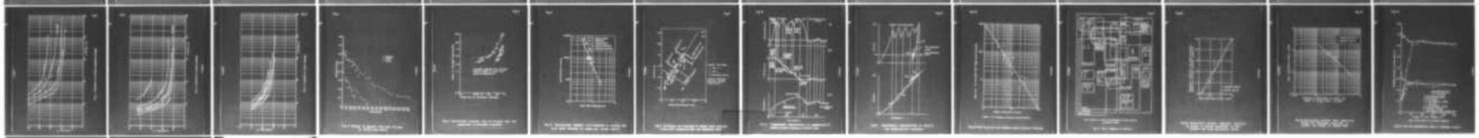
AD-A036 063 ROYAL AIRCRAFT ESTABLISHMENT FARNBOROUGH (ENGLAND) F/G 11/5
REVIEW OF TEXTILE MATERIALS RESEARCH IN MATERIALS DEPARTMENT, R--ETC(U)
MAR 76 J E SWALLOW, M WEBB

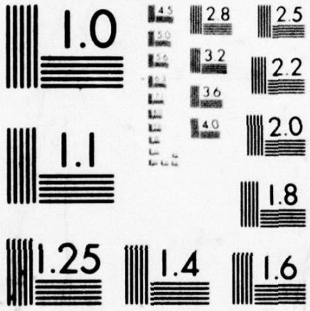
UNCLASSIFIED RAE-TR-76031 DRIC-BR-52615 NL

1 OF 1
AD
A036063






END
DATE
FILMED
3-77



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

UDC 677 : 620.193.1/2 : 536.4 : 621-567 : 677.011.68

ROYAL AIRCRAFT ESTABLISHMENT

⑨ Technical ~~Report~~, 76031

Received for printing 8 March 1976

⑥ REVIEW OF TEXTILE MATERIALS RESEARCH IN MATERIALS DEPARTMENT, RAE, 1968-1975.

by

⑩ J. E. Swallow
M. Webb

⑪ Mar 76

⑱ DRIC

⑲ BR-52615

⑫ 43p.

SUMMARY

Significant research in Textiles Section of Materials Department, RAE, during the period 1968-1975 is summarised with reference to relevant published reports. This review updates similar ones issued in 1956 and 1968.

⑭ RAE-TR-76031

Departmental Reference: Mat 279

310 450
LB

CONTENTS

1 INTRODUCTION

The wide range of Defence applications of textiles in aviation forms the background to the textile research of Materials Department, RAE. The applications have included parachutes, flying-clothing, energy-absorbing devices and inflatable structures such as balloons, escape slides and, until 1971, hovercraft skirts.

Previous unified descriptions of the work of Textiles Section were presented by Baker[1] in 1956, and by Swallow, Mikolajewski and Webb[2] in 1968. It is now opportune to review the work of the ensuing years and in this Report some investigations on weathering, heat, wear and other properties are summarised. The course adopted is, as before, to survey the background to the problems studied and then give a short summary of the methods used and some of the principal results; for further details, the reader is referred to the relevant published reports.

Much has been learnt in recent years, particularly about the properties of nylon, and this has provided a better understanding of the performance of textile materials in Service applications; the results from several sections of the work have been incorporated[3] in AvP 970, and these are presented in the Appendix.

2 WEATHERING OF TEXTILES

2.1 Effects of dyes and finishes

Earlier work[2] had indicated that certain dyes affected the resistance of textile materials to actinic attack. It was therefore desirable to establish which dyes and finishes did not accelerate the degradation and preferably exerted some protective effect, for aerospace applications such as parachutes.

A contractor and various departments of the Procurement Executive, Ministry of Defence, participated in experiments using 2503 combinations of finishing treatments or dyeing and weathering exposure on nylon textiles. The results were analysed[4], principally by analysis of variance of ten factorial sets of data. The best five overall of 25 different dyestuffs on high-tenacity thread and webbing afforded reasonable protection and were recommended for use[5]: these were CI Acid Black 132, CI Disperse Yellow 3, CI Disperse Orange 3, CI Acid Green 43 and CI Mordant Yellow 34.

Fading of the 25 dyestuffs on high-tenacity webbing[5,6] gave a good indication of strength loss when the colour change was moderate, but on extra-high-tenacity thread fading[5,7] gave no worthwhile information in any of the conditions studied. Xenon arc accelerated tests gave some prediction of strength loss of high-tenacity threads in the Australian desert, but no worthwhile correlations in the UK. With extra-high-tenacity threads, dyeing generally led to more strength loss on weathering, relative to the controls, than with high-tenacity threads. Increased amounts of dyestuff usually lowered the strength retention of extra-high-tenacity threads (high-tenacity threads were not tested).

2.2 Effects of agricultural chemicals

Parachute equipment is liable to become contaminated by accidental contact with chemicals which have been applied to land or crops. This could happen in a paratrooping exercise when a parachutist misses the designated dropping zone, and particularly if there are concentrated patches around burst or spilled containers, hosed-down areas or sheep-dip tanks.

The chemical nature of some of the more likely compounds to be encountered was ascertained[8] with the assistance of the Plant Pathology Laboratory of the Ministry of Agriculture, Fisheries and Food, and their potentially harmful effects were considered. In unfavourable circumstances, it is possible that damage to parachute materials could occur, either immediately or after storage, particularly from acidic substances or those likely to produce acids (mineral, phenolic or carboxylic) on weathering. A procedure to be followed in the event of suspected contamination was suggested.

2.3 Shrinkage of cordage

Wetting of parachutes can occur by contact with wet runways or grass, or with rain, sea etc; washing is not usually permitted in UK, partly because the dirtiness gives an indication of the amount of use, but it may be introduced to extend the working life, and it can be undertaken after descents into the sea. Rigging line length is one of the design features of a parachute, and significant shrinkage may affect deployment and opening.

The shrinkage of eight cords made from five different fibre types was therefore investigated[9] when the cords were subjected to natural weathering with or without a load, to exposure to sun only without wetting, and to immersion in water.

The various cords shrank to differing extents depending on the circumstances; an unscoured nylon cord shrank noticeably in all the tests. Shrinkage was reduced by loading. Most of the cords shrank in boiling water, though this was not a good predictor of shrinkage in other conditions.

3 EFFECTS OF HEAT ON TEXTILES

3.1 Liquid-fuel fires

Two of the main aims of the considerable world literature on textiles and fire have been to produce usable fabrics which are less flammable than previously (such as those from aromatic polyamide and polybenzimidazole fibres, and cotton treated with N-methylol dialkyl phosphono propionamide), and to devise methods of test to compare behaviour (such as the oxygen index, mannequin and fire-pit tests).

In the neighbourhood of a burning aircraft, the actual flammability of a material, such as could cause the spread of an existing fire, may be of secondary importance, since a textile in a position to catch fire will probably already have ceased to fulfil its functions of load-bearing or substratum protection.

A laboratory method was therefore devised[10] for studying the failure in function of textiles on exposure to a liquid-fuel fire in the form of a vertical wall of flame supported on a glass-fibre fabric. Temperatures over a domain of a/r ratios (distance from fire/radius of fire) were recorded against a time base using thermocouples positioned on the surface of the fabric under test and on a glass-fibre fabric acting as a substratum. Analyses of variance of times and temperatures were made.

The critical region for damage to a nylon fabric[11] acting as a protective, such that the substratum was in danger of being exposed to the flame, was when a/r was below 1.2. An untreated cotton fabric[12] caught fire below a/r = 0.5 . The presence of a protective fabric increased the time for the substratum temperature to rise, particularly if there was a gap between the fabric and the substratum.

3.2 Transmission of heat into cordage

The commercial introduction of aromatic polyamide fibres, which possess a thermal resistance superior to that of conventional nylon, afforded the possibility of increasing the lifetime of textiles suddenly exposed to airstreams at high temperatures[2]. This was confirmed[13] for plain circularly-woven cordage at low loads or at high temperatures (200-500°C), but at high loads at temperatures below 200°C there was little difference between the aromatic and conventional polyamides. The aromatic polyamide was superior to an acrylic fibre cord of similar construction in all the conditions studied, whereas nylon was superior to the acrylic except at zero load (Figs.1-3).

The transmission of heat into the aromatic polyamide cord was studied[14]. At low levels of airstream temperature, load and time (for which the differential equations governing heat flow could be integrated), the thermal difusivity into this cord was computed to be $4.1 \times 10^{-8} m^2$/second, the thermal conductivity 0.034W/K m and the surface heat transfer coefficient 31W/K m^2 (*cf.* a braided nylon cord with 4.8×10^{-8}, 0.050 and 16 respectively).

3.3 Elevated temperatures for prolonged periods

Parachutes are often subjected to elevated temperatures in normal use: thus, brake parachutes may be heated kinetically to 150°C, and deployment into a jet exhaust can raise the temperature to at least 170°C, as has been demonstrated by weaving a coloured polypropylene warp yarn into parachute lines.

The commercial introduction and subsequent widespread use of extra-high-tenacity nylon-66 yarn containing an additive to improve heat resistance necessitated an extension of the work which had earlier been done[2] on high-tenacity yarn. This new type of nylon yarn was therefore exposed[15] for up to two years at temperatures of 150° and 175°C. Variations in certain properties were determined at various times.

Count at first increased by about 7% due to shrinkage, and then decreased to 7% below the initial value. The mass decreased by more than 50%. Tenacity (Fig.4) and yarn strength decreased continuously, and only a small fraction of the original value was retained at the end of the trials. Breaking extension at first increased to about 1½ times the original, but then decreased to a very low value. Carboxyl end groups increased by about ten times before the nylon became increasingly insoluble in solvent, probably because of cross-linking.

The reaction was second order at both temperatures at the beginning, but at 175°C decreased after about a month to 0.6 (Fig.5).

3.4 Flexibility of coated fabrics

Inflatable equipment made from coated fabrics may be subjected in use to high or low temperatures, e.g. in escape slides exposed to the heat of an aircraft fire, in balloons at high altitude absorbing radiation from the sun, in cold weather use of equipment, and in the lowering of temperature during inflation.

The flexibility of the rubbers on coated fabrics may be affected to a considerable extent by temperature. Work was therefore undertaken[16] on the flexibility of nylon and other base fabrics coated with various types of rubber. The bending length of a cantilever was used as the criterion, and samples were exposed to temperatures between -40°C (in a freezer) and $+140^{\circ}$C (in an oven).

It was shown that an Arrhenius-type relationship existed between bending length and absolute temperature, with activation energy related to the total fabric thickness (Fig.6).

4 ENERGY-ABSORBING PROPERTIES OF TEXTILES

4.1 Ply-tear webbing

Ply-tear webbings are narrow fabrics woven with two sets of main warps and, usually, two wefts to form separate plies which are bound together by a third set of warps, the binders (or, in a less investigated but potentially versatile method, by binding two conventional webbings by stitching). By loading the two sets of main warps in tension in opposite directions, the breakage of successive binders can be used to absorb mechanical energy at a substantially constant and predictable force, and largely irreversibly. Conventional cordage absorbs energy at a steadily increasing force which may be greater than the body being decelerated can withstand, and a considerable portion of the energy may be stored elastically, leading to recoil. When fibres such as nylon are used in the 'undrawn' state they absorb much energy non-elastically by drawing, but they cannot be used below about 5°C, and they deteriorate in high-humidity storage unless protected[2].

The tear forces in 12 different constructions of ply-tear webbings were measured in wet and dry conditions, at a slow speed using a tensometer and in drop tests using a buckle gauge. The total energy absorption was measured by several different methods.

The energy absorbed per unit mass of webbing at a given binder strength, i.e. efficiency, was highest at a lower main-warp count, lower weft count, higher binder count, higher velocity, higher falling mass, and in wet conditions, but there was no detectable difference between different binder materials. Unfortunately, the circumstances leading to higher efficiency were those most likely to cause breakage of the main warps instead of the binders, with disastrous consequences.

An efficiency of 60J/g was achieved at a binder/warp strength ratio not much above 0.10, but this could be unsafe when wet. Above 80J/g at a ratio approaching 0.20, the construction was definitely dangerous. A safe limit for all the conditions examined was about 40J/g at a binder mass fraction of 0.08 (Fig.7). For webbings of a given mass per unit length, the efficiency was linearly related to the tear force, which in turn was linearly related to the total binder strength.

The deceleration, velocity and extension at the impacted end of the ply-tear webbing was calculated[18] by applying the equations of motion, using only information contained in the impact conditions and the force-time records. This permitted the variation with time of these related quantities to be estimated (Figs.8 and 9).

5 WEAR OF TEXTILES

5.1 Hovercraft fabrics

Textiles Section was for a time, in collaborative work with Mathematics Department, RAE, and other Establishments, concerned with the wear of fingers on an SRN5 hovercraft operated by Interservices Hovercraft Unit. In normal practice experimental materials may be tested by substituting a few fingers made from them into an otherwise standard set, but this method lacks control of error and permits conclusions of doubtful veracity to be drawn.

It was intended, in a statistically-designed experiment, to compare the rates of wear of different fabrics, to compute the correlations between the rates of wear and the results of a battery of laboratory tests, to determine the properties needing improvement, and to compile a specification for the fabrics. Not all these aims were realised before RAE was withdrawn from the work in 1971, but the contribution made by Materials and Mathematics Departments was recorded[19].

Wear rates for a given material were reasonably constant with time, but were dependent on the position on the craft, and were highly correlated with 'flagellation' values (wear during high frequency flapping), fabric mass and thickness, and tear strength. Factor analysis of the correlation matrix for all the properties studied (Table 1) indicated that, out of four factors extracted (designated Ω, ψ, χ, ϕ), one (Ω) identifiable after rotation of the axes as fabric thickness dominated most of the other properties, including wear rates. There was also a specific hovercraft factor (χ) influencing wear rates and delamination which had low correlations with all the other properties investigated, except possibly the friction on wet concrete. A plot of wear rate against fabric thickness suggested that relatively little improvement could be expected at thicknesses greater than 3mm (Fig.10).

5.2 Relationships between snatch-tear and other properties

The effect of the construction of 54 fabrics, in terms of coating and weave, on the snatch-tear coefficients[2] and 13 other properties were assessed[20] by dividing the fabrics into ten sub-sets having attributes held in common (Fig.11). Correlation matrices for the properties within each set were computed.

This method has advantages over factorial designs when many of the levels required of the latter cannot be filled, though there is loss of efficiency and knowledge of interactions between factors, and it was recognised that the properties were not necessarily independent.

The correlations and regressions within sets, and differences between sets, were examined. In particular, it was found that the snatch-tear coefficient on energy input

(1) was negatively and often highly correlated with thickness, mass per unit area, bending properties, strength and tear strength;

(2) had regressions for the relationship with breaking strength which were significantly different from zero.

5.3 Penetration of fabrics by pointed agents

When tearing of a fabric occurs by means of an energy input to a tearing agency[2], such as a nail inserted through a fabric, it is clearly a prerequisite that the nail should have already penetrated the fabric.

Apparatus was designed[21] in which nails, each of known total mass, shaft diameter and angle of point, were released from known heights above horizontal, biaxially-tensioned, cruciform specimens of rubber-coated and uncoated fabrics. The height of penetration was defined as that height at which penetration just occurred in given circumstances.

The mass of the nail and the shaft diameter were the important factors determining penetration. Fabric tensions and the angle of the point had little effect, though it should be noted that it would not be safe to extrapolate this conclusion to sharper angles than those considered.

The mean energy to cause penetration was linearly related, through the origin, to the thickness of the fabric; the coated fabrics were not distinguishable from the uncoated for the range of cover factors investigated. The energy to penetrate was related linearly (Fig.12) to the regression coefficient of penetration energy on shaft diameter and hyperbolically (Fig.13) to the regression coefficient of snatch-tear length on energy input, implying that within the range of cover factors investigated fabrics which were difficult to penetrate were also difficult to tear.

5.4 High-speed abrasion of nylon cordage on resin-coated concrete

Previous work had shown[2] that nylon cord is abraded when it runs over a concrete surface. Nylon tapes used in arrester gear suffer from this type of abrasion, particularly at their edges, during an arrest or on rewind. The possible effect of a 2mm epoxy-resin coating on the concrete in reducing this type of abrasion was investigated[22].

At low velocities, the resin was worn away without the cordage breaking, and although filaments were broken there was no melting. At high velocities, however, melting occurred. It was concluded that resin coating could be protective at the low velocities and load associated with rewind (when most damage to the tapes is thought to take place), but at high velocities there would be little benefit.

5.5 Friction of fabrics on human skin

Since friction is the resistance to movement encountered when one surface slides or attempts to slide over another, it seemed likely that the low-speed friction of clothing fabrics against skin could be one of the factors influencing the comfort and cling of garments. A procedure was developed[23] for measuring this friction, utilising fabrics having different comfort ratings. Pieces of these fabrics were moved over the forearm under various loads, both in dry and wet conditions.

It was found that the friction of wet fabrics increased to a maximum as the water content increased, and then decreased slowly. The effects of the various factors on this maximum force were assessed.

The higher friction of wet fabrics relative to dry was more marked at lower normal loads and on smooth skin. Friction increased with increasing normal load non-elastically, was substantial at zero load for wet fabrics, and, after allowing for this, was higher for wet fabrics than for dry. It was also higher on smooth skin than on hairy, and the difference between subjects may have been due largely to differences in skin hairiness. Differences between fabrics were probably related to their wetness, but there was no clear relation between the maximum force and the comfort ratings. This could be due to the different water uptake by the fabrics at maximum friction; further experiments on fabrics at equal water content, or at water contents corresponding to particular rates of physiological activity, could be illuminating.

5.6 Searing of fabrics by running cordage

When a cord runs at speed over fabrics such as nylon which are liable to melt, the conversion of frictional energy into heat may result in searing of the fabric. If the fabric is also under stress, searing damage can lead to serious tearing with possibly dangerous consequences. This can happen in the deployment of parachutes.

A main contractor, a sub-contractor, and various departments of the Procurement Executive, Ministry of Defence, collaborated in experiments to determine the conditions which could give rise to searing, and to investigate materials solutions to the problem. Altogether 612 combinations of external conditions and of treatments were tested; damage was assessed by measuring residual strength which, it was observed[24], was related to the number of broken filaments or yarns and not to weave distortion.

The following principal conclusions were reached by analysis of variance of the three experiments performed:

(a) When the cord ran across the fabric at 13.5m/second, damage was negligible in all the circumstances examined; higher velocities had an increasingly damaging searing effect on nylon and polyester fabrics, particularly if the contact conditions (pressure and time) were made more severe.

(b) Silicone treatments were helpful in reducing the searing of nylon fabrics if applied at a mass uptake on the fabrics not less than about 1%.

(c) Fabric made from aromatic polyamide fibre did not lose strength by searing in any of the conditions examined.

5.7 Core looping of textile cordage

In some braided nylon parachute cordage there is a tendency for the core yarns to loop within the sheath giving nodules, and for these to penetrate the sheath. Large quantities of cordage were thus being rejected, leading to production delays, waste and inflation of costs.

The RAE collaborated with a main contractor, a sub-contractor, and various departments of the Procurement Executive, Ministry of Defence, in experiments to determine the manufacturing conditions giving rise to this problem[25]. Two cords were tested, now designated in Specification DTD 5620 as CB203 and CC301, and two experiments were performed, involving 438 combinations of manufacturing and other conditions.

In the first experiment there were two assessors and the following principal conclusions were reached by analysis of variance:

(a) CB203 cord formed more nodules than CC301; in CB203 cord the nodules increased as sheath tension increased, and least nodules were formed at high plaits/cm; but the situation was less clear with CC301 cord.

(b) Penetrations were greatest at low plaits/cm, when also they decreased with time and decreased as the sheath tension increased.

(c) There was no evidence that core tension influenced nodules or penetrations.

In the second experiment plaits/cm were increased further, but to save cost single values of sheath tension and core tension were adopted and there was only one assessor. It was found that CC301 core had increasing nodules as plaits/cm increased, whilst the reverse was true for CB203 cord, so that at these high plaits/cm the former cord now had more nodules than the latter.

6 MECHANICAL PROPERTIES OF TEXTILES

6.1 Variability of yarns

The tensile behaviour of a yarn and the variability of its properties are important factors when selecting a material for a given application. Work was therefore undertaken[26] to quantify a number of tensile properties of yarns of the same fibre type and of different fibre types, extracted from cordage. The properties considered were count, breaking strength, tenacity, breaking extension, energy absorption (by integrating stress-strain curves) and modulus (by differentiation). The fibre types were polyester, nylon, glass, polypropylene, acrylic and aramid. The scatter associated with the measurements was analysed.

Basic data were thus obtained, applicable in further work, e.g. on yarn to cordage translational effects[27], and on the effects of weathering[9].

6.2 Translation of yarn properties in cordage

The plain, twill and braided cords from which yarns were extracted for the determination of yarn properties[26] were subjected to similar tests, to determine[27] the effects associated with the conversion of yarn into cordage. The differences and the variability were analysed using statistical methods. The penalties associated with assuming linear stress-strain curves for both yarn and cordage, by joining the origin to the breaking coordinates, were also examined[26,28].

6.3 Strength of sewn joints

In the construction of certain types of parachutes, the highest possible proportion of the strength of a material needs to be retained after sewing, to avoid the necessity of designing to carry surplus weight and bulk, and the joints should be as small as possible.

An investigation was made[29] on lap and superimposed joints in four types of webbing using two strengths of polyester sewing thread. It was shown that lap joint strength increased linearly with the number of stitches, provided that joint failure was due to sewing thread breakage. Above a certain number of stitches, the mechanism of failure altered in that the webbing broke; increasing the number of stitches did not then increase the joint strength further. Conversely, increasing the number of stitches in a superposed joint decreased the strength from that of the unsewn material to a minimum equal to the maximum achieved in the lap joints (Fig.14).

The strength and tenacity of the sewing thread were significantly lower after sewing (about 10%), and there was some evidence that the needle thread was weaker than the bobbin thread. The count of the sewing thread increased after sewing, the increase probably being greater for the needle thread.

When joint failure was due to sewing thread breakage, a reasonable prediction of the strength could be made by multiplying the loop strength of the thread by the number of stitches and by a factor related to the angle the thread subtended in the loop. This factor was of the order of 0.5, but was somewhat dependent on thread diameter, being higher for a finer thread.

7 MISCELLANEOUS PUBLICATIONS

7.1 Flow diagram for aerospace applications

The properties which need to be taken into account for the use of textiles in military aerospace applications has been presented[30] in the form of a flow diagram (Fig.15). This can be used as a basic check list. The requirements which must be met at any particular stage must be studied, the potential usefulness of materials assessed, acceptable bounds for performance stipulated, the ability of current materials to withstand imposed conditions investigated, and the possibilities for new and better materials in terms of value and safety explored. Entry or re-entry to the diagram may be made at many points, and it is likely that entry earlier than is initially apparent could often be useful.

Six principal stages may be recognised: the production of fibre from polymer; the production of basic textile structure from fibres; finishing and dyeing; making up; testing; end-use validation.

Costs are involved at each stage. Those involving raw materials, processing and manufacturing the final product, and the effort required for research, development and quality assurance are obvious; possibly less apparent are the effects on costs of logistical problems (supply, inferior performance, repair, replacement, time out of service), failures and accidents, legislation, ecology and market growth.

7.2 Statistical methods

The characterisation of textile materials is subject to considerable error (i.e. the combined effects of uncontrolled factors), so that statistical methods are usually essential in planning experiments efficiently, and in assessing the reliability of conclusions.

It was considered that a collection[31] of a number of useful methods, particularly those related to analysis of variance and regression, would be helpful, and would encourage other workers to plan and evaluate along statistical lines.

7.3 Guide to coated fabrics

A broad survey of coated fabrics and their uses in inflatable devices as high strength, flexible membranes impermeable to gases and liquids was made[32] for the general reader. The types, properties, making up and applications of coated fabrics were dealt with, and problems associated with their use, such as lower strength/weight ratio, tear strength and flexibility compared to uncoated fabrics, were pointed out.

8 FUTURE TRENDS

The lifing of textile equipments, their performance in increased severity of conditions, protection against hostile environments, the characterisation of alternative materials, and utilisation of knowledge in investigations of accidents and malfunctions all pose immediate and difficult problems of scientific and logistic character.

Work in hand or projected for the future includes studies on the damage of abseil lines, recoil of breaking ropes, weathering of coated fabrics and of a range of cords, optimisation of sewn joints, the strength of knots, and the characterisation of 'touch and close' fasteners. In addition, work on the effects of fire needs to be extended to include inherently fire-resistant fabrics, coated fabrics, sewn or glued seams, multiple layers and stressed materials, Reports on individual items of work will be issued as appropriate.

Appendix
(see section 1)

AvP 970, Vol.1 **MEMO 20/A** August 1973

DETERIORATION OF FIBROUS MATERIALS

Leaflet 801/4

The current leaflet is superseded by:

Leaflet 801/4

PRECAUTIONS AGAINST CORROSION AND DETERIORATION OF FIBROUS MATERIALS

1 Introduction

1.1 This Leaflet gives information on precautions to minimise deterioration of textiles and cordages.

2 Resistance to rotting

*2.1 Synthetic fibre materials are resistant to rotting, i.e. to attack by micro-organisms, and require no protective treatment. Some microbiological attack, generally harmless in itself, though possibly unacceptable aesthetically, may occur on surface finishes applied or where the material is contaminated.

2.2 Natural fibre materials are susceptible to rotting and require protective treatment in accordance with chapter 801, paragraph 17.2.

3 Resistance to actinic degradation

3.1 Textile and cordage fibres are susceptible to degradation and weakening by actinic attack. This needs to be borne in mind when the use or the position of the component in the aeroplane results in much exposure of the material to light.

3.2 D. Mat. Tech. Memo. No.8 (see Ref.1) describes results of continuous exposure tests of nylon, Terylene and flax webbings under tropical and temperate conditions. Considerable losses of strength occurred within an exposure period of six months. For example, webbings made from 'bright' nylon, 'bright' Terylene (see paragraph 3.6 for definition of 'bright') and flax yarns, exposed for six months in Australia, lost 53%, 48% and 41% respectively of breaking strength when exposed to direct light and 22%, 27% and 25% respectively when exposed behind 'Perspex'.

---

*The revised information given in this Memo. has been supplied by Materials Department, RAE.

*3.3 A review of the literature on the weathering of nylon is given in RAE Technical Note, Chem 1389 (see Ref.2); results of weathering trials of nylon and the assessment of some protective treatments is described in RAE Technical Report 64081 (see Ref.3). It was found that 2:4 dihydroxybenzophenone applied from solution in benzyl alcohol or methylated spirit provided some protection. For extra high tenacity nylon, 90% of the original strength was retained after 312 days exposure, and 70% after 609 days. Corresponding figures for the untreated material were 65% and 31%. For delustered nylon, the strength retention of treated fibres was 90% after 123 days, whilst untreated fibres retained only 32%.

*3.4 Where it could be applied, e.g. in certain types of rope, neoprene sleeving resulted in better than 90% strength retention after five years. Sleeved ropes after exposure were indistinguishable from new, and they did not snarl or shrink; they were also protected from abrasion.

*3.5 Correlations of fading of dyestuffs with strength loss showed that for single dyes on high tenacity nylon threads and webbings, coefficients of up to 0.75 were obtained, and fading constituted a useful non-destructive test for strength (see Ref.4). For mixtures of dyestuffs on extra-high tenacity nylon threads, no similar worthwhile correlation existed (see Ref.5).

3.6 With synthetic fibre materials, the presence in the fibre of delustering pigment accelerates actinic degradation. Fibre of the 'bright' type should preferably be used, i.e. fibre substantially free from delustering pigment. When the application involves much exposure to light, only bright type fibre shall be used (see chapter 801, paragraph 17.1.2).

4 Resistance to heat

4.1 Textile and cordage fibres are subject to degradation and weakening when exposed to elevated temperatures. RAE Technical Note Chem 1270 (see Ref.6) describes the results of tensile tests on nylon and Terylene yarns before and after ageing at temperatures up to 180°C. After 16 hours exposure in air at 150°C the room temperature strength of the nylon yarn was reduced by approximately 40%. The same duration of exposure of the Terylene yarn in air at 156°C reduced the room temperature strength by approximately 10%.

*4.2 Extra-high tenacity nylon yarn of improved heat resistance showed approximately 5% loss of room temperature tensile strength after exposure in air at 150°C for 24 hours, and approximately 35% loss after exposure in air for the same period at 175°C.

*4.3 When nylon is introduced suddenly into a hot atmosphere, its temperature takes time to rise, and useful performance may be obtained during this time. For example, the energy from a shock load may be absorbed before excessive physical deterioration has taken place. The temperature history in cordage at several load levels when exposed to ambient temperatures up to 340°C is described in RAE Technical Note CPM 7 (see Ref.7). The lifetimes, i.e. times for which a cord will bear loads without breaking, at temperatures up to 440°C are also reported. For example, in a 3.56kN (800 lbf) braided cord under loads of 0, 0.45, 1.78, 2.23kN (0, 180, 400, 500 lbf), 50 second lifetimes could be obtained when exposed to air temperatures of 380, 360, 310, 210°C respectively; for lifetimes of 500 seconds the corresponding temperatures were 300, 250, 210, 150°C.

*4.4 For circularly woven acrylic and aromatic polyamide cordages of similar construction to nylon of specification minimum strength of 6.68kN (1500 lbf) (see Ref.8) aromatic polyamide was superior to nylon at low loads or high ambient temperatures, but there was little difference at temperatures below 200°C under a high load of 3kN (675 lbf). Aromatic polyamide was superior to acrylic under all the temperature and loading conditions studied. Nylon was superior to acrylic except under zero load, when acrylic was more resistant to heat.

5 Resistance to abrasion

*5.1 Fibrous materials are susceptible to abrasion. Studies have been made (see Refs.9-12) of the abrasion which occurs when synthetic fibre cordage runs at high speed over surfaces of nylon, concrete and asphalt.

*5.2 For a nylon surface, it was found that the abrasion mechanism was largely controlled by the rate of heat production in comparison with the rate of heat loss. It is essential to avoid the use of synthetic materials such as nylon when high temperatures may be developed, unless a heat sink or suitable protective layer can be incorporated.

*5.3 With concrete, heating plays a less important role, damage being principally a matter of progressive breakage of filaments by the rough surface. For example for a 3.56kN (800 lbf) cord under a load of 5N (1.125 lbf) a velocity of 10m/second (32ft/second) for nylon and polyester, and of 5m/second (16ft/second) for polypropylene are sufficient to cause failures in a few seconds. Higher velocities can be tolerated on asphalt than on concrete.

6 **Resistance to water**

*6.1 The strength of some textile materials is affected by water. For example, wet nylon is 15% weaker than at standard humidity, and aromatic polyamide 20% weaker. Natural cellulosic fibre (cotton, flax) are a few per cent stronger, while Terylene and polypropylene are unaffected.

*6.2 Undrawn nylon degrades chemically in warm water unless protected, e.g. by oxine (see Ref.13).

*6.3 Ply-tear webbings which are satisfactory in dry conditions may become dangerous when wet because of ply failure; use of a binder/warp strength ratio of not more than 0.08 is recommended (see Ref.14).

REFERENCES

(for Leaflet 801/4)

1 Fibrous nylon in aeronautical equipments - resistance to actinic degradation.
D. Mat. Technical Memoranda No.8, January 1961

2 The deterioration of nylon by natural weathering: a literature survey.
RAE Technical Note Chem 1389, February 1962

*3 Weathering of fibrous nylon and assessment of some protective treatments.
RAE Technical Report 64081, December 1964

*4 Correlations of strength losses on weathering, strength losses under a xenon arc and fading of dyed textiles.
RAE Technical Memorandum Mat 50, January 1969

*5 Correlations of strength losses and fading of dyed extra-high tenacity nylon threads on weathering.
RAE Technical Memorandum Mat 98, September 1970

6 The effect of heat on the strength of nylon and Terylene yarns.
RAE Technical Note Chem 1270, December 1955

*7 Load capacity and heat transmission for nylon cordage thrust into a hot environment.
RAE Technical Note CPM 7, February 1963

REFERENCES (concluded)

*8 Lifetimes of cordages when loaded and thrust into a hot environment.
RAE Technical Memorandum Mat 76, February 1970

*9 High speed abrasion of nylon cordage on nylon.
RAE Technical Note CPM 83, August 1964

*10 High speed abrasion of textile cordage on concrete.
RAE Technical Report 65227, October 1965

*11 High speed abrasion of textile cordage on an asphalt surface.
RAE Technical Report 67023, January 1967

*12 High speed abrasion of nylon cordage on concrete and resin coated concrete.
RAE Technical Memorandum Mat 40, September 1968

*13 Wet oxidation of undrawn nylon 66 and model amides.
RAE report Chem 531, May 1962

*14 The energy absorbing efficiency of ply-tear webbings of various constructions.
RAE Technical Report 72051, June 1972

Table 1

FACTOR ANALYSIS OF CORRELATION MATRICES OF HOVERCRAFT FINGER PROPERTIES

Property	Factor (rotated)				Communality
	Ω	Ψ	Χ	Φ	
Wear rate on craft, mm/100h, rear	0.91	-0.06	0.30	0.12	0.96
Wear rate on craft, mm/100h, sides	0.85	0.00	0.42	0.00	0.90
Wear rate on craft, mm/100h, bow	0.83	-0.07	0.47	0.02	0.93
Flagellation loss rate, mm^2/h	0.99	0.01	0.12	0.07	1.00
Delamination on craft, rank order	0.45	-0.28	-0.25	-0.16	0.37
Wet adhesion[2], rank order	0.68	0.31	-0.08	-0.46	0.81
Direct tension dry adhesion, N/m^2	0.26	0.65	0.18	0.00	0.53
Dry fabric mass, g/m^2	-0.96	0.15	0.07	-0.17	0.99
Wet fabric mass, g/m^2	-0.96	0.13	0.07	-0.21	0.99
Total fabric thickness, mm	-0.99	0.03	0.09	-0.11	1.00
Coating thickness, mm	-0.88	0.25	0.00	-0.15	0.85
Indentation hardness of coating, Shore degrees	0.35	0.60	0.01	-0.45	0.74
Coefficient of friction on concrete, dry	-0.51	0.32	0.03	0.23	0.42
Coefficient of friction on concrete, wet	-0.35	0.22	0.26	0.11	0.27
Tongue tear strength, N, dry, across warp	-0.96	0.07	0.12	-0.06	0.95
Tongue tear strength, N, dry, across weft	-0.94	0.15	0.12	0.00	0.93
Tongue tear strength, N, wet, mean of warp and weft	-0.96	-0.03	0.10	-0.05	0.95
Bending length, warpway, mm	-0.63	-0.10	0.15	-0.64	0.86
Flexural rigidity, warpway, N mm	-0.83	-0.01	0.12	-0.54	0.99
Bending modulus, warpway, N/mm^2	0.72	0.01	0.06	-0.65	0.93
Suggested identification of factor	Total fabric thickness	Direct tension adhesion	Specific hovercraft factor	Flexibility	
Other properties influenced by factor	Most properties, including wear rates on craft	Delamination on craft, wet adhesion	Delamination on craft, friction on wet concrete	Coating hardness, wet adhesion	

REFERENCES

No.	Author	Title, etc.
1	A. Baker	The mechanical properties and porosity of parachute fabrics. RAE Report Chem 507 (1956)
2	J.E. Swallow E. Mikolajewski M. Webb	Research on textile materials in Materials Department, RAE. RAE Technical Report 68070 (1968)
3	-	Precautions against corrosion and deterioration. Deterioration of fibrous materials. In *Aeroplane design requirements*, AvP 970, Vol.1, Leaflet 801/4 (Memo 20/A), London, Procurement Executive, Ministry of Defence (1973)
4	J.E. Swallow	Effects of dyes and finishes on the weathering of nylon textiles. RAE Technical Report 74179 (1975)
5	British Standards Institution	Procedure for inspection and testing of textiles. BS 3F100 (1975)
6	J.E. Swallow M. Webb	Correlations of strength losses on weathering, strength losses under a xenon arc and fading of dyed nylon textiles. RAE Technical Memorandum Mat 50 (1969)
7	J.E. Swallow M. Webb	Correlations of strength losses and fading of dyed extra-high-tenacity nylon threads on weathering. RAE Technical Memorandum Mat 98 (1970)
8	M. Webb	The possible harmful effects of agricultural chemicals in contact with parachute materials. RAE Technical Memorandum Mat 194 (1974)
9	M. Webb	Shrinkage of cordage in various environments. RAE Technical Memorandum Mat 207 (1975)
10	J.E. Swallow	A method for studying the behaviour of textiles on exposure to liquid-fuel fires. RAE Technical Memorandum Mat 173 (1973)

REFERENCES (continued)

No.	Author	Title, etc.
11	J.E. Swallow	Behaviour of a nylon fabric on exposure to a liquid-fuel fire. RAE Technical Memorandum Mat 186 (1974)
12	J.E. Swallow	Behaviour of some fire-retarded cotton fabrics on exposure to a liquid-fuel fire. RAE Technical Memorandum Mat 212 (1975)
13	Shirley A. Watts	Lifetimes of cordages when loaded and thrust into a hot environment. RAE Technical Memorandum Mat 76 (1970)
14	R.D. Larke	Heat transmission into Nomex cordage. RAE Technical Memorandum Mat 68 (1969)
15	M. Webb	Effect of time and temperature on a heat-resistant nylon yarn. RAE Technical Report 75113 (1975)
16a	M. Webb	The bending behaviour of some coated fabrics from -40°C to +140°C. RAE Technical Memorandum Mat 101 (1970)
16b	J.E. Swallow M. Webb	The bending behaviour of some coated fabrics from -40°C to +140°C. *J. Coated Fabrics*, 3 (3), 171-180 (1974)
17	J.E. Swallow M. Webb Shirley A. Watts	The energy-absorbing efficiency of ply-tear webbings of various constructions. RAE Technical Report 72051 (1972)
18	J.E. Swallow M. Webb	(a) Calculated motions in impacted ply-tear webbing. RAE Technical Memorandum Mat 143 (1972) (b) Tearing force and energy absorption in impacted ply-tear webbing. In *Stresses and Strains in Textile Structures*, Shirley Institute Publication S10, Manchester, Shirley Institute (1974)

REFERENCES (continued)

No.	Author	Title, etc.
19	J.E. Swallow J.H. Cadwell M. Webb	Fabric properties and the wear of hovercraft fingers. RAE Technical Report 71210 (1971)
20	J.E. Swallow E. Mikolajewski M. Webb	The relationships between snatch-tear and other properties for sets of uncoated and coated fabrics. RAE Technical Report 70112 (1970)
21	J.E. Swallow E. Mikolajewski	Penetration of fabrics by pointed agents. RAE Technical Memorandum Mat 48 (1969)
22	M. Webb	High-speed abrasion of nylon cordage on concrete and resin-coated concrete. RAE Technical Memorandum Mat 40 (1968)
23	J.E. Swallow M. Webb	Some experiments on the friction of fabrics on human skin. RAE Technical Report 72037 (1972)
24	J.E. Swallow	Searing of lightweight fabrics by running cordage. RAE Technical Report 75137 (1975)
25	J.E. Swallow	Core looping of textile cordage. RAE Technical Report 75136
26	Bridget Stagg	The tensile behaviour and variability of textile yarns. RAE Technical Report 74009 (1974)
27	Bridget Stagg	Translation of textile yarn properties in cordage. RAE Technical Report 74085 (1974)
28	Bridget Stagg	Errors induced by assuming linearity of stress-strain curves of cordage. RAE Technical Memorandum Mat 191 (1974)
29a	M. Webb	Some observations on the behaviour of superimposed and lap sewn joints. RAE Technical Report 74183 (1975); *Clothing Research J.*, in the press

REFERENCES (concluded)

No.	Author	Title, etc.
29b	M. Webb	The effect of increasing the number of rows of transverse stitching on sewn joints. *Clothing Research J.*, in the press
30	J.E. Swallow	A flow diagram for selecting textiles for aerospace use. RAE Technical Memorandum Mat 127 (1971)
31a	J.E. Swallow M. Webb	Some statistical methods used in the Textiles Section, Materials Department, RAE. RAE Technical Memorandum Mat 86 (1970)
31b	J.E. Swallow	Application of some statistical methods in parachutes materials research. Proceedings of the Royal Aeronautical Society Symposium on parachutes and related technologies (1971)
32	J.E. Swallow G. Shaw	A guide to coated woven fabrics for inflatable equipment. RAE Technical Memorandum Mat 47 (1968) D. Mat./Aviation Report 155 (1968)

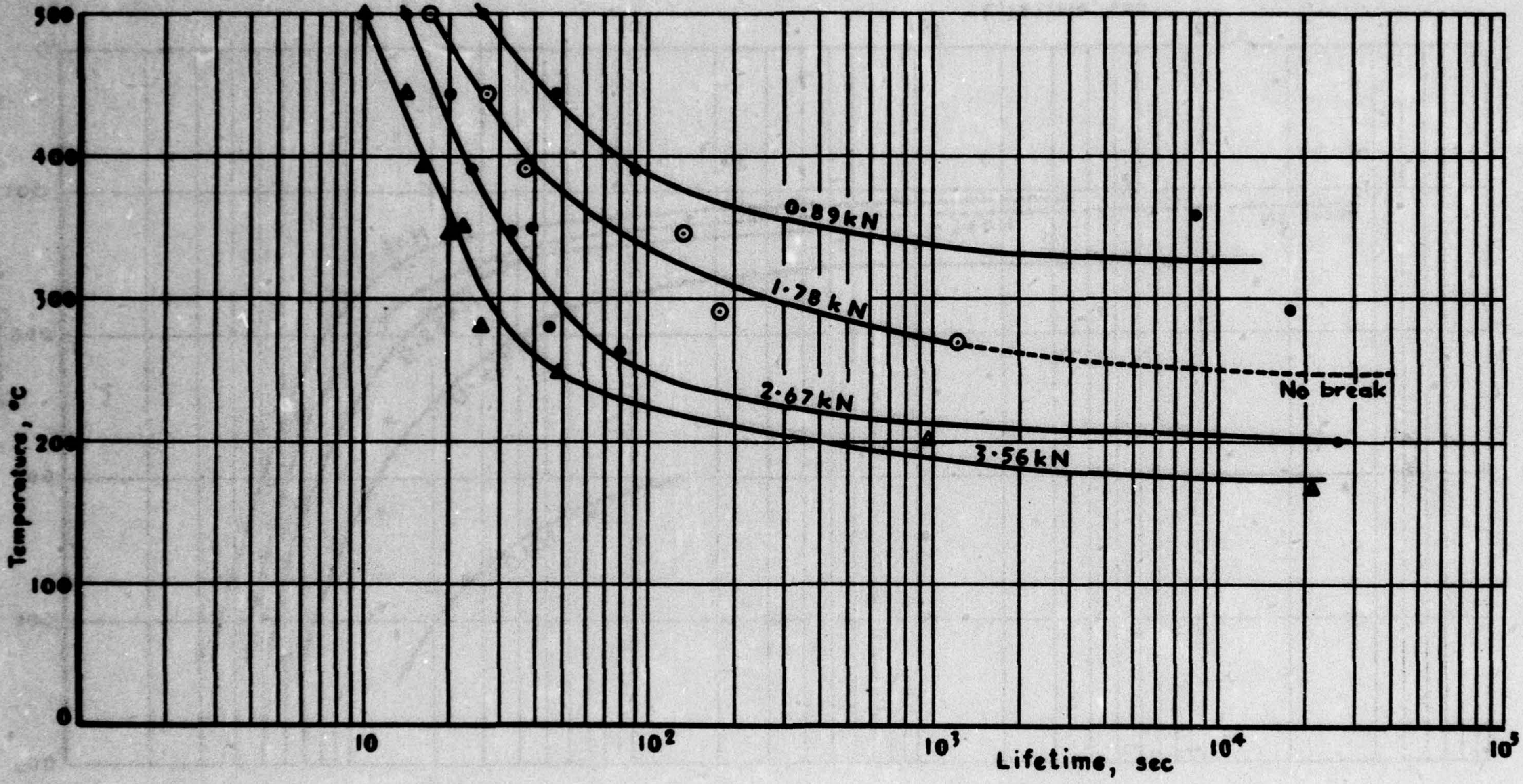


Fig.1 Lifetimes of aromatic polyamide cordage

Fig. I

Fig. 2

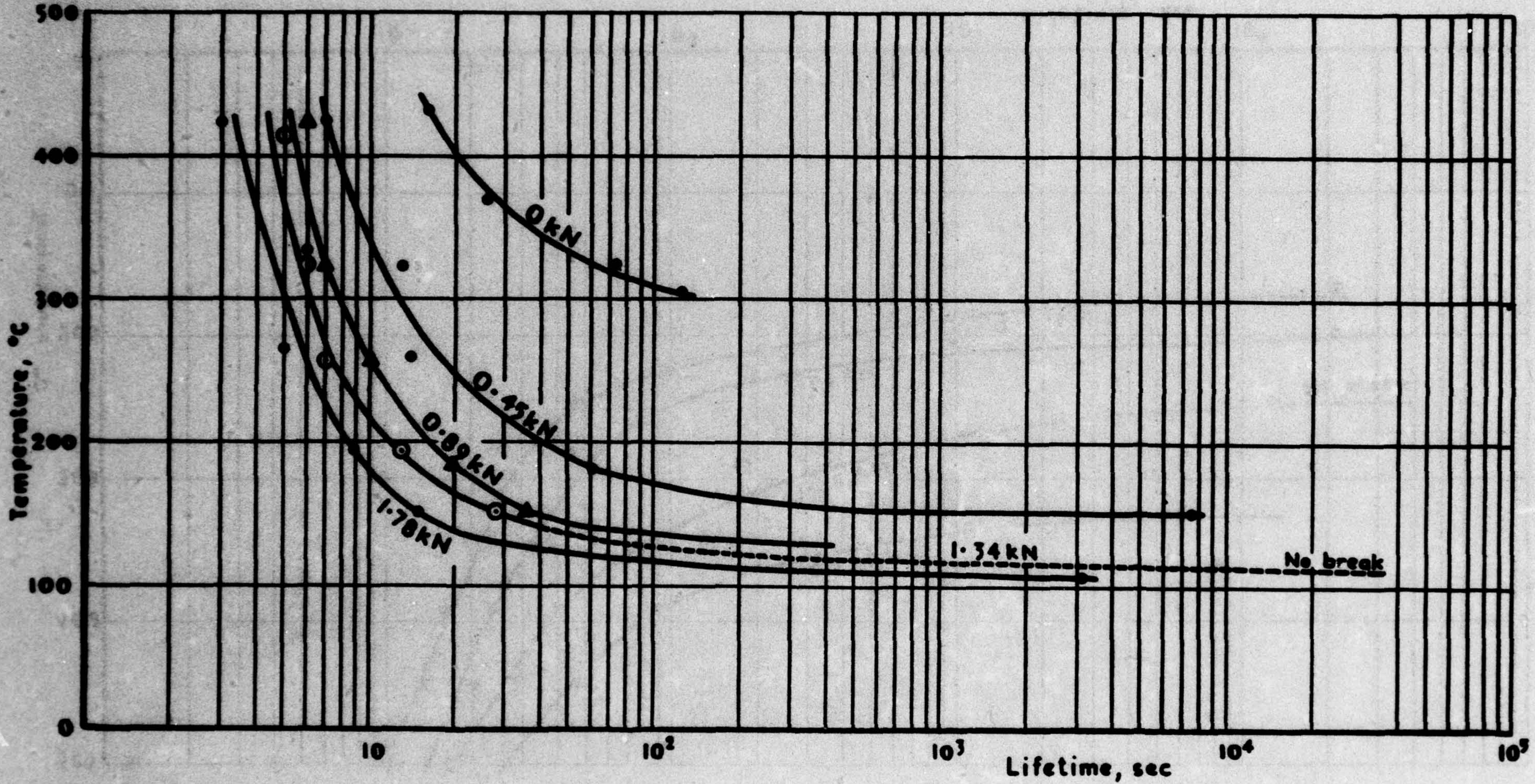


Fig. 2 Lifetimes of acrylic cordage

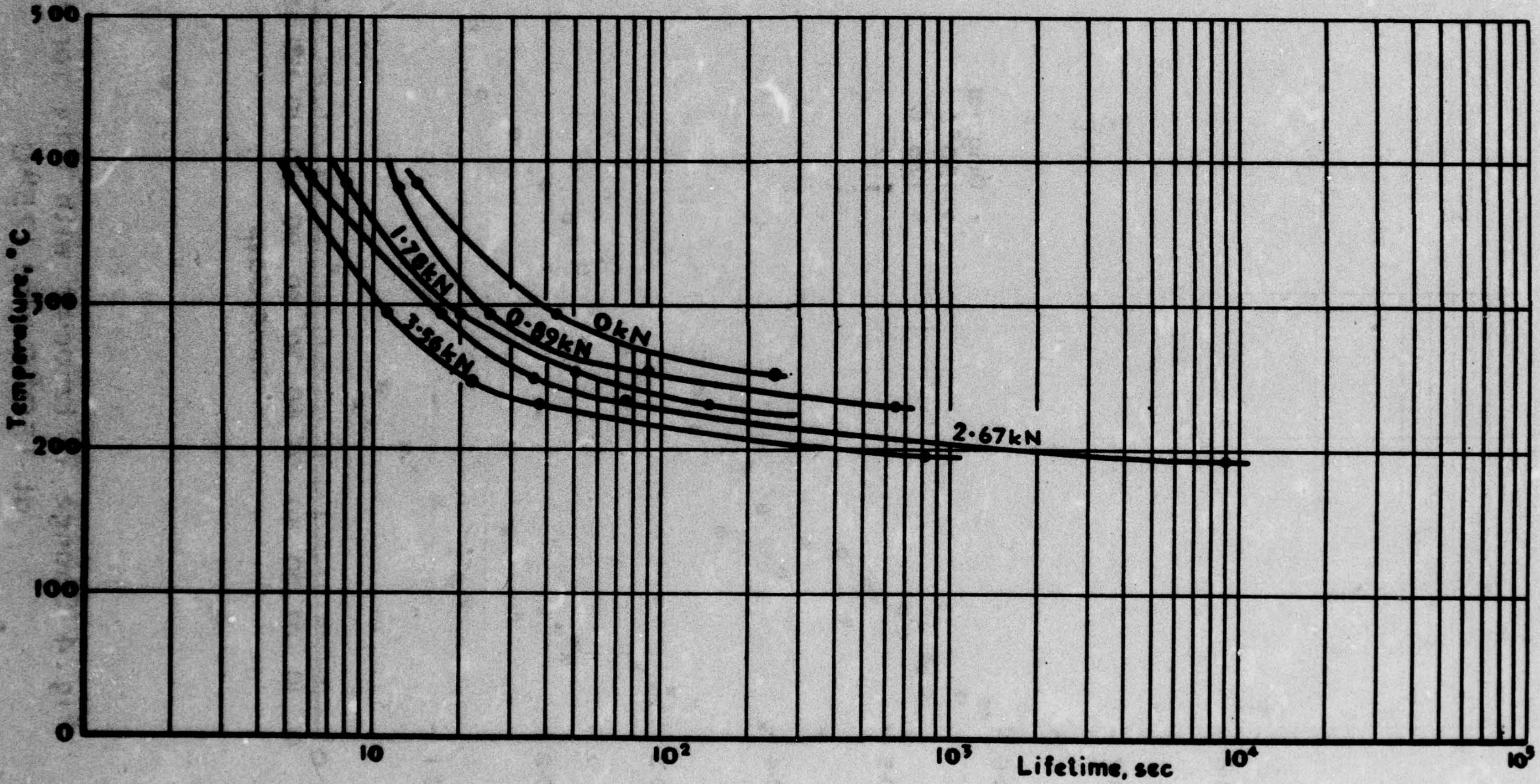


Fig. 3 Lifetimes of nylon cordage

Fig 3

Fig. 4

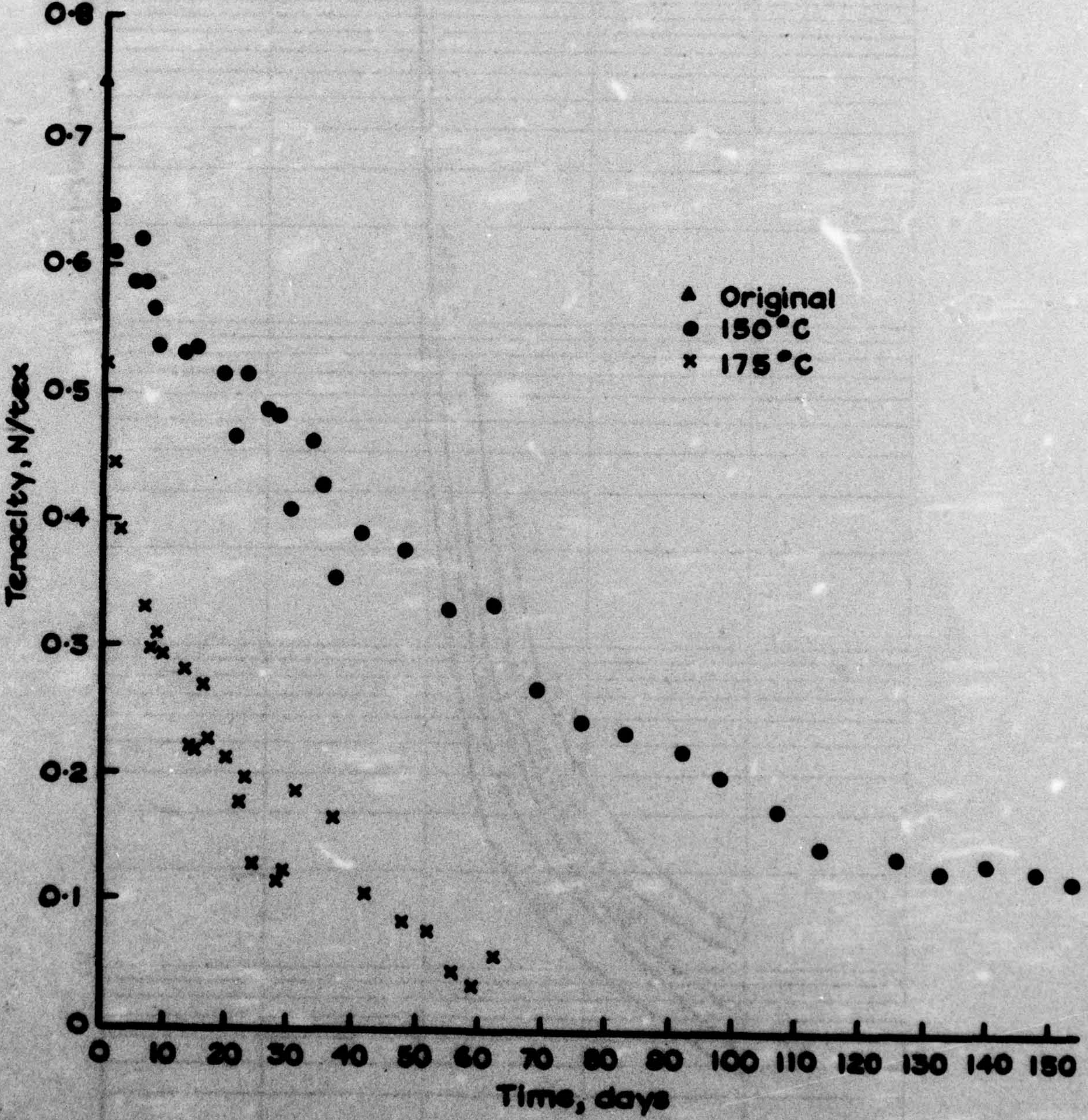


Fig. 4 Change in tenacity with time for yarn at 150°C and 175°C

TR 76051

Fig. 5

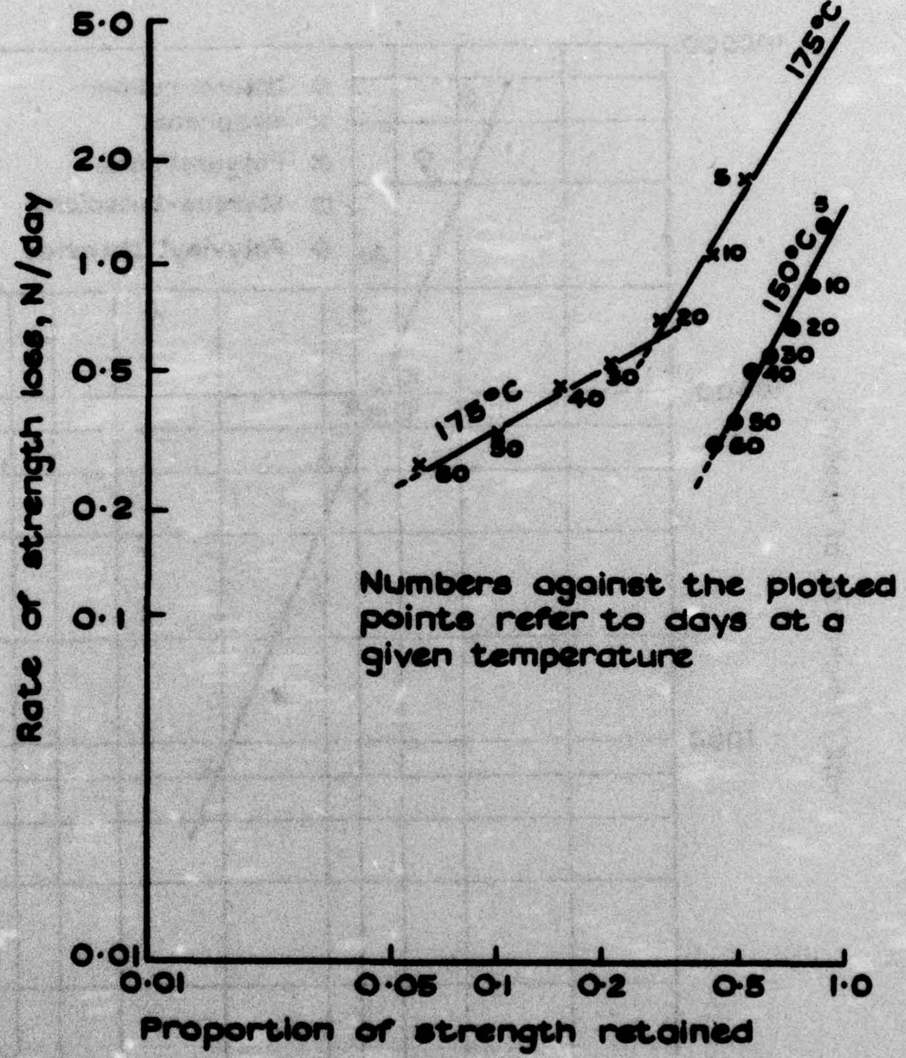


Fig. 5 Relationship between rate of strength loss and proportion of strength retained

Fig. 6

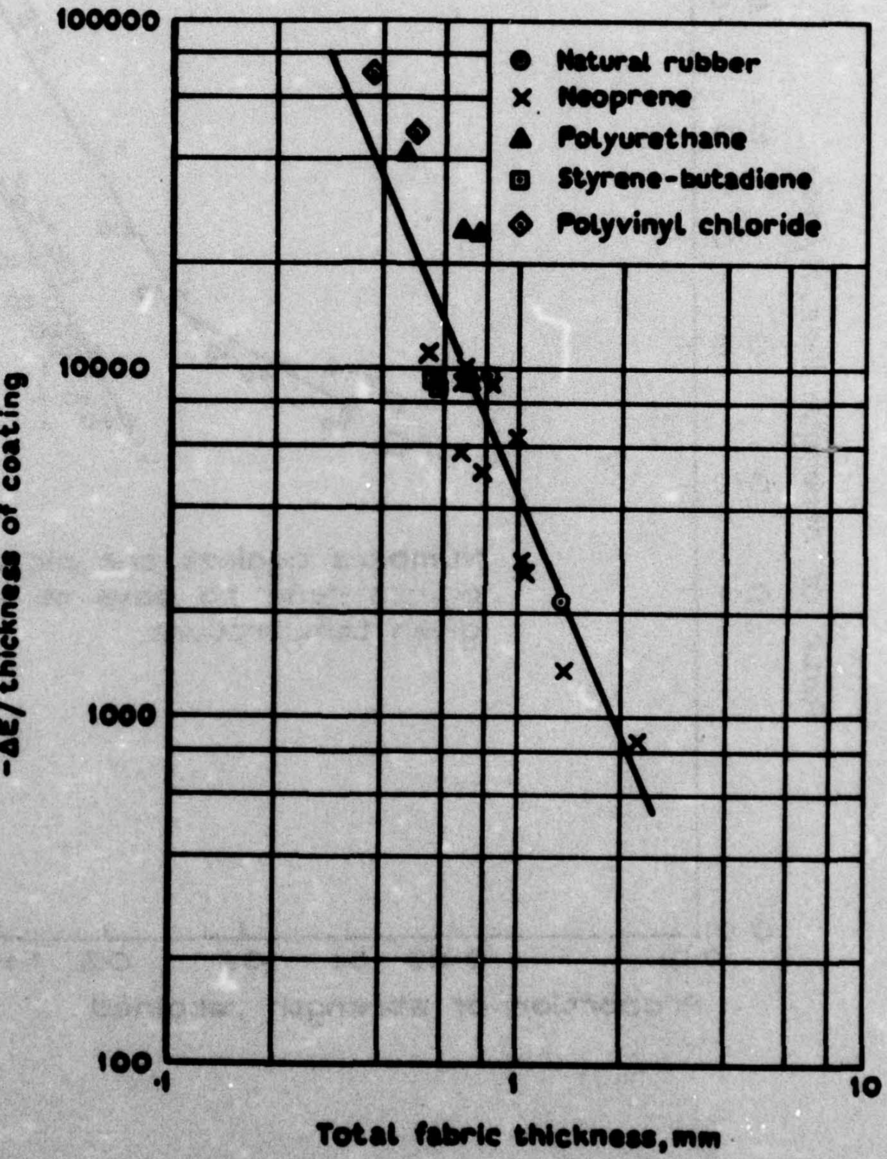


Fig. 6 Relationship between -ΔE/thickness of coating and total fabric thickness for single-ply coated fabrics

TR76031

Fig.7

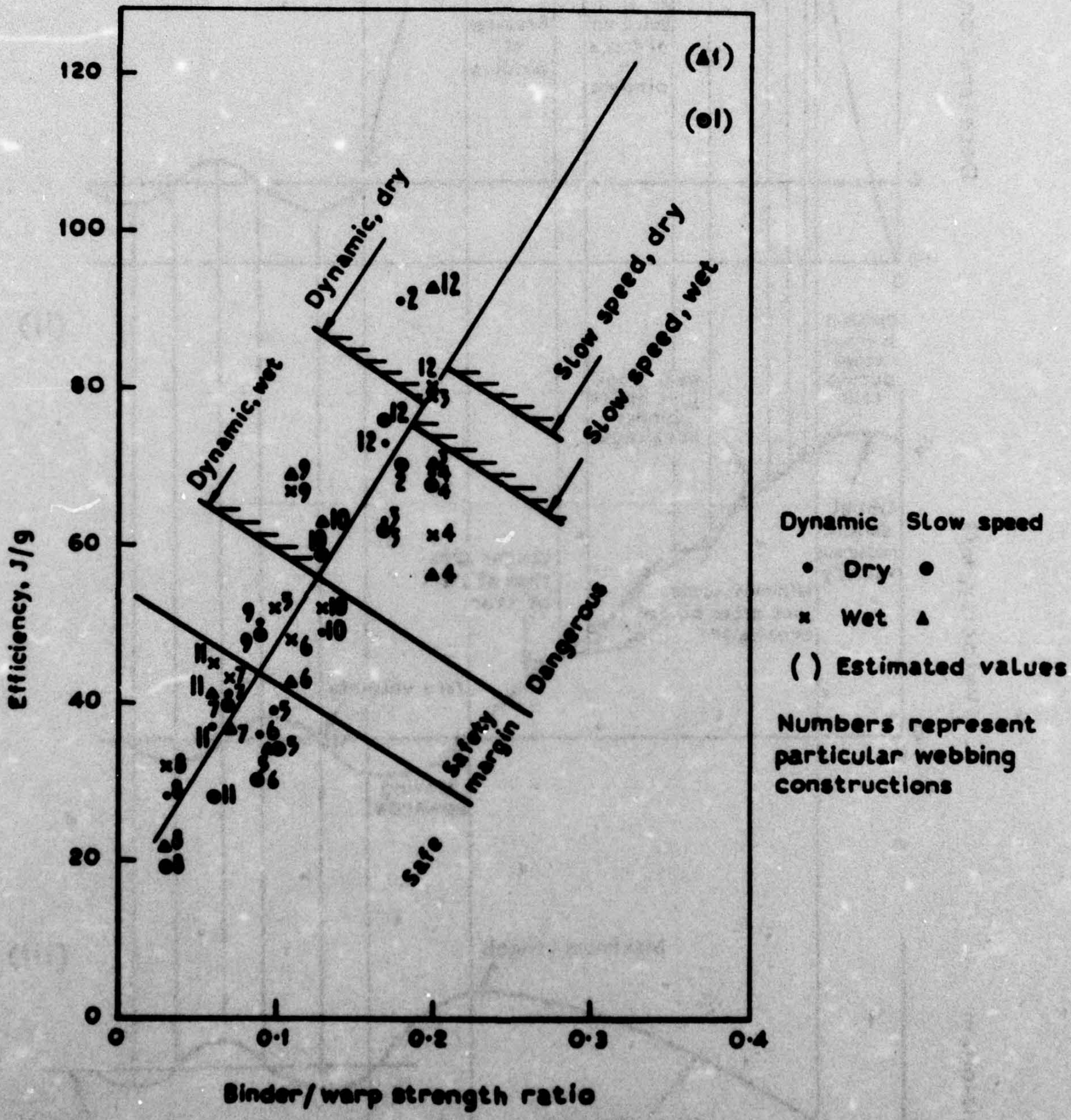


Fig. 7 Efficiency as a function of binder / warp strength ratios, with suggested safe and dangerous zones

Fig. 8

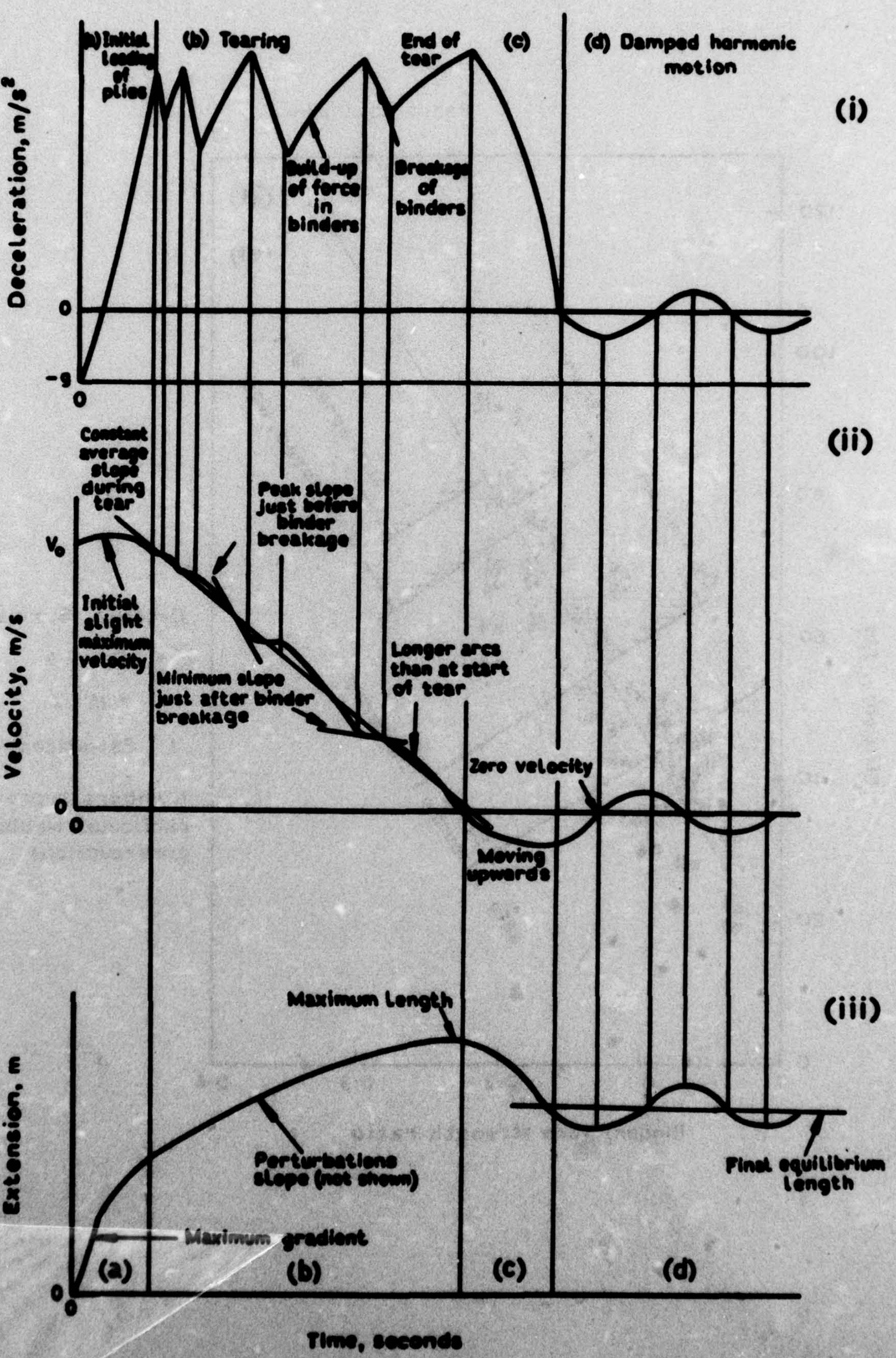


Fig.8 Diagrammatic representation of deceleration (i) velocity (ii) and extension (iii) with time

Fig. 9

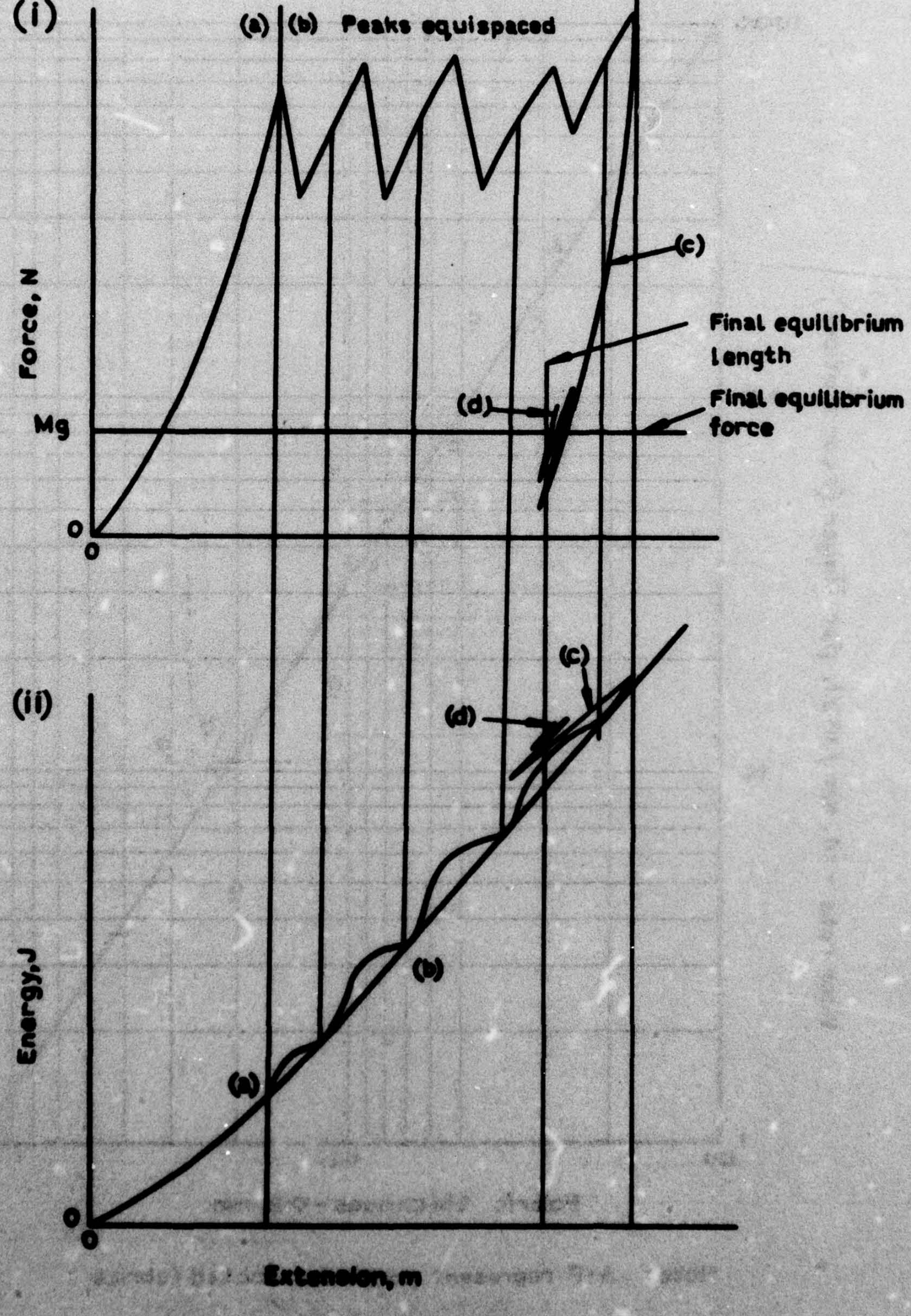
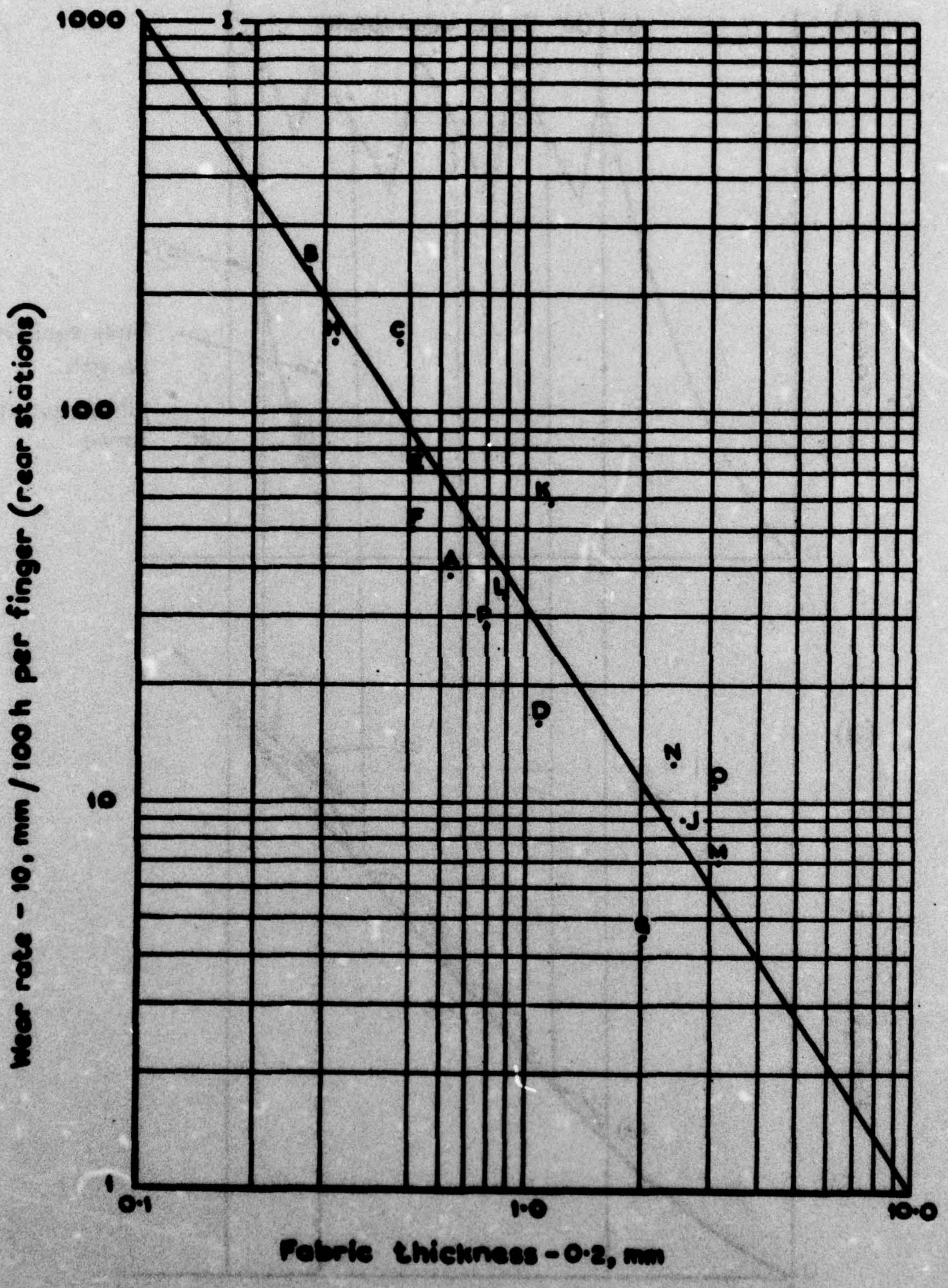


Fig. 9 Diagrammatic representation of force (i) and energy (ii) with extension

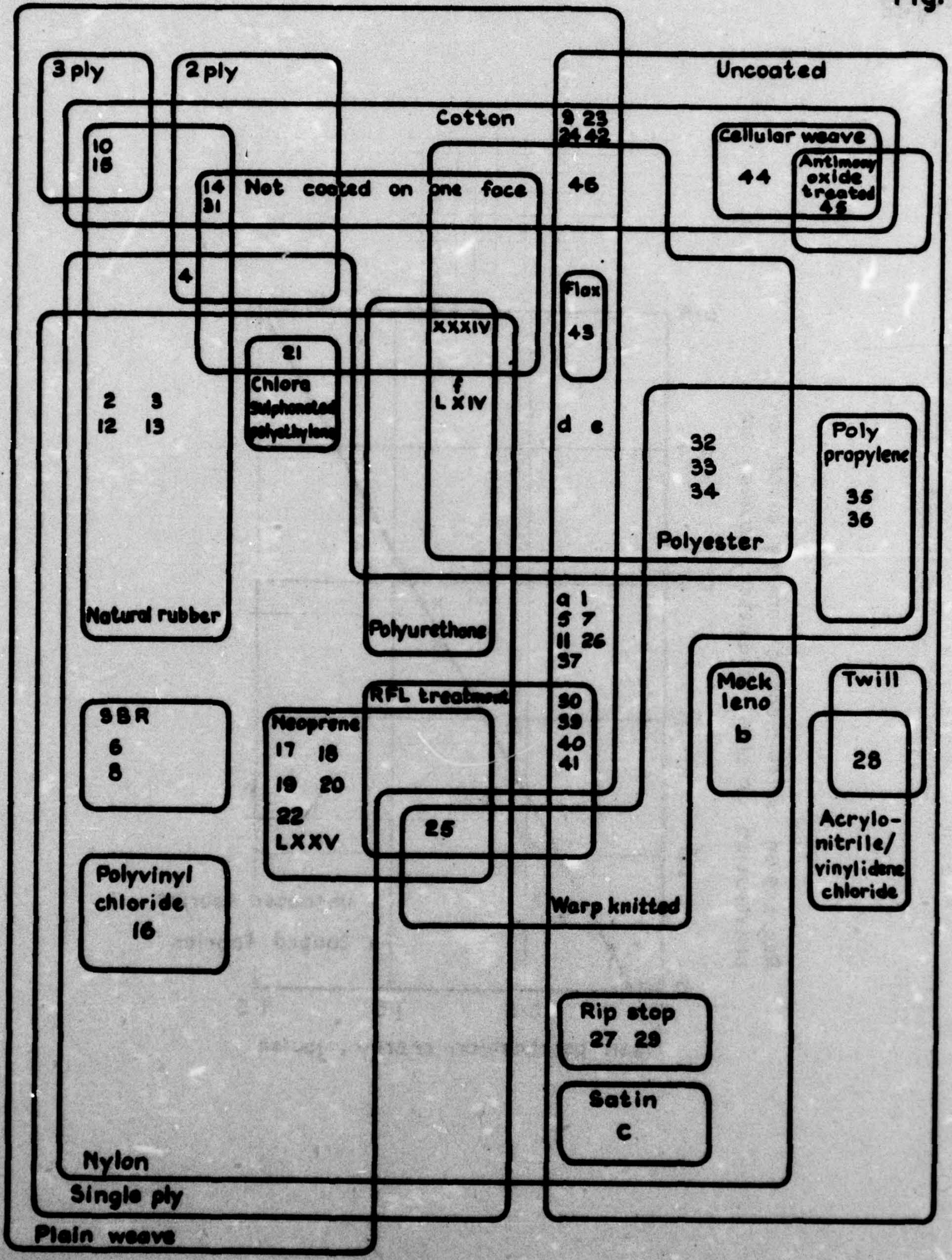
TR 76091

Fig. 10



Note: A-P represent particular coated fabrics

Fig. 10 Wear rates at rear stations plotted against thickness



Note: Numbers or letters at intersections of sets represent particular fabrics

Fig. 11 Venn diagram of fabrics

Fig.12

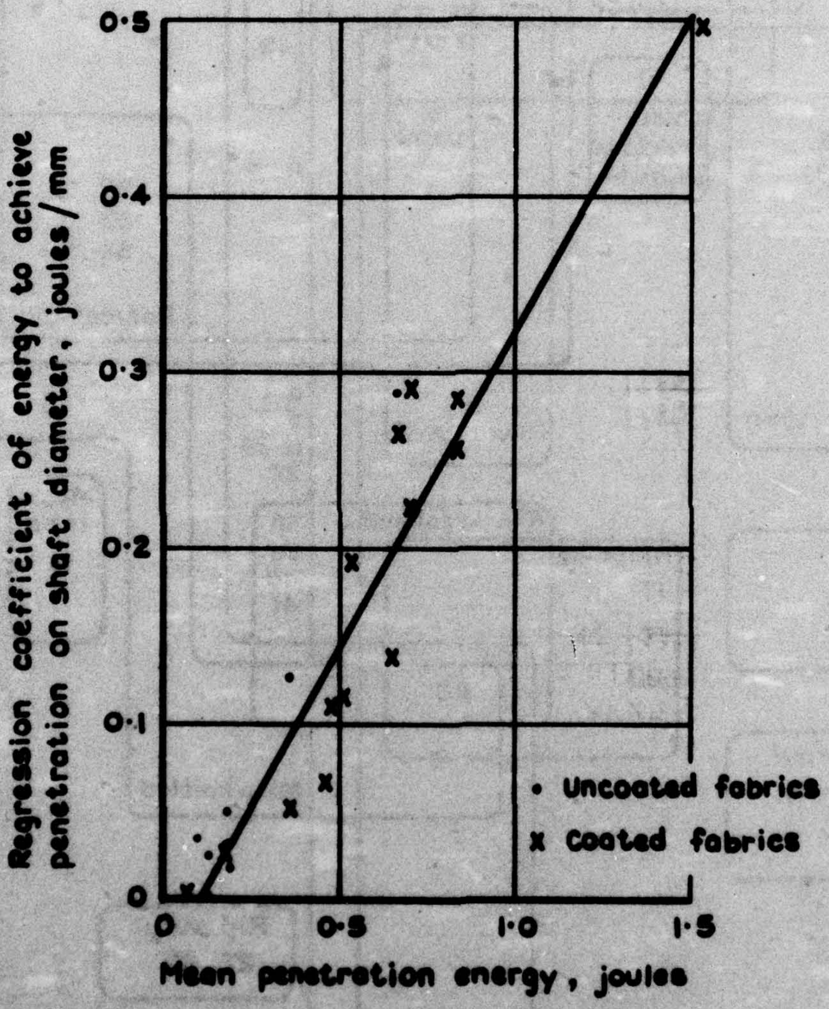


Fig.12 Relationship between regression coefficient of energy to achieve penetration on shaft diameter and mean penetration energy

TR76051

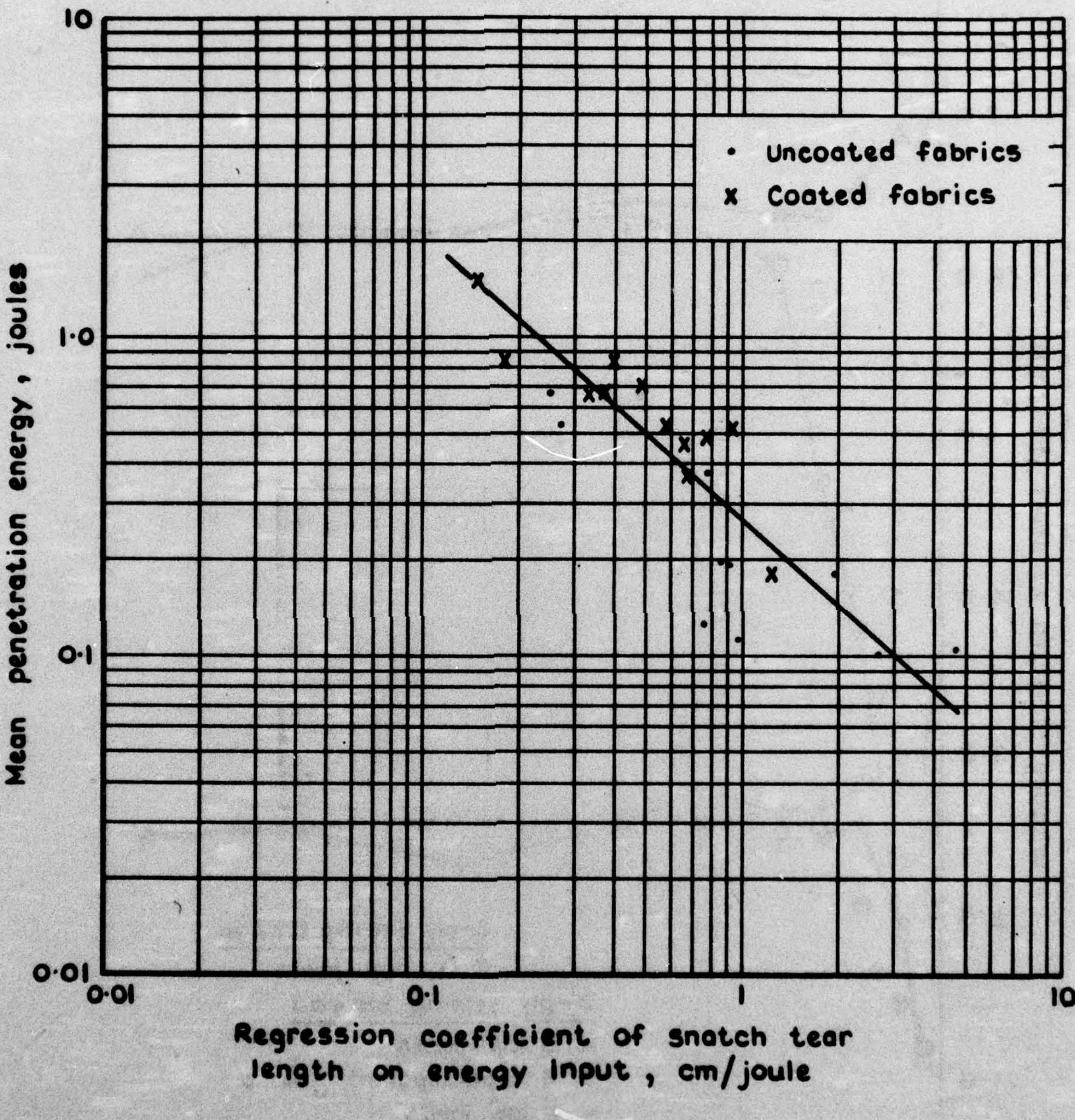
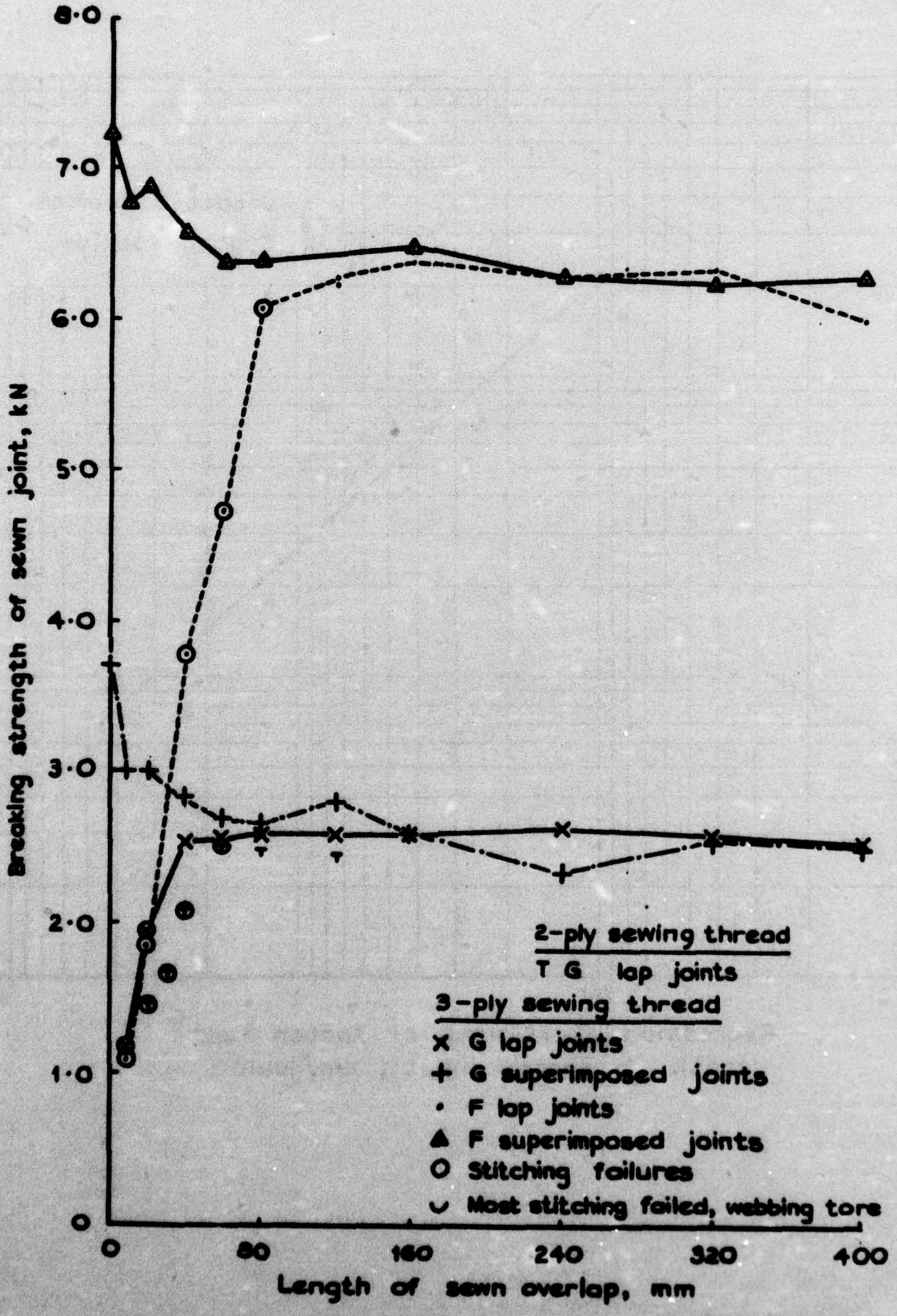


Fig. 13 Relationship between mean penetration energy and regression coefficient of snatch tear length on energy input

Fig.14



Note: F and G refer to particular webbings

Fig.14 Lap and superimposed joints in webbings F and G

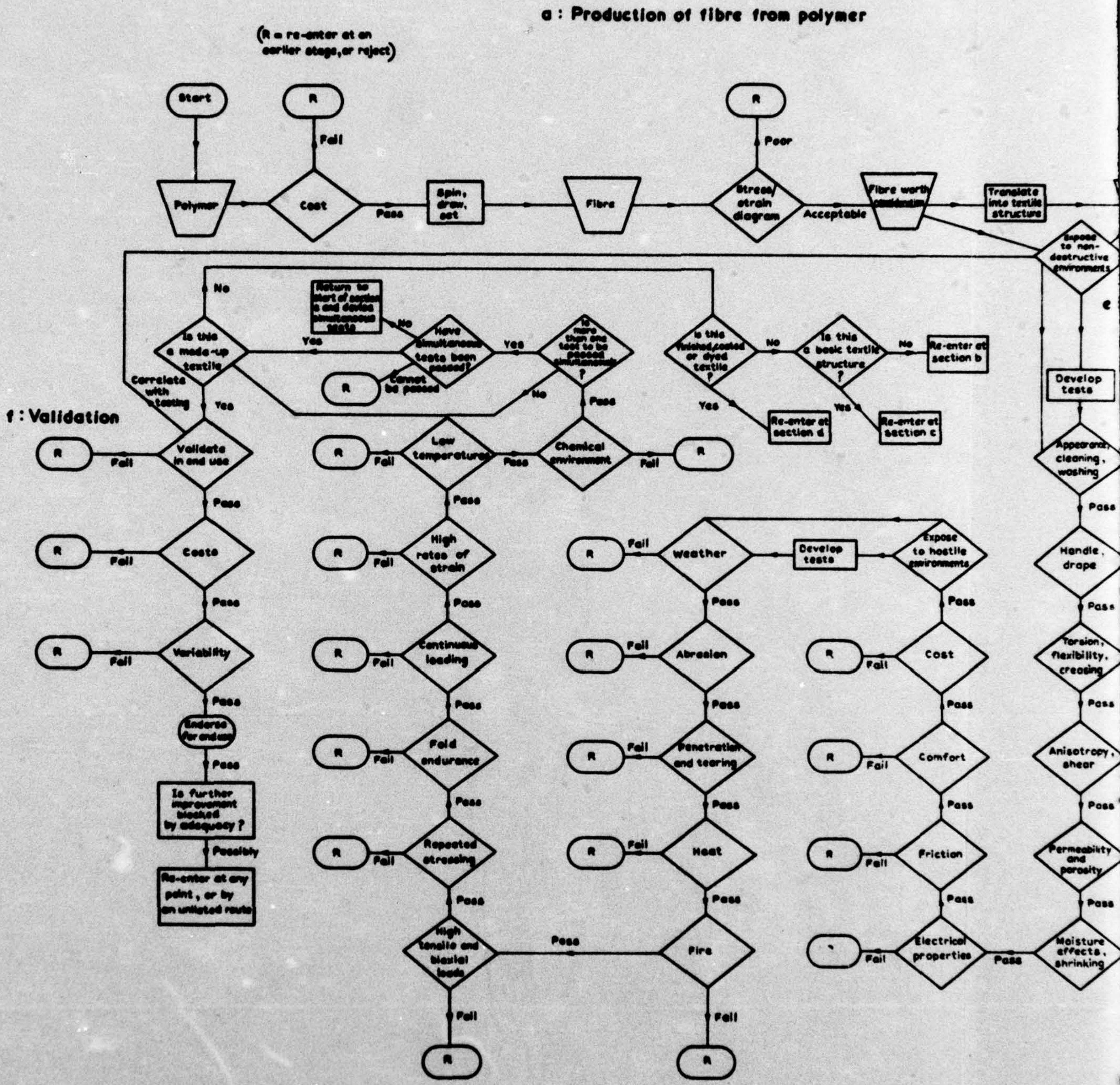


Fig.15 Flow diagram for text

Fig. 15

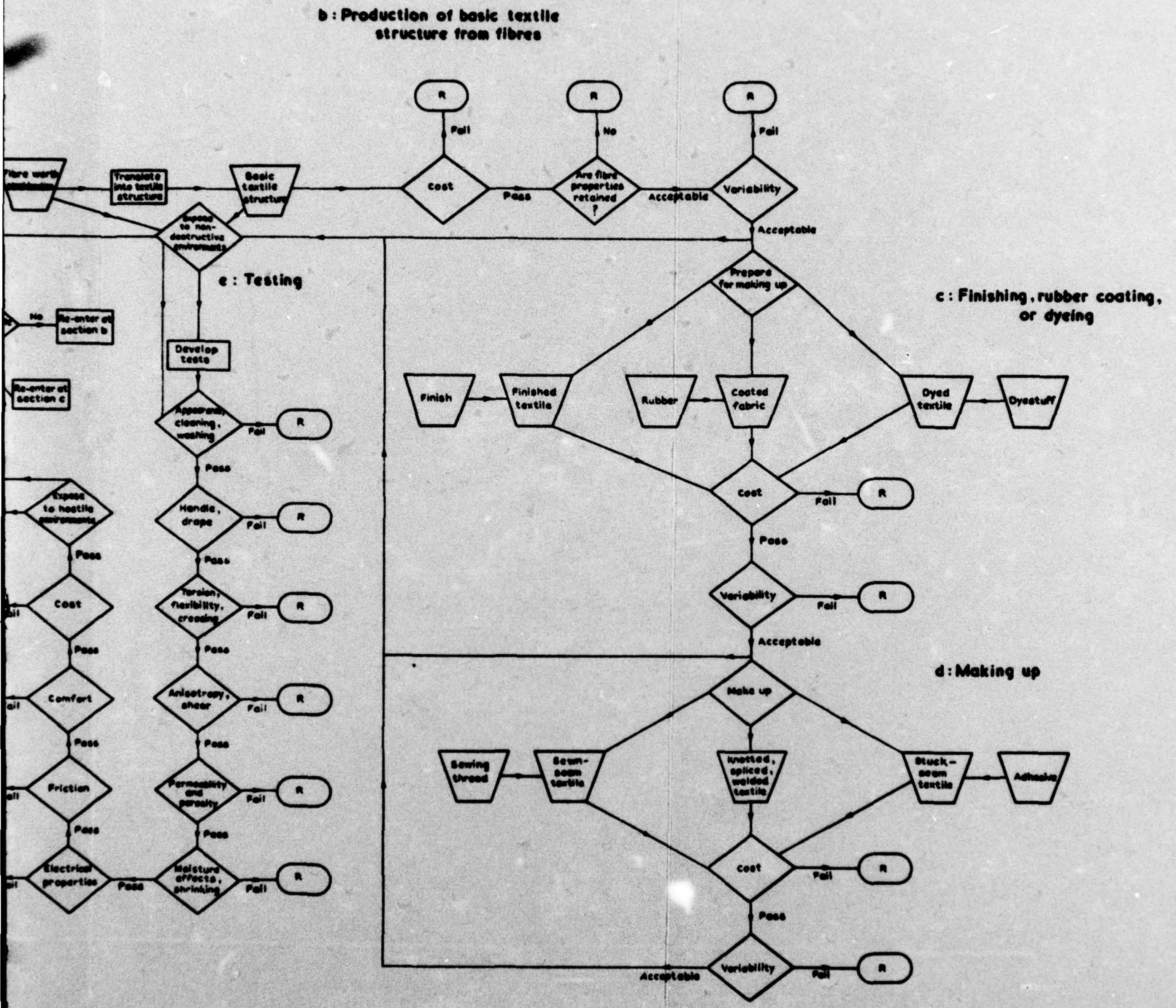
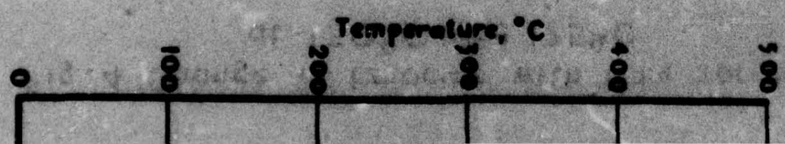


diagram for textile investigations 2


Temperature, °C
0
100
200
300
400
500