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FINNIGAN J.A.
ICI Fibres, U.K.

The creep behaviour of high tenacity yarns and fabrics used in civil engineering applications

Das Kriechverhalten hochfester Garne und Stoffe in der Bauindustrie

Unter Zugbelastung dehnensich Textilmembranen, unter bleibender Belastung kriechen sie, d.h. sie dehnen sich weiter. Die Verformungsneigung hochfester Polyester und Polyamidgarne wurde festgestellt, um das zu erwartende Kriechen von Textilstoffen, die fuer Industriezwecke gedacht sind, festzulegen. Dauerbelastungsversuche ueber 1000 Stunden werden beschrieben und ein Kurzer Laborversuch, mittels dessen die Neigung zum Kriechen der zwei Garne quantifiziert wird, wird abgeleitet. Der Einfluss der aufgebrachten Belastung sowie der Effekt des Weiterverarbeitens durch Fachen und Weben werden untersucht. Moeglichkeiten zur Veraenderung der Kriechneigung durch Waermebehandlung werden besprochen.

INTRODUCTION

With fabric membranes finding increasing use in civil engineering it is important to be completely familiar with the material properties relevant to the end-use. In the case of woven fabrics, the change in extension on continued loading 'in situ' is one such important parameter. For non-woven fabrics this parameter is dominated by structural effects rather than by the properties of the constituent yarns. Little is known of the time dependent extension or 'creep' behaviour of the yarns and fabrics currently being used. This paper describes work undertaken to quantify the level of creep to be expected from woven fabrics produced from high tenacity multifilament polyester and polyamide yarns. Two high tenacity yarns -

a 1100 dtex polyester (TERYLENE Type 125) and

b 940 dtex polyamide (ICI nylon 6.6 Type 114)

both of which have breaking loads close to 8 kg, were chosen as a basis for the experiments as they are suitable for inclusion in engineering fabrics.

No attempt is made to interpret the results at a molecular level. Indeed accepted theories of creep of filamentous materials suggest there are two components of creep. The first part of the time dependent elongation, so called, 'primary creep', is recoverable after removal of the applied load and is constant in magnitude on reapplication of the load. There is however a second non-recoverable part which decreases on repeated loading and unloading as the sample becomes 'mechanically conditioned'. This permanent set occurs through 'secondary creep'. No attempt has been made here to differentiate between primary and secondary creep and it is assumed that, in use, the material will be loaded only once to the prescribed load. The creep values determined therefore represent essentially maximum expected values.

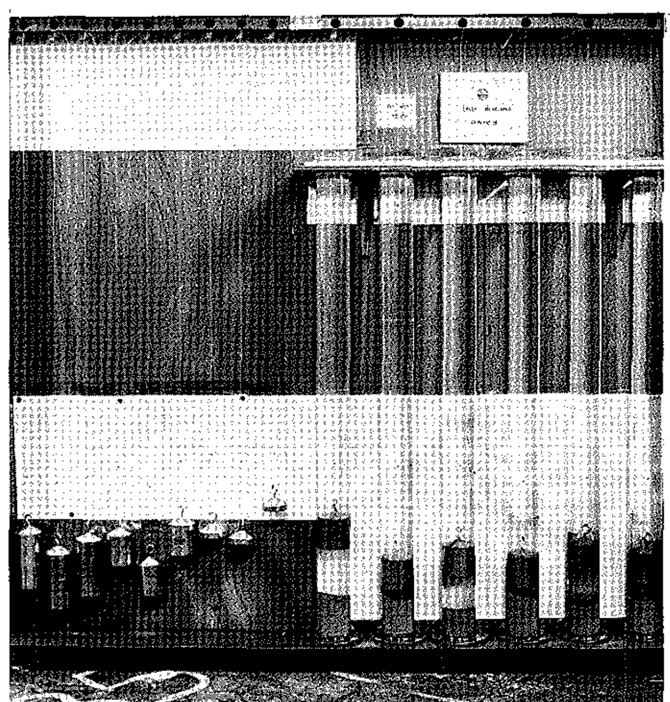

FIGURE 1. STATIC FRAME APPARATUS USED IN LONG TERM YARN EXPERIMENTS

ANALYSIS AND EXPRESSION OF RESULTS

When a yarn, or fabric, is subjected to a constant load the resulting elongation consists of an immediate extension occurring directly the load is applied followed by a delayed extension, or creep, which continues with time at a decreasing rate. Expressed algebraically the total elongation of the material at time t is given by:-

$$\epsilon_t = \epsilon_o \text{ (initial extension)} + \text{constant} \times \text{function } (t)$$

It will be shown subsequently that up to 10^3 hours the elongation is closely linear when plotted as a function of log (time). The following relation is therefore valid and is used throughout the analysis of results.

$$\epsilon_t = \epsilon_o + b \cdot \log_{10} 10t \qquad -(1)$$

where b, the creep coefficient (expressed in units of % per log 10t), gives a measure of the rate at which the elongation increases with time, t, expressed in minutes. Given a set of extension/time data points for a particular material the best values for b and ϵ_o may be obtained by linear regression analysis and later used to predict the probable elongation at any other time.

If a yarn is loaded at a high level for an extended period of time the elongation might be such that creep rupture occurs. This is a catastrophic process, possibly initiated by defects in the material itself, and results in a break at less than the recognised breaking strain. Recent work on the polyester yarn suggests that providing loadings less than 50% of the ultimate tensile strength are applied, creep rupture is unlikely to occur before 10^6 minutes. As in civil engineering end-uses a factor of safety of at least 2 on

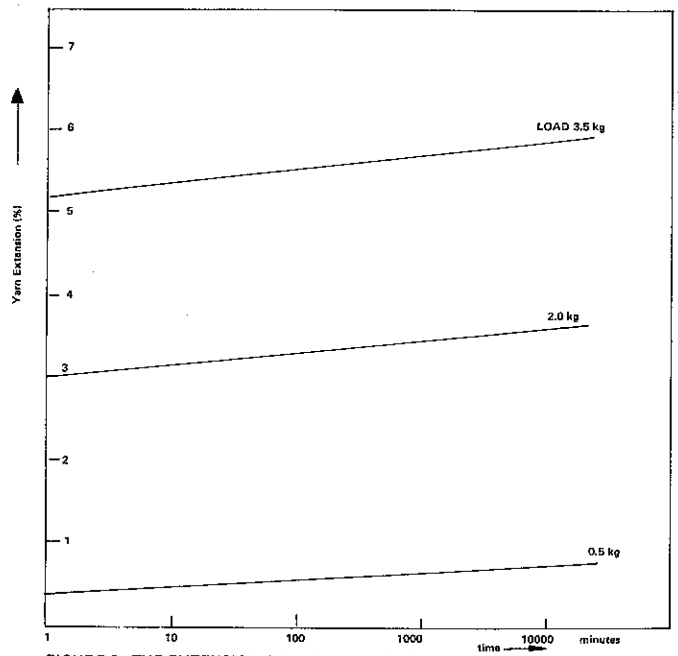

FIGURE 2. THE EXTENSION OF 1100 dtex HIGH TENACITY POLYESTER PLOTTED AGAINST A LOGARITHMIC TIME SCALE (STATIC FRAME TESTS)

applied loadings would be used the present work has been restricted to loadings of less than 50% of breaking load.

LONG TERM YARN TESTS

In order to validate Equation (1) a static frame (Fig 1) was built to enable the long term loading of polyester and polyamide yarns to be made. Metre lengths of yarn, marked off with fiduciary lead shot, were loaded at various levels and the changes in length between the marks recorded up to 10^3 hours

TABLE 1. SINGLE END RESULTS FOR FLAT POLYESTER AND POLYAMIDE YARN

	POLYESTER				POLYAMIDE			
Load (kg)	0.5	2.0	3.5	5.0	0.5	2.0	3.5	5.0
% OF BREAKING LOAD	5.9	23.5	41.2	58.8	6.8	27.3	47.7	68.2
Static Frame Results								
Initial Extension, ϵ_o%	0.35	2.89	5.02	–	1.49	6.08	7.96	–
Creep coefficient, b	0.077	0.144	0.173	–	0.253	0.140	0.219	–
Correlation Coefficient	0.932	0.992	0.991	–	0.987	0.969	0.994	–
Numer of data points	24	25	25	–	25	25	25	–
% level of significance	>99.9	>99.9	>99.9	–	>99.9	>99.9	>99.9	–
Instron Test Results (Means for 4 ends)								
Initial Extension, ϵ_o%	0.345	2.831	4.923	5.248	1.202	7.04	8.236	9.547
Creep Coefficient, b	0.011	0.174	0.192	0.194	0.296	0.196	0.161	0.277
Estimated standard deviation on b.	0.001	0.009	0.006	0.015	0.050	0.007	0.005	0.013

using the graduated backboard of the apparatus. Figure 2 shows the results for the ends of polyester plotted against a log time scale, and confirms the linear nature of the relationship expressed in Equation (1). This is further evidenced in Table 1 which sets out all the results obtained by a least squares fit to the data for both polyester and polyamide yarns. The validity of Equation (1) is substantiated through the high correlation coefficients.

SHORT TERM TESTS AND THE EFFECT OF THE LEVEL OF THE APPLIED LOAD

The possibility of a shorter term test arises as, in all the cases tested (see eg Fig 2), 25% of the creep measured after 1000 hours is recorded within 1 hour. Thus data on this shorter period could be realistically extrapolated to cover a longer period. Against this information a novel short term test, with increased precision and wider applicability, was devised.

The new test involves holding a length of the material, 50 cm long in the case of yarn, between the jaws of an Instron Tensile Tester. The material when loaded to the prescribed load is then held at that load using the load cycling facility of the instrument. By cycling over a small load increment ($\pm$ 0.5%) it is possible to have quasi-static loading. Changes in the length of the material are then recorded, using the instrument extension dial, periodically up to 20 minutes loading time. Such a method facilitates the rapid testing of several specimens of the same type, different yarn types as well as processed yarns and fabrics. The accuracy of measurement too is increased dramatically through the use of the tensile testing machine as extension measurements may be made to $\pm$ 0.004%.

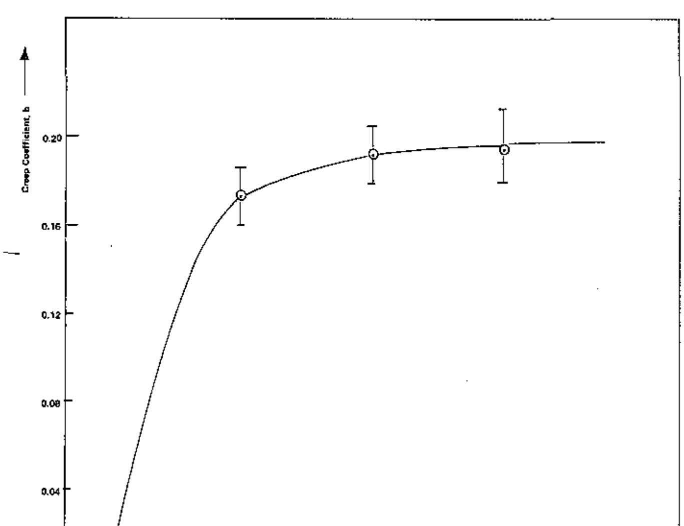

FIGURE 3. THE EFFECT OF LOAD ON THE RATE OF CREEP OF POLYESTER. (THE UNCERTAINTY BARS REPRESENT 95% CONFIDENCE LIMITS ON THE MEAN VALUE OF b.)

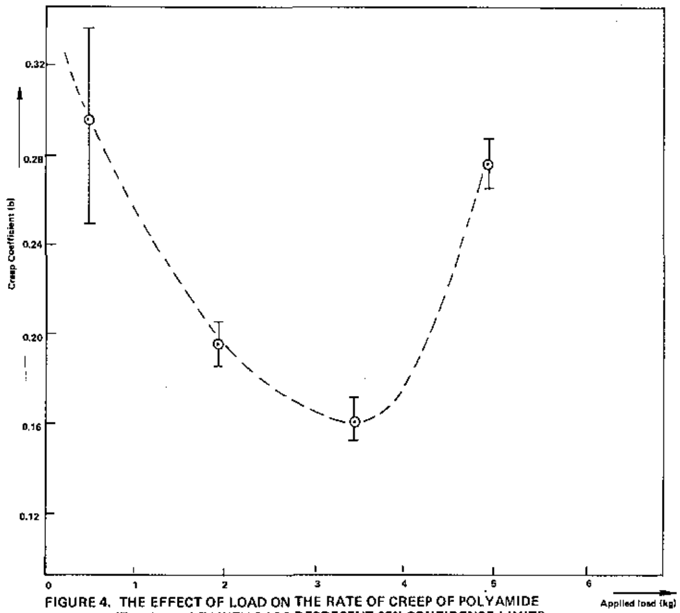

FIGURE 4. THE EFFECT OF LOAD ON THE RATE OF CREEP OF POLYAMIDE (THE UNCERTAINTY BARS REPRESENT 95% CONFIDENCE LIMITS ON THE MEAN VALUE OF b)

To establish whether this method was a viable replacement to the longer term static measurements, several ends of polyester and polyamide yarns were loaded and their initial extension and creep coefficients computed as before. All measurements were made at 65% relative humidity and 21°C. The results are listed in Table 1, and show concordance between the long term (10^3 hour) static frame creep measurements and the 20 minute Instron tests, giving a correlation coefficient (0.83) significant at 95%. The Instron test which again shows good linear behaviour of creep against log (time) over 20 minutes has permitted some data on specimen to specimen variability to be obtained and these results are given in Table 1. Typically the coefficient of variation for the creep coefficient for yarn results lies between 2 and 8%.

Figures 3 and 4 show the creep coefficients plotted as a function of the applied load for polyester and polyamide respectively obtained by the short term method described. For nylon there is a defined minimum in creep at around 45% of its breaking strength whilst polyester shows a distinct 'saturation' in creep potential after loading to levels above 25% of its breaking load.

THE EFFECT OF YARN PROCESSING

Yarns are rarely used in civil engineering without structural modification and it is important to appreciate how the recorded creep values might be affected by various yarn processing steps such as twisting, plying and weaving, and whether heat treatment can modify the creep tendency.

To establish the influence of plying and twist 5 fold polyester and polyamide yarns were produced by twisting ends together at 100 turns per metre. The creep tendency of these multifold yarns was then measured according to the Instron method using stress ratings equivalent to those used for singles yarn. The results for the creep coefficients at

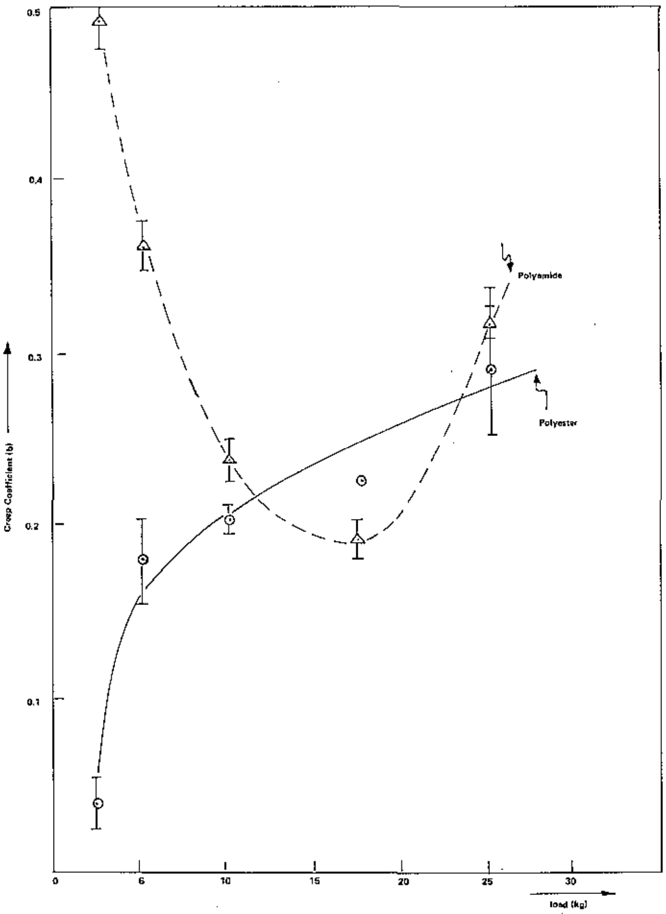

FIGURE 5. EFFECT OF LOAD ON THE CREEP COEFFICIENT OF PLIED POLYESTER AND POLYAMIDE YARNS

different loadings are shown in Fig 5. Comparison of these results with those for the singles yarn indicates that in plied form the creep is slightly higher possibly due to a small component arising from the twisted structure.

When considering a possible end-use application it may be of interest to know whether the creep behaviour of a textile can be modified or 'tailored' to fit particular requirements. To ascertain whether heat treatment, eg stretching or relaxing, can offer a means of creep modification 5 fold yarns of polyester and polyamide were processed as follows

(I) nylon at 225°C for 75 seconds with stretch ratios of -2, 0, +2, +5 and +10%, and

(II) polyester at 235°C for 75 seconds with stretch ratios of -2, 0, +2 and +5%.

The creep behaviour was then obtained on the Instron for all the processed yarns using a 10 kg loading. The findings, set out in Fig 6, clearly show that the creep tendency can be significantly reduced by heat stretching and that the degree of reduction can be predicted from the initial extension of the processed yarn (Fig 7).

In most applications the yarns discussed will be used in fabric form and consequently the work has been extended to woven fabrics. This work has confirmed that knowledge of the constituent yarns and their state (eg whether twisted or hot stretched) enables an estimate of the fabric creep to be computed. A polyester woven fabric with the following constructional details will be taken as an example -

Warp	6.5 ends/cm	1100 dtex polyester
Weft	5.5 picks/cm	1100 dtex polyester
Weight	154 g/m^2	

The fabric was resin impregnated (25% by weight) to assist field handleability. Using strips of the fabric 5 cm wide, and a 30 cm test length, the creep tendency of the fabric was determined by the developed Instron method. Several loadings were applied to the warp direction and the creep results obtained are shown in Fig 8. This again displays the general pattern of a saturated creep tendency at high stress ratings with polyester. Actual creep levels, although slightly higher than for single yarns (probably through the yarn being interlaced in the woven fabric) are small and of the same order of magnitude as data from the unprocessed yarn.

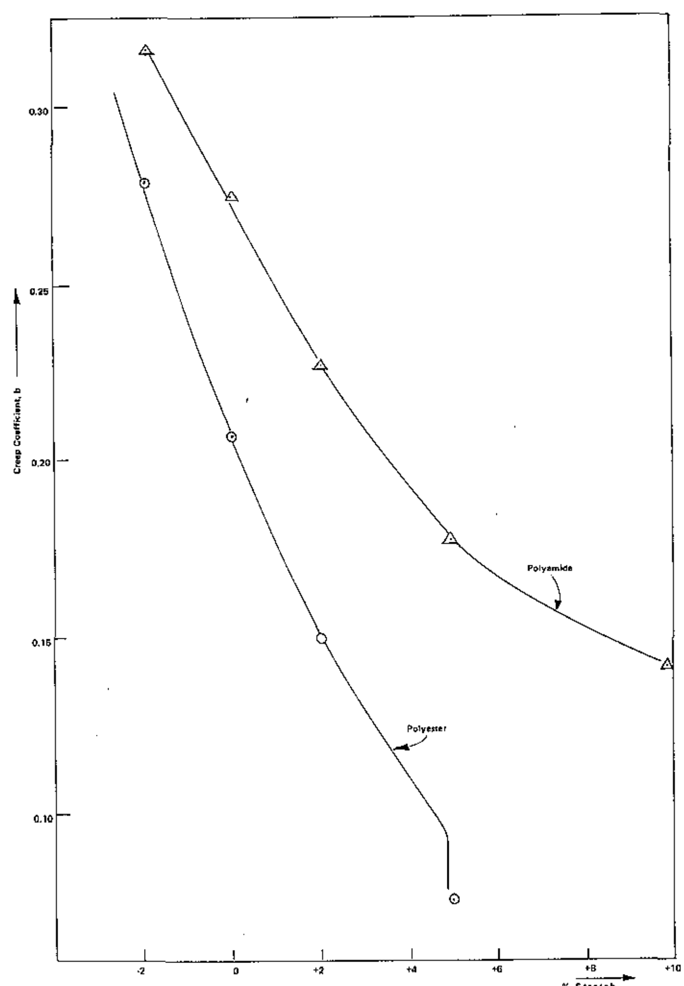

FIGURE 6. THE EFFECT OF HOT RELAXING AND STRETCHING ON THE CREEP TENDENCY OF 5 FOLD POLYESTER AND POLYAMIDE YARNS

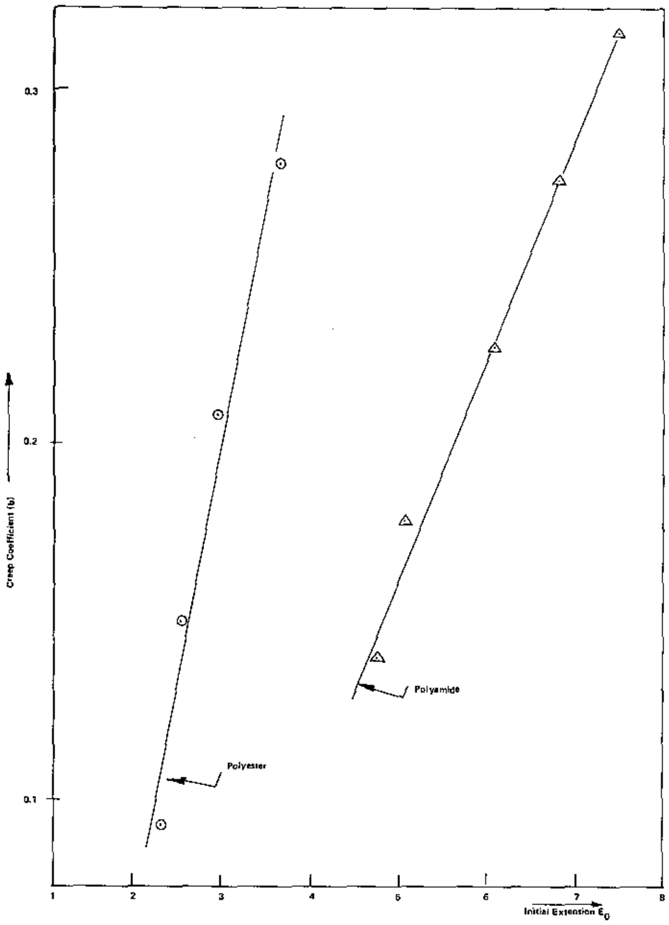

FIGURE 7. THE RELATION BETWEEN CREEP AND INITIAL EXTENSION OF HEAT SET PLIED YARNS WITH A 10 kg APPLIED LOAD

Finally, the question of the effect of field environment on the creep tendency of these materials must be considered and in this respect some results have been obtained to date on the effect of water on yarn creep behaviour. Using part of the static

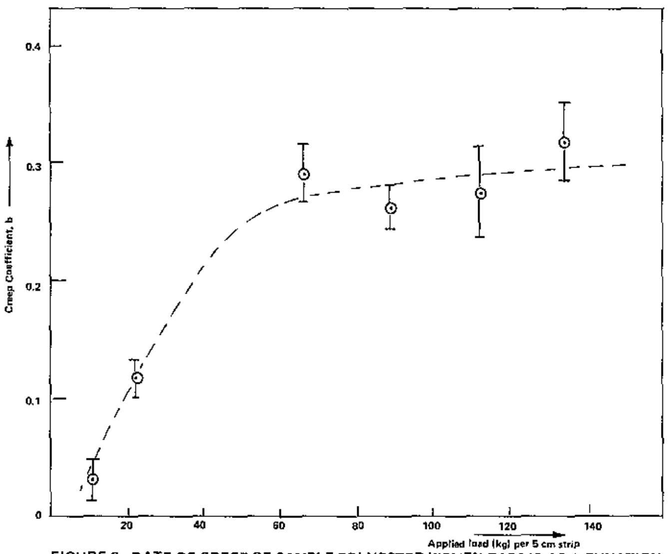

FIGURE 8. RATE OF CREEP OF SAMPLE POLYESTER WOVEN FABRIC AS A FUNCTION OF THE APPLIED LOAD

frame (Fig 1) yarn sample lengths were weighted with 2 kg in water and the extension change recorded up to 10^3 hours alongside similar experiments of yarn in air. Table 2 gives the results and indicates that neither yarn is significantly affected by the presence of water. Further work would however be needed to increase the confidence limits on the effect of moisture on the creep of these yarns.

TABLE 2. CREEP BEHAVIOUR OF POLYESTER AND POLYAMIDE YARNS IN WATER (AS MEASURED OVER 10^3 HOURS ON STATIC FRAME)

Environment	Water	Air
Load (kg)	1.75	1.75 (interpolation from Table 1 - Static frame measurement)
POLYESTER Mean creep coefficient b	0.144	0.13
POLYAMIDE Mean creep coefficient b	0.140	0.15

CONCLUSIONS

The confirmation that over the period 1 minute to 1000 hours loaded high tenacity polyester and polyamide yarns deform linearly with respect to log (time) and the subsequent derivation of a quick laboratory creep test based on this fact, has permitted a wide appreciation of the levels of creep to be expected from these yarns in various states. Both yarns show low levels of creep and typically one might expect some 1% change in length over 10 years when a yarn is loaded to 20% of its breaking load. For polyamide, as the applied load is increased the creep tendency goes through a minimum before increasing with the applied load, whilst polyester creep increases initially with load and then appears to be limited to a set creep value as the load is further increased.

Plied yarns and fabrics show slightly higher creep values (typically 20 and 50% higher respectively) compared with their constituent yarns. As a first approximation the creep can be lowered by reducing the complexity of the structure. Therefore lower plies, lower twist, straighter warps will all reduce creep in structured items. Where creep may be critical the deformation tendency of both yarns (and fabrics therefrom) can be significantly reduced by hot stretching.