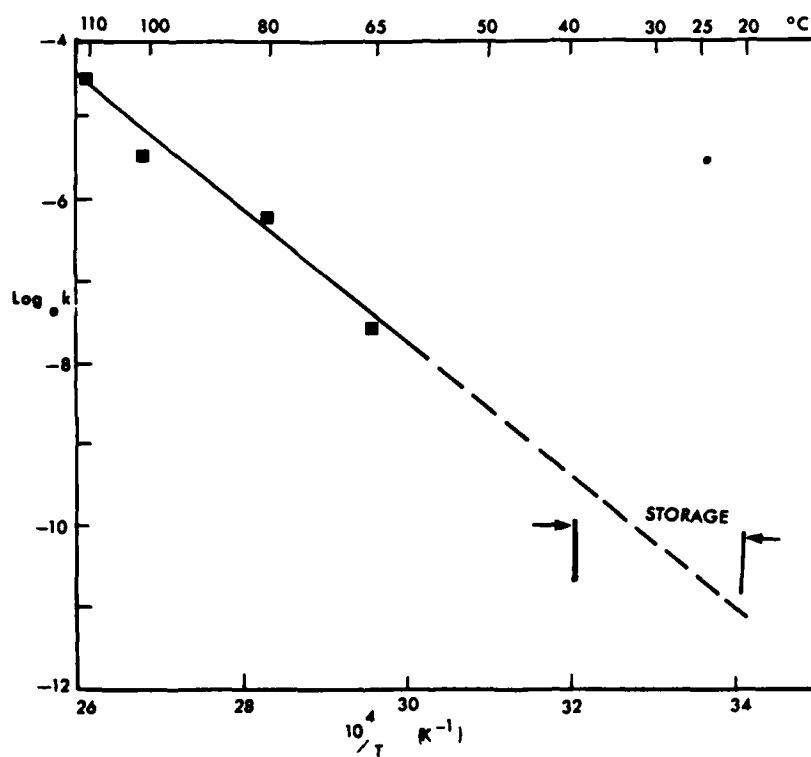


FIG. 4. The dependence of the rate of degradation of strength of nylon 66 taffeta (PX-parachute repair material) on temperature. The linear relation is extrapolated to storage temperatures to estimate the rate of strength loss during storage.

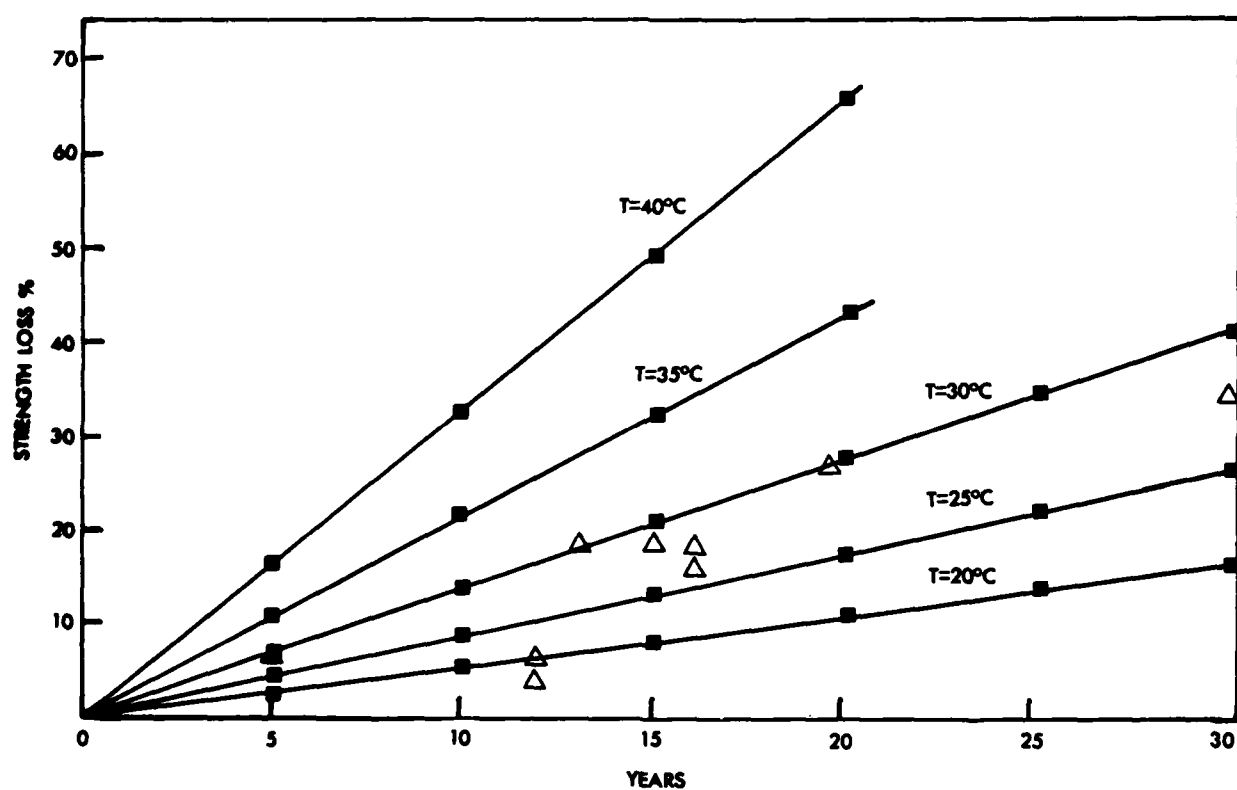


FIG. 5. Calculated rates of strength loss for nylon 66 taffeta canopy material at temperatures likely to be encountered in storage. Calculations are based on the extrapolated data in FIG. 4.

△ Strength loss measurements made on canopies of PX-1 Parachutes summarised in Table 1.

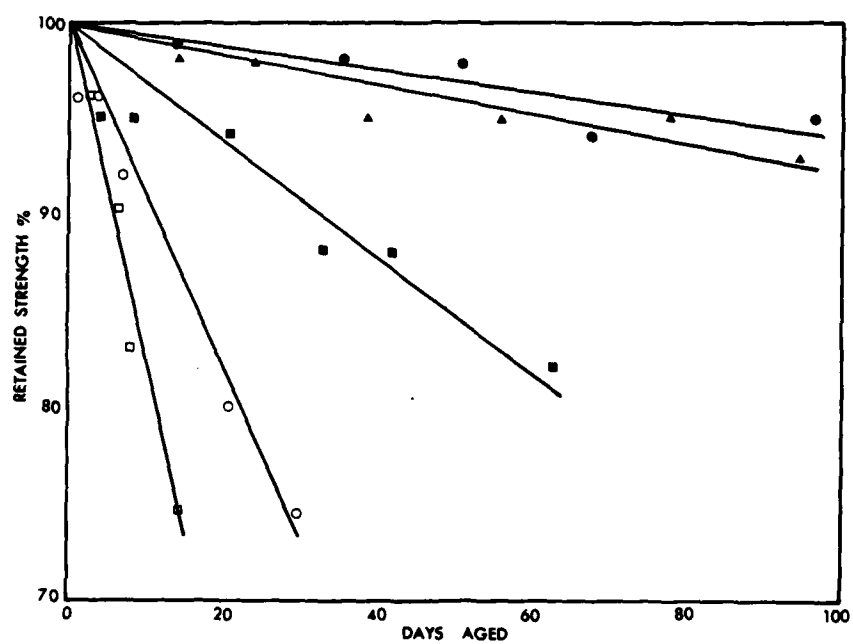


FIG. 6. Changes in percent strength retained by nylon 66 olive drab ripstop repair material with time of ageing.

- T = 70°C
- ▲T = 80°C
- T = 100°C
- T = 110°C
- T = 120°C

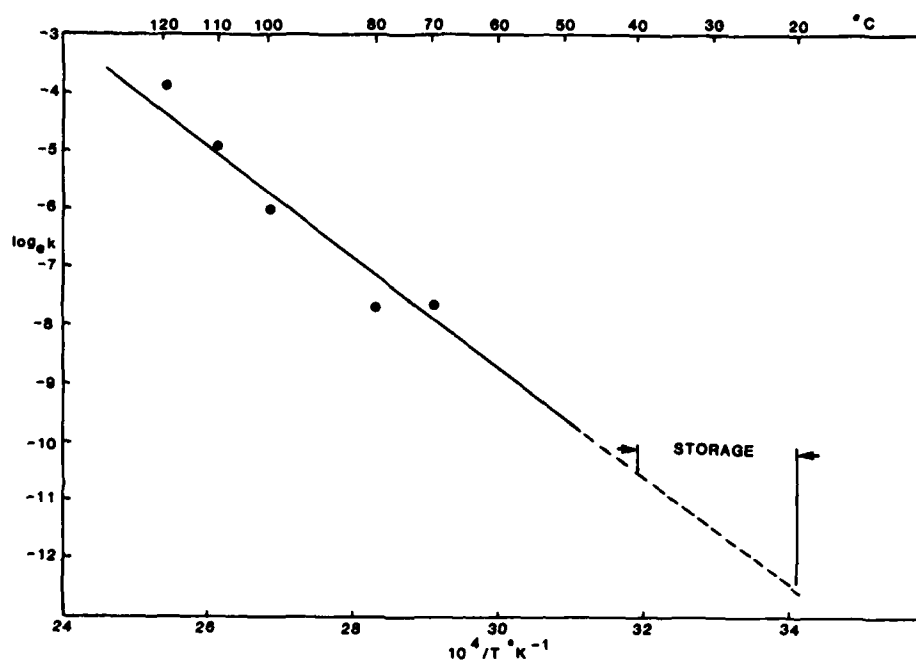


FIG. 7. The dependence of the rate of degradation of strength of nylon 66 dyed olive drab ripstop material on temperature. The linear relationship is extrapolated to storage temperatures to estimate the rate of strength loss during storage.

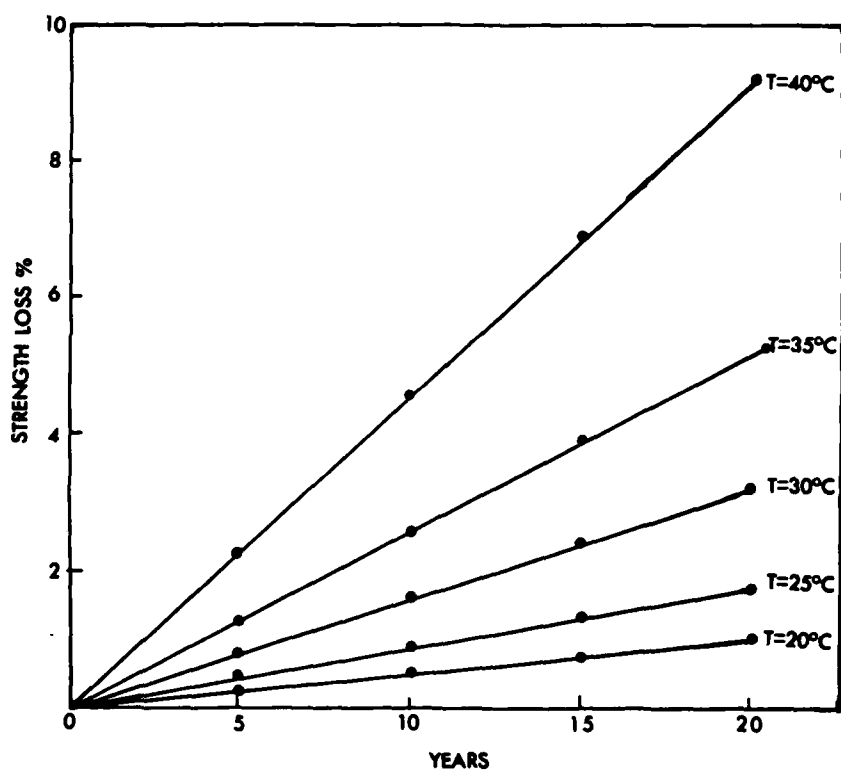


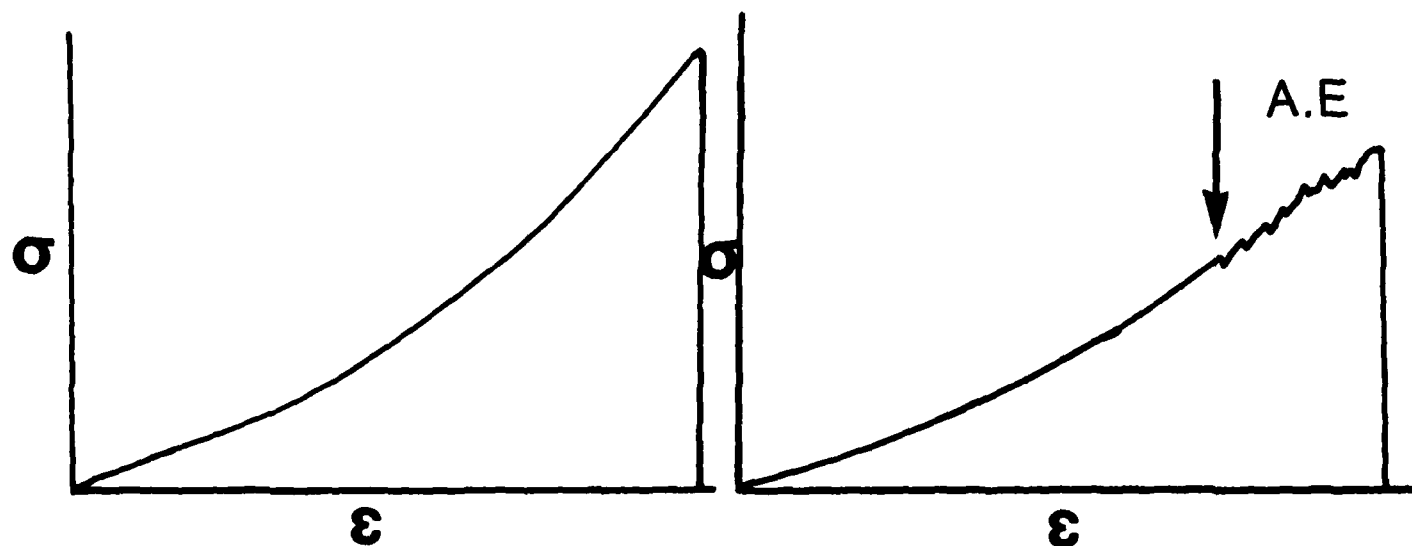
FIG. 8. Calculated rates of strength loss for nylon 66 dyed olive drab ripstop repair material at temperatures likely to be encountered in storage. Calculations are based on the extrapolated data in FIG. 7.

STRESS/STRAIN CURVES

A: Suspension lines

0 Jumps

80 Jumps



B: Yarns from lines

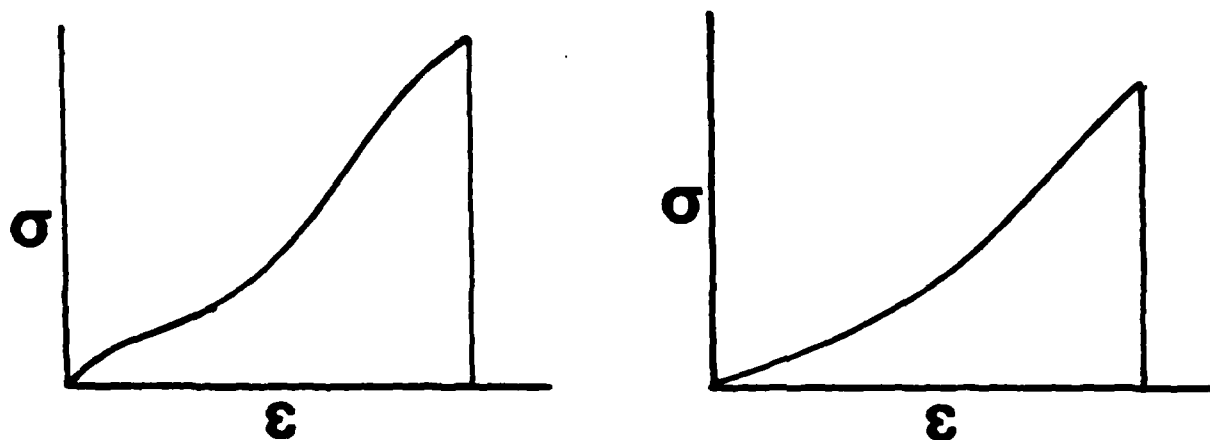


FIG. 9. The effect of jump history on the stress-strain behaviour of suspension lines from PX-series parachutes. Premature yarn failure is accompanied by acoustic emission from the point marked on the load elongation curve of the lines. Individual yarns taken from the lines do not show this behaviour.

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