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Textiles: Some Technical Information and Data II: Conversion Factors, Fibre Properties, Spinning Limits, Typical Twist Factors, Weaving Performance and Transfer Printing Temperatures

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TEXTILES: SOME TECHNICAL INFORMATION AND DATA II: CONVERSION FACTORS, FIBRE PROPERTIES, SPINNING LIMITS, TYPICAL TWIST FACTORS, WEAVING PERFORMANCE AND TRANSFER PRINTING TEMPERATURES

by L. HUNTER

INTRODUCTION

The response to Part I of this series has been so good that it was considered worthwhile to extend the work to cover a wider field. This publication therefore contains material not covered in Part I, although it also supplements and updates certain topics. It concentrates on conversion factors, general fibre properties, spinning limits, typical twist factors and weaving performance. Some information is also included concerning transfer printing.

Subsequent parts will deal with high performance fibres, cotton and wool in more detail.

Most of the information has been reproduced in the words or form used in the source from which the information was obtained. The author, therefore, lays no claim to originality but has merely attempted to compile some facts and figures which are often required in the textile industry.

CONVERSION FACTORS AND OTHER DATA

The trend throughout the world is towards the use of metric units, or more particularly the SI units. Some of the units commonly encountered in the textile industry together with the relevant conversion factors are, therefore, given here.

RECOMMENDED TEXTILE UNITS

In what follows below it is to be understood that the recommended units on the left can be obtained by carrying out the operation shown on the right on the original units.

Count or Linear Density (Fineness)

The tex unit (grams per 1 000 metres) is recommended, together with decitex (dtex), millitex (mtex) and kilotex (ktex).

The above units can be obtained from other commonly used units as follows:

$$\text{tex (mg/m)} = \frac{1\,000}{\text{metric count}} \qquad \text{(Metric count = Nm)}$$

$$\text{tex} = \frac{886}{\text{worsted count}} \qquad \text{(Worsted count = Ne worsted)}$$

$$\text{tex} = \frac{590{,}6}{\text{English cotton count}} \qquad \text{(Cotton count = Ne)}$$

tex = 0,1111 x denier

tex = 0,1 x dtex

tex = 0,001 x mtex

= 1000 x ktex

dtex = 1,11 x denier

ktex (g/m) = 6,2 x (oz/5 yds)

ktex (g/m) = 0,04845 x (drams/40 yds)

ktex (g/m) = 0,071 x (grains/yd)

To illustrate:

It is desired to convert a worsted count of 1/34's (or 34's worsted) into tex.

From the above we have: $\text{tex} = \frac{886}{34} = 26{,}1$

∴ the linear density is 26,1 tex.

Tenacity

Two ways of expressing tenacity are being recommended, viz. cN/tex and mN/tex or even perhaps N/tex where 1 cN/tex = 10 mN/tex (i.e. to convert from cN/tex to mN/tex multiply by 10)

To obtain cN/tex from other units proceed as follows:

$$\text{cN/tex} = \frac{9{,}8 \times 10^{-3}}{\rho} \times \text{kgf/cm}^2$$

$$\text{cN/tex} = \frac{0{,}69}{\rho} \text{ (thousand pounds per square inch)}$$

where ρ = fibre density in g/cm^3 or the relative density (specific gravity) of the fibre.

For cotton this should lead to: cN/tex = 0,454 (Pressley in 1 000 psi) but in general the following conversion is used:

cN/tex = 0,486 (commercial Pressley in 1 000 psi)
cN/tex = 0,98 x (g/tex)
= 0,98 x (gf/tex)
= 0,98 x (RKM)
= 8,83 x (g/denier)
= 8,83 x (gf/denier)

where gf denotes gram-force.

If mN/tex is required multiply the above by 10 and if N/tex is required multiply by 0,01.

Tear Strength

Tear strength should be expressed in newtons (N).

where N = 0,98 (hectograms or hg)
= 4,448 x (lbs force)

Bursting Strength (or Pressure)

Here it is recommended to use kPa or Pa where Pa = N/m^2.

kPa = 0,001 x (N/m^2)
= 6,89 x (lbf/in^2)
= 98,07 x (kgf/cm^2)

Pressure

It is recommended to use pascal (Pa) or kilopascal (kPa) for pressure where Pa = N/m^2.

Therefore:

kPa = 6,89 x (lbf/in^2)
= 98,07 x (kgf/cm^2)
= 9807 x (kgf/mm^2)
= 10^4 x (h bar)
= 0,1 x (m bar)
= 0,1333 x (mm of mercury)
= 0,2491 x (in of water)
= 0,098 x (cm of water)
= 3,386 x (in of mercury)
= 0,04788 x (lbs/ft^2)
= 10^{-4} x (dynes/cm^2)
= 0,1333 x (torr)

Viscosity

Dynamic viscosity — Pa.s (pascal second)

Pa.s = 0,001 x (centipoise or cP)
= 0,1 x (poise or P)

Kinematic viscosity = m^2/s

m^2/s = 10^{-6} x (centistoke)

Bending and Twisting Rigidity

mN. mm^2 is used.

= 9,81 x (gf.mm^2)

Flexural Rigidity

It is recommended to use mN.mm

To get mN.mm from mgf.cm multiply by 0,098

Surface Tension

It is recommended to use mN/m

To get mN/m from dyne/cm x by 1

To get mN/m from erg/cm^2 x 1

Twist

Turns per metre (turns/m) have been recommended;

turns/m = 39,4 x tpi (where tpi is turns per inch)

Twist Factor or Twist Multiplier

The tex twist factor (turns/cm $\sqrt{\text{tex}}$) has been recommended although the twist factor (α dtex) based on decitex has also been suggested[1] since it is numerically equal to the metric twist factor $\alpha_m = \dfrac{\text{turns/m}}{\sqrt{\text{Nm}}}$, widely used in Europe.

We have;

tex twist factor (α_{tex}) $= 0{,}316 \times \alpha_m$
$= 11{,}70 \times$ Worsted twist factor
$= 9{,}57 \times$ English Cotton twist factor
$= 0{,}316 \times \alpha_{dtex}$

where

English Cotton twist factor $= \alpha_e = \text{tpi}/\sqrt{\text{Eng. Cotton Count}} = \dfrac{\text{tpi}}{\sqrt{\text{Ne}}}$

Worsted Twist factor $= \alpha_w = \text{tpi}/\sqrt{\text{Worsted Count}}$

$$\alpha_e = 1{,}22\,\alpha_w = 0{,}033\,\alpha_m$$

e.g. Convert a metric twist factor (α_m) of 110 to a tex twist factor (α_{tex})

From the above we have:

$\alpha_{tex} = 0{,}316 \times \alpha_m = 0{,}316 \times 110$
$= 34{,}76$

i.e. tex twist factor = 34,76.

Similarly an English cotton twist factor of 4 equals a tex twist factor of 38,3.

These calculations do not allow for fibre density variations and it has been suggested[2] that, to allow for such variations, the tex twist factor shall be defined as $\frac{\text{turns/cm}\ \sqrt{\text{tex}}}{\sqrt{\text{relative density}}}$ and the following table is presented.

TWIST FACTOR

	English Cotton Twist Factor (α_e)	Tex twist factor (α_{tex})
typical weft	3	23
typical warp	4,5	23
typical hard twist	10	77

Fabric Mass per Unit Area

Units of grams per square metre

(g/m^2) have been recommended:

$$g/m^2 = 33{,}9 \times (oz/yd^2)$$

The most important single calculation in textile design is regarded as the determination of fabric mass per unit area (i.e. weight)[3].

Convert from ozs/yd^2 to g/m^2 as follows:

$$g/m^2 = 33{,}91 \times oz/yd^2$$

$$oz/yd^2 = 0{,}0295 \times g/m^2.$$

Fabric mass per unit area (g/m^2) can be calculated as follows[3]:

Fabric mass/unit area (g/m^2) = $0{,}1\ [(\text{picks/cm}) \times (\text{tex}_2) + (\text{ends/cm}) \times (\text{tex}_1)]$ where tex_2 is the linear density of the weft yarn and tex_1 is the linear density of the warp yarn. This calculation, however, does not allow for warp and weft yarn crimp; more correctly it should read:

$g/m^2 = 0{,}1\ [(\text{picks/cm}) \times (\text{tex}_2) \times (\text{crimp}_2) + (\text{ends/cm}) \times (\text{tex}_1) \times \text{crimp}_1)]$ where crimp_2 is the weft crimp and crimp_1 is the warp crimp, both crimps being expressed as a fraction (plus one).

Breaking Load (Tensile Strength)

Either newton (N) millinewton (mN) or centinewton (cN) can be used although it appears that the first mentioned two are to be preferred. Nevertheless, for fibres and yarns cN is preferred since it is very close to the gf unit widely used in the past (1 cN = 1,02 gf, i.e. to convert gf to cN multiply by 0,98).

cN = 0,98 x (gf)
= 0,1 x (mN)
= 444,8 x (lbs-force)
= 100 x newtons
= 981 x (kgf)
= 27,8 x (oz)

Fluidity

It is recomended to use $m^2/(N.s)$ or $1/(Pa.s)$ or $Pa^{-1}s^{-1}$. To convert from rhe or reciprocal poise to $1/Pa.s$ or $m^2/(N.s)$ multiply by 10.

Density

It is recommended to use kg/m^3

To convert g/cm^3 to kg/m^3 multiply by 1000. The term specific gravity is being replaced by relative density.

Work of Rupture

Generally N.m should be used although N.cm is less clumsy.

To obtain N.cm from gf.cm multiply by 0,00981.

Initial Modulus

Either mN/tex/100% extension (written mN/tex)

or cN/tex/100% extension (written cN/tex)

To obtain mN/tex/100% extension from gf/den/100% extension, multiply by 88,3.

To obtain mN/tex/*100% from kgf/mm² multiply by 9,8/ρ*

where ρ is fibre density (g/cm³) or relative density

To obtain cN/tex/100% from mN/tex/100% multiply by 0,1

Woven Thread Count

Use number per centimetre.

To get picks/cm or ends/cm from picks/inch or ends/inch multiply by 0,394. Similary for courses and wales per centimetre and also for stitches per centimetre (sewing).

Cover Factor

Woven cover factor (k_c) is generally calculated as follows:

$$K_C = 0{,}1045\sqrt{tex}\,[\,W_p + W_f - 0{,}00373\sqrt{tex}\,(W_p + W_F)]$$

where W_p and W_f are the number of warp ends and picks per centimetre, respectively, and the yarn linear density (tex) is the same in both warp and weft (filling) directions.

It has been suggested[4] that a nominal cover factor for a woven structure be defined as:

$$4{,}0 \times 10^{-3} \text{ picks or ends/cm} \sqrt{\frac{\text{tex}}{\text{fibre density}}}$$

Then the fraction of area covered = $C_1 + C_2 - C_1C_2$

Where C_1 = warp cover and C_2 is weft cover calculated as above.

Bayes[2] gives the following:

$$\text{Tex cover factor} = \frac{\text{threads per centimetre} \times \sqrt{\text{tex}}}{\sqrt{\text{specific gravity of the fibre substance}}}$$

In the table below three figures of openness of weave are given:

COVER FACTOR

	Peirce's paper (with cotton counts)	Tex cover factor
Open scrim	4	31
Fairly close plain weave	15	117
Maximum cover	28	217

Fibre Linear Density and Fibres in Yarn Cross-Section

Fibre linear density (in tex) can be calculated as follows:

linear density (tex) $= 0{,}0007854 \times d^2 \times (1 + 0{,}0001\ V_d^2)\ \rho$

where d is the fibre diameter in micrometre (μm), ρ is the fibre density in g/cm³ or the relative density (specific gravity) and V_d is the coefficient of variation of diameter in %.

For wool ($\rho = 1{,}31$) this reduces to

$$0{,}001029 \times d^2\ (1 + 0{,}0001\ V_d^2)$$

and if we assume $V_d = 24{,}5\%$ which is quite common then it reduces to:

Fibre linear density (tex) $= 0{,}00109d^2$

APPROXIMATE DECITEX (dtex) VALUES FOR GIVEN FIBRE DIAMETERS[5]

Fibre Diameter (μ m)	**Decitex**				
	Nylon 6.6	***Orlon***	***Terylene***	***Rayon***	***Wool***
14			2,2		
15			2,6		
16	2,1		2,9	2,3	
17	2,4	1,9	3,2	2,7	
18	2,8	2,0	3,6	3,0	
19	3,1	2,1	3,9	3,3	4,0
20	3,6	2,3	4,3	3,7	4,4
21	3,9	2,6	4,8	4,1	4,9
22	4,3	2,8	5,2	4,4	5,3
23	4,7	2,9	5,7	4,8	5,9
24	5,1	3,1	6,2	5,1	6,3
25	5,6	3,3	6,8	5,6	6,9
26	6,1	3,7	7,3	6,0	7,3
27	6,6	3,9	7,9	6,4	7,9
28	7,0	4,2	8,4	6,9	8,4
29	7,4	4,6	9,1	7,3	9,0
30	8,0	5,0	9,8	7,7	9,6
32	9,1	5,8	11,1	8,6	10,8
34	10,4	6,9		9,6	12,0
36	11,6			10,6	13,3

If fibre obliquity (i.e. the effects of twist) is ignored then the average number of fibres (n) in the yarn cross-section can be calculated as follows:

$$n = \frac{\text{yarn tex}}{0{,}0007854 \text{ x } d^2 \text{ x } \rho \text{ x } (1 + 0{,}0001 \, V_d^2)}$$

which for wool becomes (i.e. $\rho = 1{,}31$)

$$n = \frac{972 \text{ x yarn tex}}{d^2 \, (1 + 0{,}0001 \, V_d^2)}$$

and if a CV of fibre diameter (V_d) of 24,5% is assumed, we have for *wool*:

$$n = \frac{917 \text{ yarn tex}}{d^2}$$

For cotton $n = \dfrac{590600}{CH}$

where C is the English cotton count (Ne) and H is the fibre linear density in mtex (i.e. mg/km).

Ideal Irregularity

According to Martindale[6] we have for the ideal or limiting yarn irregularity (CV_I in %):

$$CV_I = 100 \sqrt{\frac{1 + 0{,}0004\, V_d^2}{n}} = \frac{C}{\sqrt{n}}$$

where the symbols have the same meaning as in the previous section. For wool with a CV of fibre diameter of 24% this reduces to:

$$CV_I = \frac{111}{\sqrt{n}} = 111\, n^{-0,5}$$

often 112 is used instead for wool[7] while for cotton we have[8]:

$$CV_I = \frac{106}{\sqrt{n}} = 106\, n^{-0,5}$$

and for uniform (homogeneous) synthetics[7]:

$$CV_I = \frac{100}{\sqrt{n}} = 100\, n^{-0,5}$$

perhaps $102\, n^{-0,5}$ if a CV of fibre diameter of 10%[8] is assumed.

The following values of C have been compiled by Wegener[9] from the work of various authors:

Fibre	C
Cotton	106
	104,4
Wool	107,85 to 114,13
	Average 112
	Average 110
	107 to 117

Merino and Crossbred	107,7 to 114,6 Average 111
Carpet yarn wools	134
Wool (Uster Calculator)	111,4
Flax (linen)	130
Flax and Hemp (not after wet spinning)	106 to 108
Hemp/Jute	114
Viscose	102
Synthetics	100 to 103

Dyson[10] recommended the following approach to ideal irregularity (CV_I) to allow for variations in fibre extent within the yarn:

Consider now a model strand similar to Martindale's simplest model but one in which the fibres all have the same linear density and the same extent, *k*, defined as the ratio of the axial length occupied by the fibre in the strand to the straightened fibre length. This means that the effective fibre linear density in the strand is 1/k times the actual linear density, and hence: $CV_I = \frac{100}{\sqrt{n}}$ becomes

$$CV_I = \frac{100}{\sqrt{nk}}$$

By considering a more realistic model in which the variability of both fibre fineness and fibre extent is introduced and hence the concomitant additional variablity in effective fibre linear density, where these two sources of variation are independent, Dyson concluded that by using $k = 0{,}95$ (from Hearle) for carded cotton yarn the ideal irregularity could be expressed

$$CV_I \text{ (ring)} = \frac{109}{\sqrt{n}}$$

where *n* is the average number of fibres per cross-section, calculated as the ratio of fibre linear density to yarn linear density.

The mean fibre extent in open-end-spun yarns produced on a commercial machine is of the order of 0,8 and thus the ideal irregularity in this case is:

$$CV_I\ (OE) = \frac{119}{\sqrt{n}}$$

An example of the use of these two expressions is in the comparison of ring- and open-end-spun yarns, particularly if the Index of Irregularity, I, is calculated for each yarn by means of the above expressions.

Consider a typical pair of such yarns, for each of which n = 200 and the coefficients of variation of linear density are:

CV (ring) = 15% ; CV (OE) = 11%

then using $CV_I = 106/\sqrt{n}$ gives values of I of 2,00 and 1,47, respectively. By comparison the use of $109/\sqrt{n}$ and $119/\sqrt{n}$ gives values of I of 1,94 and 1,34, which indicates that the open-end-spun yarn is an even closer approach to the idealized, random, fibre array than it is if it is assessed in the former manner[10].

GENERAL CONVERSIONS

(Units or abbreviations given in parenthesis)

To convert from	to	multiply by
denier	tex (tex)	0,111
denier	decitex (dtex)	1,11
denier	millitex (mtex)	11,1
grams force (g or gf)	centinewton (cN)	0,98
grams force (g or gf)	millinewton (mN)	9,8
grams per denier (g/denier)	centinewton/tex (cN/tex)	8,83
grams per tex (g/tex or gf/tex)	centinewton/tex (cN/tex)	0,98
grams per denier (g/denier)	millinewton/tex (mN/tex)	88,3
grams per tex (g/tex or gf/tex)	millinewton/tex (mN/tex)	9,8
RKM	centinewton/tex (cN/tex)	0,98
RKM	millinewton/tex (mN/tex)	9,8
pounds force (lbs-force)	newton (N)	4,448
kilograms-force (kg or kgf)	newton (N)	9,8
ounces (oz)	grams (g)	28,35
pounds (lbs)	kilograms (kg)	0,4536
UK gallons	litres (ℓ)	4,546
litres	cubic metres (m^3)	0,001

grams per cubic centimetre (g/cm^3)	kilograms/metre cubed (kg/m^3)	1 000
pounds per cubic inch (lbs/in^3)	kilograms/metre cubed (kg/m^3)	27 680
pounds per cubic foot (lbs/ft^3)	kilograms/metre cubed (kg/m^3)	16,02
dynes per square centimetre (dynes/cm^2)	pascal (Pa or N/m^2)	0,10
pounds per square foot (lbs/ft^2)	pascal (Pa or N/m^2)	47,88
pounds per square inch (lbs/in^2)	pascal (Pa or N/m^2)	6 895
kilograms force per square centimetre (kgf/cm^2)	pascal (Pa or N/m^2)	98 070
kilograms force per square millimetre (kgf/mm^2)	pascal (Pa or N/m^2)	9,807 x 10^6
h bar	pascal (Pa or N/m^2)	1 x 10^7
bar	pascal (Pa)	1 x 10^5
millibar (mbar)	pascal (Pa)	100
millimetre of mercury (mmHg)	pascal (Pa)	133,3
inches of water pressure (in H_2O)	pascal (Pa)	249,1
inches of mercury pressure (in Hg)	pascal (Pa)	3386
newtons per square metre (N/m^2)	pascal (Pa)	They are equivalent
Kilonewtons per square metre (kN/m^2)	pascal (Pa)	1000
kilopascal (kPa)	pascal (Pa)	1 000
Atmosphere$_o$(atm)	pascal (Pa)	1,013 x 10^5
Angstrôm (Å)	nanometre (nm)	0,1
centipoise	millipascal second (mPa.s)	1
Centistokes	Square millimetre per second (mm^2/s)	1
Clo	K m^2/W	0,200
grain	gram (g)	0,0648
Calorie (Cal)	joule (J)	4,19
kilocalorie referred to often as Calorie in practice (e.g. in calculating energy values of food and drink).	joule (J)	4187
British Thermal Unit (Btu)	joule (J)	1055,1
horsepower (HP)	watt (W)	746

kilowatt-hour (kWh)	megajoules (MJ)	3,6
micro-inch	nanometre (nm)	25,4
micron (µm)	micrometre (µm)	1
millitorr	millipascal (mPa)	133,3
viscosity (poise)	pascal second (Pa.s)	0,1
Fluidity (rhe or reciprocal poise)	$(\text{pa.s})^{-1}$ or $m^2N^{-1}s^{-1}$	10
ounces per square yard (oz/yd^2)	g/m^2	33,91
stokes	mm^2/s	100
tablespoon	millilitre (mℓ)	≈ 14,5
teaspoon	millilitre (mℓ)	≈ 5
thou	micrometre (µm)	25,4
torr	pascal (Pa)	133,3
watt-hour	kilojoules (kJ)	3,6
Twist (turns per inch)	turns/metre (turns/m)	39,4

Twist Factors

(English cotton or α_e)	tex twist factor (turns/cm x $\sqrt{\text{tex}}$	9,57
(metric or α_m)	tex twist factor (turns/cm x $\sqrt{\text{tex}}$	0,316
(worsted or α_{worsted})	tex twist factor (turns/cm x $\sqrt{\text{tex}}$	11,70
(Tex twist factor α_{tex})	decitex twist factor (α_{dtex})	3,16
ends per inch (e/inch)	ends per centimetre (ends/cm)	0,394
picks per inch (picks/inch)	picks per centimetre (picks/cm)	0,394
dynes/cm	newtons per metre (N/m)	1×10^{-3}

$$\text{tex (in mg/m)} = \frac{886}{\text{worsted count}}$$

$$\text{tex (in mg/m)} = \frac{590{,}6}{\text{English Cotton Count}} = \frac{590{,}6}{Ne}$$

$$\text{tex (mg/m)} = \frac{1000}{\text{Metric Count}} = \frac{1000}{Nm}$$

Metric Count = Nm
English Cotton Count = Ne

The following tables have been given for shoe and hosiery sizes[11]:

SHOE-SIZE/HOSIERY-SIZE CHART

Shoe Size Children	Boys & Men	Ladies	Hosiery size	Wearer's Foot Length (inch)
Baby			3	2 1/4-2 3/4
00			3½	3 3/4-3 1/4
0-1			4	3 1/4-3 3/4
1½ - 2½			4½	3 3/4-4 1/4
3-4			5	4 1/4-4 3/4
4½-5½			5½	4 3/4-5 1/4
6-7			6	5 1/4-5 3/4
7½-8½			6½	5 3/4-6 1/4
9-10			7	6 1/4-6 3/4
10½-11½			7½	6 3/4-7 1/4
12-13	1		8	7 1/4-7 3/4
13½-1½	1½-2½	2½-3½	8½	7 3/4-8 1/4
2-3	3-4	4-5	9	8 1/4-8 3/4
	4¼-5½	5½-6½	9½	8 3/4-9 1/4
	6-6½	6½-7½	10	9 1/4-9 5/8
	7-8	8-9	10½	9 5/8-10
	8½-9	9½-10½	11	10 - 10 3/8
	9½-10	10½-11½	11½	10 3/8-10 3/4
	10½-11	11½-12	12	10 3/4-11 1/8
	11½-12½		13	11 1/8-11 5/8
	13-14		14	11 5/8-12 1/8

Sock Size	Foot Length	Shoe Size
Small (6-7)	14-17	6-10
Medium (7½-8½)	17-21	10½-3½
Large (9-11)	21-26	4-10½

CONVERTING SOCK SIZE TO FOOT LENGTH IN CENTIMETRES

Sock Size	Foot Size	Sock Size	Foot Size
3	6	$3^1/_2$	8
4	9	$4^1/_2$	10
5	11	$5^1/_2$	13
6	14	$6^1/_2$	15
7	17	$7^1/_2$	18
8	19	$8^1/_2$	20
9	22	$9^1/_2$	23
10	24	$10^1/_2$	25
11	26	$11^1/_2$	27
12	28	13	29
14	30		

Skein Strength (CSP)

Grover and Hamby[12] give the following equation showing the dependence of the skein strength on staple length for cotton yarns processed on the long draft system:

$$S = \frac{91{,}5\ (L) - 18{,}3\ C - 70{,}3}{C}$$

where S is the predicted skein strength in lbs, L is the staple length in 32nds of an inch, C is the yarn count (English cotton).

The value of 18,3 appearing in the formula represents the count-strength correction. It has been suggested that the CSP results of carded yarns be corrected as follows:

$$C_2S_2 = C_1S_1 - (C_2 - C_1)\ 18{,}4$$

where C_2 is the nominal yarn count (English cotton)

S_2 is the required skein strength (lbs) at this count

C_1 is the actual measured count, and

S_1 is the actual measured skein strength.

Initially 21,7 was used as the constant instead of 18,3 and 17,64 has even been suggested[12].

ISO has recommended[13] the use of skein breaking strength (SBT) as a measure of yarn strength. The breaking strength of a 50 metre skein (50 wraps) is determined and the SBT calculated as follows:

$$\text{SBT} = \frac{\text{Breaking Load (in gf)}}{100 \text{ x yarn tex}}$$

Skeins of 100 metres (100 wraps) appear preferable[13].

Yarn Strength Index (YSI) has been defined as breaking strength (in gf) of a 100-metre skein (100 wraps) divided by the yarn linear density (in tex).

Values so derived are numerically very similar to the corresponding CSP values.

If yarn linear density does not differ by more than 10% from the nominal a correction can be applied to skein breaking strength as follows[14].

$$S_2 = (T_2/T_1)\, S_1 \text{ or } S_2 = (C_1/C_2)\, S_1$$

where

S_1 = observed breaking load

S_2 = adjusted breaking load

T_1 = observed yarn count in a direct system

T_2 = specified yarn count in a direct system

C_1 = observed yarn count in an indirect system, and

C_2 = specified yarn count in an indirect system.

More general equations (correction) applicable to cotton and valid over a wide range of yarn counts are:

$$S_2 = (T_2/T_1)\, S_1 + K\, [(T_2/T_1) - 1]$$

or $$S_2 = (C_1/C_2)\, S_1 + K\, [(C_1/C_2) - 1]$$

where symbols are as before and K is a constant, usually 8 for load expressed in kgf and 18 for load expressed in lbs[14].

There are several variables such as twist, yarn linear density and evenness which influence the relationship between single thread and skein strength results[12].

Normally for singles yarn, if the single thread strength is multiplied by a factor which ranges from 0,56 to 0,81 the skein strength (per thread) is obtained while for two-ply yarns the range is 0,72 to 0,91. It has also been suggested that:

$$S_2 = \frac{C_1 S_1 - (C_2 - C_1) K}{C_2}$$

where $K = 0{,}7\ (74 - C_2)$

Skein strength is generally expressed in pounds and from this the Count-Strength-Product (CSP) or break factor can be calculated.

The following equations can be used as a general guide for relating single thread strength to skein strength[12].

Carded Yarns: $S_S = -6 + 119{,}5 S_{se}$

Combed Yarns: $S_S = -6 + 132{,}1\ S_{se}$

where S_S = skein strength in lbs and S_{se} is the single thread strength also in pounds.

It has also been stated that[12]:

$S_S = (100 \text{ to } 125)\ S_{se}$ for single yarns, and

$S_S = (120 \text{ to } 140)\ S_{se}$ for two-ply yarns

To convert CSP to gf/tex divide by 208,3 and for CSP to cN/tex divide by 212,6.

Elasticity

Elasticity is the tendency of a material in a deformed state, as a result of stress, to return to its original shape (or size) on removal of stress. Often elasticity is taken to be the load (or strain) at which it will just return to its original size when that load is removed. A measure of toughness is simply the breaking strength of a material multiplied by the extension at break, divided by 200. This is a rough approximation of the area underneath the stress-strain curve and is based on the assumption that the stress-strain curve is a straight line.

Elastic limit is normally taken to be the yield point and can be expressed as follows:

$$\text{Yield stress (cN/tex)} = \frac{\text{Load at yield point (in cN)}}{\text{tex}}$$

$$\text{Yield strain (\%)} = \frac{\text{elongation at yield point}}{\text{original length}} \times 100$$

Resilience is defined as the ability of the fibre to absorb work without permanent deformation and can be taken as the area under the stress-strain curve up to the elastic limit (i.e. up to the yield point).

Modulus of resilience = load at yield point (in cN) x elongation at yield point/200 x tex.

where elongation at yield point is in %.

TYPICAL RING SPINNING TWIST FACTORS

The roving twist factors to be used in the various counts for getting satisfactory performance at ring frame are given below[15]. The twist factors indicated are adequate to obtain satisfactory unwinding at the ring frame without resulting in stretch or breaks in the creel. Higher twist factors are many times used in the mills to reduce the breakage rates at the speed frame. Experience indicates that it is preferable to control the speed frame breakages by reducing the flyer speed than by increase of twist, speed frame efficiencies and production can be maintained at a satisfactory level by such action. Use of false twist masters in the fly frame will also help to maintain the twist in the roving at a lower level.

Thus, the spinning technician should try to use closer apron spacing at the ring frame especially in short staple cottons and, if necessary, reduce the roving twist if spinning performance gets adversely affected.

OPTIMUM TWIST FACTORS FOR ROVING[15]

Mixing	tex	Hank of roving Ne	Twist factor of roving	
			English Cotton	tex
Coarse	590 to 740	0,8 to 1,0	1,55	14,8
Medium	370 to 492	1,2 to 1,6	1,45	13,9
	246 to 295	2,0 to 2,4	1,50	14,4
Fine	236 to 295	2,0 to 2,5	1,25	12,0
	118 to 148	4,0 to 5,0	1,30	12,4
Superfine	169 to 197	3,0 to 3,5	1,10	10,5
	84 to 98	6,0 to 7,0	1,15	11,0

Most cotton knitting yarns have tex twist factors which lie within the range 26,8 to 30,6 (2,8 to 3,2 English cotton count) although slightly higher twist factors may be required for warp knits and certain double knits[16]. The following tables give some average values for the twist factors employed for various types of yarns[17].

	Fine Spun Yarns	α_m	α_e	α_{tex}
Cotton	Roving	20-40	0,7 - 1,3	6-13
	Fine yarns	75-165	1,5 - 5,4	23-52
	Coarse yarns	60-110	2,0-3,6	19-35
Wool	Worsted yarns	40-90	1,3-2,9	13-29
	Woollen spun	50-100	1,7-3,3	16-32
	Carpet yarns	55-90	1,8-3,0	17-29

The following twist factors have been suggested for various end-uses[18]:

TWIST FACTORS OF DIFFERENT YARNS[18]

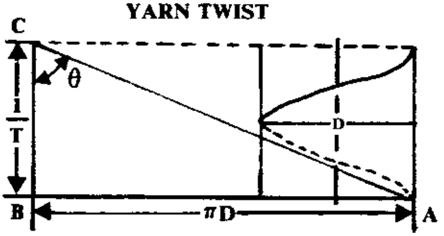
	Warp Yarn			Weft Yarn			Knitting (hosiery yarn)		
	a_{dtex} +	α_e	α_t	a_{dtex} +	α_e	α_t	a_{dtex} +	α_e	α
Cotton									
Short	120-150	4-5	38-48	100-115	3,2-3,8	31,7-36,5			
Medium	115-135	3,8-4,5	36,5-43	90-105	3,0-3,5	28,6-33,5	75-90	2,5-3,0	24,0-28,6
Long	100-115	3,4-3,8	31,7-36,5	75-90	2,5-3,0	24,0-28,6	65-80	2,2-2,6	20,5-25,5
Staple									
Medium	90-115	3,0-3,8	28,6-36,5	75-90	2,5-3,0	24,0-28,6			
Long	65-100	2,2-3,3	20,5-31,7	60-75	2,0-2,5	19,0-24,0			

+ $a_{dtex} = a_m$ α_e = English Cotton Twist factor $= \dfrac{\text{tpi}}{\sqrt{\text{Cotton Count}}}$

α_t = Tex Twist factor = (turns/cm) $\sqrt{\text{tex}}$

α_m = Metric twist factor $= \dfrac{\text{turns/m}}{\sqrt{\text{Metric Count}}}$

YARN TWIST



$$\pi D = \frac{1}{T} \tan\ \theta \qquad T = \frac{\tan\theta}{\pi D} \qquad D = \frac{\tan\theta}{\pi T}$$

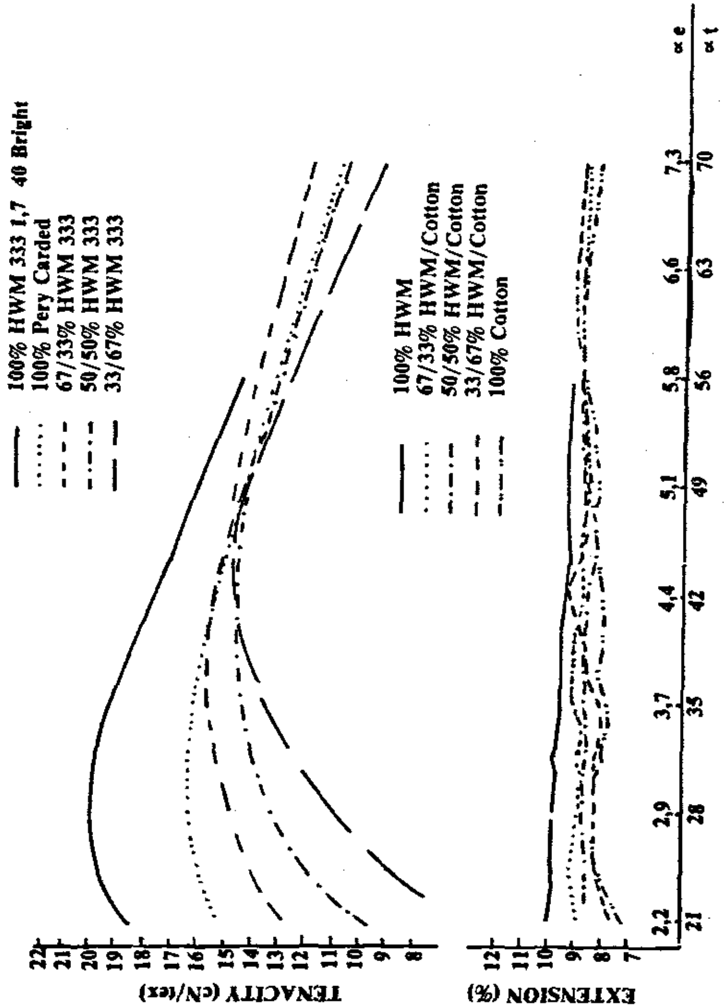
θ = helix angle[19] where T is the number of turns per unit length and D is the yarn diameter.

Some typical twist factors given in another article are also given below for several spun yarns[19]:

Yarn	Metric or α_{dtex}	Twist factor	
		Tex units (α_t)	**English cotton units (α_e)**
Cotton:			
low twist warp	114	35,9	3,75
ordinary warp	121	38,3	4,00
low twist weft	98,4	31,1	3,25
ordinary weft	106	33,5	3,50
hard twist yarn	136	43,1	4,50
ultra hard twist yarn	144	45,6	4,75
high grade knitting yarn	$<$60,4	less than 19,1	less than 2
ordinary knitting yarn	83-98	26,3-31,1	2,75-3,25
Worsted:			**Worsted units**
grey single yarn	88	28	2,4
grey two ply yarns	85	27	2,3
dyed single yarn	86	27,2	2,3
dyed two ply yarns	82	25,9	2,2
single grandrelle yarn	88	27,8	2,4
two ply grandrelle yarns	121	38,2	3,3
single knitting yarn	60	19,0	1,6
two ply knitting yarns	29	9,2	0,8
hand knitting yarn	33	10,4	0,89
Woollen:			**Worsted units**
ordinary woven yarn	90-130	28-41	2,4-3,5
hard twist woven yarns	145-170	46-54	3,9-4,6
knitting yarn	80-90	25-28	2,1-2,4

In filament yarns Twist Factor (k) = (turns/m)$\sqrt{\text{Denier}}$.

The following figure relates yarn twist factor to yarn tenacity and extension for viscose (high wet-modulus (HWM 333) and cotton and their blends[20]. The viscose has a linear density of 1,7 dtex and a 40 mm staple length. The cotton is a Peru carded cotton and the values are based on a 20 tex yarn.



For acrylic weaving yarns the following twist factors have proved successful.

Smooth worsted yarns: α_t = 31,6 (100 metric) for spinning
α_t = 41 to 47 (130 to 150 metric) for plying
Smooth woolen yarns: α_t = 35 (110 metric) for spinning
α_t = 47 (150 metric) for plying

The American Cotton Handbook[21] gives the following twist factors for cotton:

	α_e	$\alpha_{dtex} = \alpha_m$	α_t
Hosiery	2,75-3,25	83-98	26,3-31,1
Filling (Weft)	3,25-4,00	98-121	31,1-38,3
Warp	4,00-5,00	121-151	38,3-47,9

Short cottons would, however, require higher twist factors than the above[21].

For Indian hosiery yarns the twist factors normally fall within the following ranges:

	α_e	α_{dtex} α_m	α_t
Carded Yarn	3,5-4,0	106-121	33,5-38,3
Combed Yarn	2,8-3,5	85-106	26,8-33,5

Some setting conditions for stabilising twist are given below[19].

TWIST SETTING CONDITIONS OF VACUUM SETTING MACHINE						
Yarn	**Tetoron**	**Tetoron**	**Tetoron**	**Tetoron**	**Tetoron**	**Tetoron**
dtex	33	33	56	56	56	83
turns/m	1 000	300	1 000	800	300	800
Temperature (°C)	110-120	70-80	100-110	90-100	70-80	80-90
Time (min)	30	30	30	30	30	30
Yarn	**Tetoron**	**Tetoron**	**Pylen**	**Pylen**	**Pylen**	**Pylen**
dtex	83	111	56	56	83	83
Turns/m	300	300	300	1 000	300	1 000
Temperature (°C)	70	70	90	100	90	100
Time (min)	30	30	40	40	40	40

Steaming method:

By using the steam from a boiler, for example:

Silk : 90° C,20 min
Rayon : 100° C,20 min
Acetate : 75° C,20 min
Polyester : 120° C,20 min
Nylon : 110° C,20 min

RING SPINNING LIMITS

A comparison of spinning speeds of various staple-fibre spinning systems is made in the table below[22]:

TWISTED			
Continuous	**Speed***	**Break**	**Speed***
Ring	15	Roller vortex	503
Living ring	18-46	Turbine	46
Pavena Pavil	15	Electrostatic	61
* Equivalent twist insertion speed in metres per minute			
TWISTLESS			
Dry (false twist)	**Speed***	**Wet (zero twist)**	**Speed***
Fasciated	396	Integrated composite	305
Aerodynamic brake	99	Pavena Paset	305
Self-twist	99-183	TNO	152-305
* Equivalent twist insertion speed in metres per minute			

According to studies by Rieter AG, Winterthur, Switzerland, the following average yarn breakage rates occur in spinning[23]:

Spinning	
wool	80 end breaks/1 000 spindle hours (± 50%)
wool/polyester	60 end breaks/1 000 spindle hours (± 50%)

Heap[12] states that, for cotton rotor (OE) yarns the spinning limit lies between about 80 and 120 fibres in the cross-section whereas for ring yarns it is about 50 fibres. Generally yarns finer than about 12,5 tex are spun on the combed cotton system.

For cotton an end breakage rate of 40 per 1 000 spindle hours is often taken as an average for ring spinning and 60 per 1 000 rotor hours for rotor (OE) spinning. Cotton yarns are classified as follows:

Class	English Cotton Counts of	tex
Thick	1 to 10	60 to 600
Coarse	11 to 22	27 to 54
Medium	23 to 46	13 to 26
Medium/Fine	47 to 80	7 to 13
Fine	81 and over	7 and below

The highest count at which a yarn would be expected to give a lea (skein) count strength product (CSP) of 2 000 (carded) or 2258 (combed) has been defined as the *highest standard* count.

The following table gives some ranges of highest standard count for various cottons[25].

Cotton	Highest Standard Counts (English Cotton)	Equivalent tex
Sea Island St Vincent V.135	148-176 combed	3,3-4
Egyptian Sudan GS	108-122 combed	4,8-5,5
Ashmouni	34-41 carded	17,4-14,4
American Upland type		
Uganda BP 52	59-65 carded	9,1-10
Tanzania CLA	56-62 cardedd	9,5-10,5
Tanzania MZA	37-47 carded	12,6-16
Nigeria NA 1	34-41 carded	14,4-17,4
USA 15/16 M	15-21 carded	28,1-39,4

The qualities of cotton fibre, based on upper limits of suitability of spinning to various linear densities are given in the table below[26]:

THE QUALITIES OF FIBRE BASED ON UPPER LIMITS OF SUITABILITY FOR SPINNING INTO VARIOUS YARNS

Type	Staple Length		Approximate Yarn Counts (Ne)	Tex
	(inch)	(mm)		
Pima	> 1,38	> 34,9	greater than 70's	< 8,4
Acala 1517	1,13 to 1,16	28,6-29,4	50-70's	8,4-11,8
SJ series	1,06 to 1,13	27-28,6	40-50's	11,8-14,8
Modal type	1 to 1,09	25,4-27,8	20-40's	14,8-29,5
Short staple	< 1	< 25,4	less than 30's	> 19,7

YARN NUMBERS AND STAPLE LENGTHS[27]

Staple		**Carded Yarn**			
(ins)	**(mm)**	**Warp**		**Filling (weft)**	
		English Cotton	**tex**	**English Cotton**	**tex**
0,5 to 0,63	12,7 to 15,9	Up to 10s	> 59	Up to 10s	> 59
0,63 to 0,75	15,9 to 19,1	10s to 14s	42 to 59	10s to 20s	30 to 59
0,75 to 0,88	19,1 to 22,2	14s to 20s	30 to 42	20s to 30s	20 to 30
0,88 to 1	22,2 to 25,4	20s to 30s	20 to 30	30s to 36s	16,4 to 20
1 to 1,13	25,4 to 28,6	30s to 36s	16,4 to 20	36s to 45s	13,1 to 16,4
1,13 to 1,25	28,6 to 31,8	36s to 50s	11,8 to 16,4	45s to 60s	9,8 to 13,1
1,25 to 1,38	31,8 to 34,9	50s to 70s	8,4 to 11,8	60s to 80s	7,4 to 9,8
		COMBED YARN			
1 to 1,13	25,4 to 28,6	Up to 30s	> 20	Up to 40s	> 15
1,13 to 1,25	28,6 to 31,8	30s to 60s	9,8 to 20	40s to 70s	8,4 to 15
1,25 to 1,38	31,8 to 34,9	60s to 70s	8,4 to 9,8	70s to 100s	5,9 to 8,4

Source: *Textile World Fact File,* Volume 105, No. 9M (Mid-September, 1955), p.23

The following limits have been given for the ring-spinning of cotton[18].

STAPLE LENGTH mm	**FIBRE FINENESS (dtex)**	**APPROXIMATE LIMITS (tex)**
18	4,55	42
20	4,17	34
22	3,85	28
24	3,33	23
26	2,94	17
28	2,63	13
30	2,38	10
32	2,17	7,6
34	2,00	6,4
36	1,82	5
38	1,67	4
40	1,25	2,8

The following classification for American Upland Cottons according to their spinning potential (limiting count) has been made[28]:

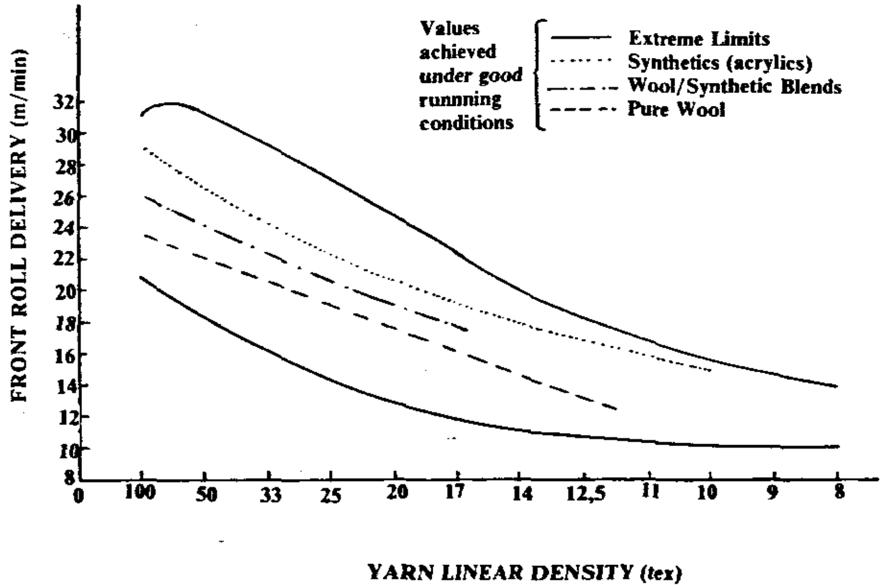
SPINNING POTENTIAL (LIMITING LINEAR DENSITY TEX)

Description	Short Staple	Medium Staple	Long Staple
Low	15,1-19,1	9,4-10,7	7,1-7,7
Average	12,3-14,8	8,2-9,2	6,6-7,0
High	10,4-12,1	7,3-8,1	6,1-6,5

The following table gives some spinning limits (ring-spinning on cotton system)[29]: Number of fibres in yarn cross-section given in parenthesis.

TYPE OF FIBRE				
Fibre Details dtex/mm	Viscose dtex/Nm	Nylon dtex/Nm	Acrylic Spinning limits dtex/Nm	Polyester dtex/Nm
1.4/40	91/110(65)	—	—	83/120(60)
1.7/40	110/90 (65)	100/100(59)	110/90(65)	100/100(59)
2,2/40	165/60 (76)	145/70 (65)	165/60(76)	145/70 (65)
3,3/40	250/40 (76)	210/48 (63)	250/40(76)	210/48 (63)
2,4/60	165/60 (69)	145/70 (60)	165/60(69)	145/70 (60)
3.3/60	250/40 (76)	200/50 (61)	210/48(63)	200/50 (61)

The optimum deliveries for various yarn linear densities (counts) and material are shown below. This diagram is based on data collected in spinning mills which have processed the most varied material on the Rieter worsted ring spinning frame model H6. The values of front roll deliveries, marked in three curves for spinning wool, wool/synthetic blends and pure synthetics therefore represent average values which are actually achieved in normal operation[30]:



On ring frames spinning limits for wool vary from about 36 to 50 fibres in the yarn cross-section depending upon the particular conditions[31].

Downes[32] states that, for wool worsted yarns, a number of spinning experiments have shown that an end breakage rate of 100 per 1 000 spindle hours is achieved at an acceptable spinning speed when there are an average 36 fibres in the yarn cross-section. In industrial practice when spinning near "limit counts" it is customary to operate with a safety margin, having about 45 fibres in the yarn cross-section on average[32].

Some calculations of "limit" values of tex for wools of different mean diameter, based on assumed values for N of 37 and 45 (fibres in cross-section), are given in the table below (assuming a typical CV of fibre diameter of 24,5%)[32].

The "limit" tex values thus calculated for the fine (19 μm) wool correspond well with the fine yarn counts actually produced in commercial quantities [e.g. 4,2% of Japanese weaving and knitting yarn production in 1973 was 13,9 tex (72 metric count)]. Counts of 11,10 and even 9 tex are spun in the Huddersfield fine suiting trade, using wools finer than 19 μm although the 1973 production statistics for Europe and North America do not include any count finer than 17,9 tex[32].

TEX VALUE

Average Fibre Diameter (μm)	19	21	23	25
N = 37	14,6	17,8	21,3	25,2
N = 45	17,7	21,6	26,0	30,7

Note: for wool the average number of fibres in the yarn cross-section (N) can be calculated as follows: $N = \frac{972T}{d^2 (1 + 0{,}0001V^2)}$

where T is the yarn linear density (tex)
d is the mean fibre diameter (μm)
and V is the CV of fibre diameter (%)
If a typical CV of 24,5% is assumed the formula reduces to:

$$N = \frac{917T}{d^2}$$

For wool the following spinning limits have also been given[18]:

Class	**Fibre Diameter (μm)**	**Crimp/cm**	**Limiting tex**
AAA	17-18	11-13	10
AA	18-20	9-10	12,5
A	20-23	7-9	17
B	23-26	6-7	20
C	26-31	5-6	25
D	31-37	4-5	42
E	37-40	4-5	50

YARN BREAKAGES DURING WEAVING

According to studies by Rieter, the following average yarn breakage rates occur in weaving[23]:

wool — warp 20 end breaks/100 000 picks (± 50%)
— weft 16 weft breaks/100 000 picks (± 50%)

Wool/polyester

- — 8 end breaks/100 000 picks (± 50%)
- — 4 weft breaks/100 000 picks (± 50%)

Messrs Zellweger Uster Ltd give the following experience values for the frequency of short stops in cotton weaving[33]:

Type of Cloth	Warp Stops per 10^5 ends per 10^5 picks			Weft stops per 100 000 m of weft yarn	Mechanical stops per 100 000 picks
	Carded Staple	Combed staple and worsted	Filament		
Single Shuttle (plain)	200	150	20	2,0	0,5
Multi-shuttle (Coloured)	300	225	30	3,0	1,0

The following table compares warp breaks for rotor and ring yarns on various looms:

WARP BREAKS PER 10 000 PICKS[35]
PER 1 000 ENDS

Machine	Linear Density	Ring-yarn	Rotor-yarn
Sulzer	30 tex (Ne 20)	0,198	0,124
Kovo Air-jet	25 tex (Ne 24)	0,140	0,093
Automatic Loom	37 tex (Ne 16)	0,153	0,091
	50 x 2 tex (Ne 12/2)	0,365	0,232

Some comparative rates of production for different fabric manufacturing systems are given below[34]:

Production Process	Linear speed of production (metres/min)	Typical width (m)	Rate of area production (m^2/min)
Weaving	0,1	1,5	0,15
Weft knitting	1,0	2,0	2,0
Warp knitting	0,5	3,0	1,5
Lace	1,0	3,0	3,0
Non-woven	15	2,0	30,0
Textiles-from-film	35	0,9	31,5
Spun-bonding	75	0,9	67,5
Integrally-extruded net	60	1,2	72,0

GENERAL FIBRE PROPERTIES

The specific gravities (or relative densities) of the principal fibres arranged in order, are[2, 17]:

Fibre	Relative Density (specific gravity)
Polypropylene	0,90-0,92
Polyethylene	0,95-0,96
Rubber fibres	0,96
Polyamide (Rilsan)	1,05
Nylon 6 and 66	1,03-1,14
Nylon 66	1,17
Nylon 6	1,18
Acrylic	1,18-1,19 and 1,14-1,42
Silk (boiled-off)	1,25
Wool	1,31 and 1,32
Triacetate	1,32
Acetate	1,29-1,33
Silk (raw)	1,34
Modacrylic	1,34
Polyester	1,38
Polyvinyl chloride	1,4
Hemp and jute	1,48
Carbon fibre type 1	1,5

Fibre	Relation Density (Specific Gravity)
Linen	1,5
Rayon	1,50-1,53
Ramie	1,52
Cupprammonium filament	1,52
Cotton	1,53-1,54
Carbon fibre type 2	1,6
Vinylidene chloride co-polymer	1,7
Alginate	1,78
Glass fibre composite	1,9
Asbestos (chrysolite)	2,4-2,6
Glass filament	2,45-2,60
Triton ceramic	2,56
Aluminium L65	2,8
Titanium	4,5
Steel S97	7,8
Metal fibre (tinsel)	7,90

FINENESS RANGES AND FIBRE DIAMETERS OF VARIOUS TEXTILE FIBRES (ASTM D629)

U.S. WOOL CLASSIFICATION					
Wool Grades			Wool Top Grades		Pulled Wool
Numerical System	Average Diameter (μm)	Blood System	Numerical System	Average Diameter (μm)	Grades
80's	17,7 to 19,1	Fine	80's	18,1 to 19,5	AA
70's	19,2 to 20,5	Fine	70's	19,6 to 21,0	AA
64's	20,6 to 22,0	Fine	64's	21,1 to 22,5	AA
62's	22,1 to 23,4	1/2	62's	22,6 to 24,0	A
60's	23,5 to 24,9	1/2	60's	24,1 to 25,5	A
58's	25,0 to 26,4	3/8	58's	25,6 to 27,0	A
56's	26,5 to 27,8	3/8	56's	27,1 to 28,5	B
54's	27,9 to 29,3	1/4	54's	28,6 to 30,0	B
50's	29,4 to 30,9	1/4	50's	30,1 to 31,7	B
48's	31,0 to 32,6	1/4	48's	31,8 to 33,4	B
46's	32,7 to 34,3	Low 1/4	46's	33,5 to 35,1	C
44's	34,4 to 36,1	Common	44's	35,2 to 37,0	C
40's	36,2 to 38,0	Braid	40's	37,1 to 38,9	C
36's	38,1 to 40,2	Braid	36's	39,0 to 41,2	C

HAIR FIBRES AND SILK					
Mohair		Miscellaneous Hair Fibres		Silk	
Grade	Fineness Range (μm)	Fibre	Average Fineness (μm)	Fibre	Average Fineness (μm)
40's	23,55 to 25,54	Vicuna	13,0 to 14,0	Cultivated silk	10,0 to 13,0
36's	25,55 to 27,54	Cashmere	14,5 to 19,0	Tussah silk	28,5
32's	27,55 to 29,54	Camel hair	17,0 to 23,0		
30's	29,55 to 31,54	Alpaca	26,0 to 28,0		
28's	31,55 to 33,54	Llama	20,0 to 27,0		
26's	33,55 to 35,54				
22's	35,55 to 38,04				
18's	38,05 to 40,0				

Vegetable Fibre		Glass Fibre			
Fibre	Average Fineness (μm)	Filament Diameter Designation	Theoretical Diameter (μm)	Staple Fibre Diameter	Average Diameter (μm)
Cotton	16,0 to 21,0	D	5,3	E	7,1
Flax (linen)	15,0 to 17,0	E	7,4	G	9,7
Jute	15,0 to 20,0	G	9,0	J	11,4
Hemp	18,0 to 23,0				
Kapok	21,0 to 30,0				
Ramie	25,0 to 30,0				

Some crimp levels for various staple synthetic fibres[36]:

Polymer	**Fibre**	**Crimp (%)**	**Crimp/cm**
Polyester	B-type	10-18	8-11
	W-type	14-22	6-10
	Converter tow	7-15	5-9
Polyamide	B-type	9-13	10-16
	W-type	11-20	11-13
	T-type	20-30	6-12
Polyacrylonitrile	W-type	15-22	9-12
Polypropylene	T-type	15-25	7-10
Cellulose	W-type	17-25	9-11

Some tensile properties of common fibres[37]:

Fibre	**Tenacity (cN/tex)**	**Breaking length (km)**	**Breaking extension (%)**	**Work of rupture (cN/tex)**	**Modulus (cN/tex)**	**Elastic recovery at 5% strain (%)**
Cotton	32	32	9	1,1	260	43
Wool	14	14	43	4,6	220	63
Silk	33	33	16	3,7	1080	45
Normal viscose	18	18	19	2,5	880	42
High tenacity viscose	41	42	12	2,8	880	62
Acetate	11	11	35	2,8	310	72
Triacetate	11	12	30	1,8	310	45
Nylon 6.6	46	47	22	6,2	350	95
Polyester	45	46	22	7,5	880	90
Acrylic	25	25	38	6,2	400	60
Polyurethane elastomer	3,1	3,1	540	6,5	0,71	100
Polypropylene	65	67	17	7,1	710	90

The following tables of general fibre properties have been given in one article[38]:

TEXTILE TECHNOLOGICAL DATA OF DIFFERENT FIBRES

	Relative density	Strength (cN/tex)	Elongation %	Melting point °C	Swelling %	Light fastness	Weather resistance
Polyester	1,38	23-60	20-50	257	3-5	V. Good	Good
Nylon 6.6	1,14	32-63	15-70	255	10-12	Good	Satisfactory
Nylon 6	1,14	32-63	15-70	215	10-12	Good	Satisfactory
Acrylic	1,15-1,18	18-32	20-60		4,5-6	Excellent	Excellent
Wool	1,32	9-18	25-45	—	42	Fair	Fair
Cotton	1,50-1,54	27-40	6-10	—	45	Fair	Fair

USAGE PROPERTIES OF DIFFERENT FIBRES[38]

	Foam stability	Stability to setting	Easy care	Crease stability	Pilling resistance	Dyeability	Abrasion res.	Recovery
PES	***	***	***	***	*	*	**	*
PA	**	***	**	**	*	***	***	***
PAC	*	*	**	**	*	**	*	**
Wool	*	**	—	**	*	***	*	**
Cotton	*	— —	*	*	*	***	— —	[illegible]

*** Very good ** Good — Fair

* Satisfactory — — Poor

A general comparison of the properties of various textile materials[39].

	Animal Fibres in Wool	Vegetable Fibres e.g. Cotton	Proban Treated Cotton	Nomex	Asbestos	PVC	PBI	Kordolan
Safety Factors								
Flame resistance	1-2	5*	2	1-2	1	2	1	1-2
Heat resistance	1	1-2	1-2	3-4	1	3-4	3-4	2
Antistatic Properties	1	2	2	4	1	4	4	2
Performance								
Water repellency	1-2	4-5	3	3	5	3	4	4
Abrasion resist	2-3	2-3	4	1-2	3-4	2	2	2
Shrink resist	4*	2	1-2	1-2	4	1-2	1-2	1-2
Wash performance	4*	2	3	1-2	5	1-2	1-2	1-2
Drycleaning performance	1	1	1	3	5	4	3	3
UV Stability	1-2	2-3	2-3	5	1	2-3	?	?
Comfort								
Warmth	1	2	3	5	4	4	4	3
Moisture Absorption	1	2	2-3	5	4	4	5	3
Elasticity	1-2	3-4	4	3	5	3	4	3
Porosity	1-2	1-2	2	2	2	2	2	2
Permeability	1-2	1-2	2	2	2	2	2	2
Appearance								
Drape	1	3	4	4	5	3	4	2
Texture	1-2	1-2	2	3	4	2	4	2
Colour	1-2	2	2	4	5	3	5	2
Crease resist	4	4	4	2	5	2	2	2
Wrinkle recovery	2	4	4	4	5	4	4	3

- Performance can be improved by applying special treatments.

Ratings: 1 = Excellent 2 = Very Good 3 = Good 4 = Moderate 5 = Poor.

The following general comparison of fibres has also been made[40]:

	Cotton	Wool	Polyester	Nylon	Acrylic
Excellent	Absorbency Static Resistance Pilling Resistance Heat Resistance	Bulk and Loft Wrinkle Recovery Absorbency	Wrinkle Recovery Press (Wet) Retention Strength Abrasion Resistance Stability	Strength Abrasion Resistance Stability	Bulk and Loft Stability
Good	Strength Stability	Static Resistance Abrasion Resistance Heat Resistance		Wrinkle Recovery Press (Wet) Retention	Heat Resistance Wrinkle Recovery
Fair	Abrasion Resistance	Pilling Resistance Strength	Heat Resistance	Static Resistance Pilling Resistance Heat Resistance	Static Resistance Strength Abrasion Resistance
Unsatisfactory	Bulk and Loft Wrinkle Recovery Press (Wet) Retention	Press (Wet) Retention Stability	Bulk and Loft Absorbency Static Resistance Pilling Resistance	Bulk and Loft Absorbency	Absorbency

COMPARISON OF FIBRE QUALITIES RELATING TO APPEARANCE RETENTION FOR CARPETS[41]

Fibre	Resilience	Abrasion resistance	Colour fastness	Soilhiding	Easy-clean	Static	Flammability
Nylon	1	1	1	4	1	4	2
Acrylic	2	3	1	2	2	2	3
Polyester	2	3	1	3	2	2	2
Polypropylene	4	2	3	2	1	3	—
Rayon	4	4	4	4	4	2	4
Wool	3	3	1	2	3	3	1

Key: 1 = Excellent 2 = Very good 3 = Good 4 = Fair

The following tables gives a fair comparison of relative abrasion resistance of different types of fibres (car upholstery)[42]:

Fibre type	Relative Abrasion Resistance
Nylon	100
Polyester	60
Wool	20
Cotton	20
Acrylic	20
Viscose rayon	10
Acetate rayon	5

PHYSICAL AND MECHANICAL PROPERTIES OF THE MAIN TYPES OF TEXTILE FIBRES[43]

Type of the fibre	Relative Density	Tensile Strength (kgf/mm^2)	Tenacity (cN/tex)		Elongation (%)		Resistance to washing in relative units
			dry	wet	dry	wet	
Wool	1,28-1,33	15 to 25	8,3-13	7 to 12	25 to 40	30 to 60	430
Cotton	1,52	23 to 45	22,5 to 27	26 to 29	7 to 10	9 to 12	50
Flax	—	60 to 95	—	—	2 to 3	20 to 25	—
(Viscose) rayon	1,52	16 to 78	13 to 22	7 to 11	15 to 30	25 to 35	79
(Cellulose) acetate	1,32	16 to 60	10 to 13,2	7 to 9	17 to 30	28 to 35	50
(Cellulose) triacetate	1,28	—	10,3 to 11	6-7	25	28 to 30	—
Polyamide (nylon 6)	1,14	35 to 72	31 to 45	26 to 39	20 to 80	25 to 90	640
Polyester	1,38	50 to 80	31 to 39	30 to 39	20 to 60	20 to 60	290
Polyacrylonitrile	1,17	20 to 40	23,0 to 29	21 to 27	16 to 30	16 to 30	53
Polyvinyl chloride	1,50	18 to 40	18 to 25	18 to 25	20 to 40	20 to 40	34

TYPICAL FIBRE PROPERTIES[44]

	Polyester	Polyamide (nylon)	Polyacrylic	Viscose	Cotton	Wool
Relative density	1,36-1,38	1,14	1,14-1,18	1,52	1,50-1,54	1,32
Moisture absorption (%)	0,2-0,5	3,5-4,5	1,0-15	11-14	7-11	15-17
Water retention (%)	3-5	10-15	5-12	65-120	45-50	40-45
Melting temperature (°C)	250-256	6 255-260 6.6 215-220	—	—	—	—
Decomposition (°C)	—	510-530	250-360	175-205	400	
Tenacity (cN/tex)	N = 25-65 T = 70-95	40-90	20-45	N = 18-35 M = 35-75	25-50	10-20
Extension at break (%)	N = 15-40 T = 10-20	N = 30-80 T = 15-25	20-70	N = 15-30 M = 8-15	6-10	25-60
Acid resistance	good, attacked by conc. acids	Sufficient attacked by conc acids	good, dissolved in conc acids (exc. HCL)	poor	poor	good, attacked by conc. acids
Alkaline resistance	attacked by conc. lye	good attacked by 10% NaOH	good-fair attacked by conc lye	good degradated by 10% NaOH	good attacked by 10% NaOH	poor degradated by conc lye
Resistance to light	very good	poor	very good	poor	poor	poor
Static charges	average	average	average	low	low	low
Creasing (dry)	little	little	medium	pronounced	pronounced	little
Washability	good	good	average	good	good	average

COMPARISON OF PROPERTIES OF NASLON (STAINLESS STEEL) AND OTHER FIBRES[45]

Properties		Stainless Fibre	Glass Fibre	Cotton	Wool	Nylon	Polyester	Acrylic
Specific gravity (relative density)		7,9	2,5	1,54	1,32	1,14	1,38	1,17
Young's modulus	Kg/mm²	19 000	7 000	1 200	130-300	200-450	1 100-2 000	260-650
	cN/tex	3 020	3 514	971	124-274	177-397	795-1 413	221-514
	g/denier	342	398	110	14-31	20-45	90-160	25-65
Breaking Strength	Kg/mm²	150-250	140-350	31-77	14-20	47-64	78-93	21-42
	cN/tex	24-40	71-176	25-63	13-19	51-70	71-84	22-44
	g/denier	2,7-4,5	8,0-19,9	2,8-7,1	1,5-2,2	5,8-7,9	8,0-9,5	2,5-5,0
Knot Strength	Kg/mm²	106-140	15	30-54	8-13	35-49	37-43	17-34
	cN/tex	17-22	8	24-43	8-12	38-53	34-39	18-35
	g/denier	1,9-2,5	0,9	2,7-4,9	0,9-1,4	4,3-6,0	3,8-4,4	2,0-4,0
Elongation (%)		1,0-2,0	3,0	3-7	25-35	28-42	20-30	25-50
Elastic recovery (Percentage elongation)		100 (1%) 66 (1,5%)	100	74 (2%) 45 (5%)	99 (2%) 93 (20%)	98 100 (3%)	95 100 (3%)	97 (3%) 90 (5%)
Regain	20°C 65% RH	0	0	7,0	15,0	3,5-5,0	0,4-0,5	1,5
Heat resistant	Softening point (°)		735			180	240	190-240
	Melting point (°C)	1400-1450	—	—	—	215-220	255-260	-
	Others	Strength lessened by 10% at 425°C and by 90% at 1000°C	Strength lessened 50% at 340°C	Resolves at 150°C	Hardens at 100°C and resolves at 130°C	Starts burning gradually while melting	Starts burning gradually while melting	Resolves at 230°C
Thermal conductivity (Cal/cm.sec °C)		0,039	0,0026	—	—	0,00058	-	
Specific Heat (Cal/g °C)		0,12	0,10	—	—	0,44	--	
Electrical resistance (μ Ω-cm)		72	2 x 10^{17}	—	—	4,5 x 10[illegible]	7 x 10^{14}	-
Acid resistance		Stabilized in nitric and phosphoric acids, but corroded in sulphuric acid and hydrochloric acids	Dissolves in fluoric, concentrated hydrochloric concentrated sulphuric and hot phosphoric acids	Dissolves in hot rare and cool strong acids	Dissolves in hot sulphuric acid	Dissolves in strong acids	Strength not lessened in concentrated hydrochloric acid and solution of 70% sulphuric acid	Dissolves in strong acids
Alkali resistance		Not affected	Corroded	Expands	Corroded	Almost endures	Strength a little lessened by strong caustic alkali	Corroded in alkali of density medium or more

A COMPARISON OF SOME FIBRE PROPERTIES[46]

Fibre	Type	Relative Density	Regain at 65% RH and 21° C (%)	Tenacity (cN/tex)		Effect of Heat (° C)			
				Wet	Dry	Sticking	Softening	Melting	
	Acetate	1,32	6	7-10,6	10,6-13,2	177-191	204-229	260	Burns relatively slowly
	Triacetate	1,3	3,2	7-9	11-12	177-191 or > 240 (treated)	—	302	
	Acrylic	1,14-1,19	1,3-2,5	16-29	18-31	232-258	—	—	
	Aramid Filament Staple	1,38	5	34-42 18-26	40-51 26-35	—	—	—	Decomposes above 371° C
	Modacrylic	1,3-1,37	0,4-4	18-31	18-31	—	—	—	Will not support combustion. Shrinks at 121° C stiffens at > 149° C
	Novoloid (Kynol) (phenolic polymer)	1,25	5,5	12-20	13-22	—	—	—	Does not melt converts to carbon fibre which resists over 2760° C. Minimal shrinkage. Physical properties slowly degrade above 177° C
	Nylon 6 Filament Staple	1,14	4,5	44-71 18	53-84 22	—	—	212-220	
	Nylon 66 Reg. Tenacity Filament High Tenacity Filament Staple	1,14	4-4,5	23-48 44-71 28-57	27-53 53-84 31-64	229	—	260	
	Olefin Polypropylene	0,91	0	42-62	42-62	—	—	163-168	
	Polyester Reg. Tenacity Filament High Tenacity Filament Reg. Tenacity Staple High Tenacity Staple	1,22 or 1,38 depending upon type	0,4 or 0,8 depending upon type	35-44 55-83 22-44 44-56	35-44 56-84 22-44 44-57	—	—	249-288	
	Rayon Regular Tenacity Medium Tenacity High Tenacity High Wet Modulus	1,5-1,53	13	6-16 11-17 17-41 16-35	6-23 21-28 27-53 22-49	—	—	—	Does not melt Decomposes at 177 - 240° C Burns readily
	Saran (Vinylidene Chloride)	1,7	0	$\leqslant$ 13,2	$\leqslant$ 13,2		116-138		Self-extinguishing
	Spandex (segmented polyurethane)	1,2-1,21	0,75-1,3	5-8	5-8	—	—	230-270	Degrades slowly at temperatures above 149° C
	Vinyon (vinyl chloride)	1,33-1,35	Up to 0,5	6-9	6-9	66	77	127	Becomes tacky and shrinks at 66° C but will not support combustion

The following comparison of fibre properties has been given

Item	Unitika Ester T/507	Rayon	Cotton	Wool
Relative density	1,38	1,5-1,52	1,54	1,32
Moisture Regain (%)	0,4	11,0	8,5	15,0
Dry Tenacity (cN/tex)	57-62	22-37	26-43	9-18
Dry elongation (%)	25-30	16-24	6-10	20-40
Young's Modulus (kg/mm²)	500-600	400-1200	450-500	150-200
Young's Modulus (cN/tex)	355-426	286-779	286-318	110-146

TEXTILE TECHNOLOGICAL DATA OF DIFFERENT FIBRES[47]

	Relative Density	Strength (cN/tex)	Elongation (%)	Melting point (°C)	Swelling (%)	Light fastness	Weather Resistance
Polyester	1,38	23-60	20-50	257	3-5	V. good	Good
Nylon 6,6	1,14	32-63	15-70	255	10-12	Good	Satisfactory
Nylon 6	1,14	32-63	15-70	215	10-12	Good	Satisfactory
Acrylic	1,15-1,18	18-32	20-60	—	4,5-6	Excellent	
Wool	1,32	9,18	25-45	—	42	Fair	Fair
Cotton	1,50-1,54	27-40	6-10	—	45	Fair	Fair

TYPICAL PROPERTIES OF FIBRES[48]

	Natural			Man-made							
	Wool	**Cotton**	**Hemp**	**Asbestos**	**Nylon 6.6**	**TFE**	**Glass**	**Low Carbon steel**	**Carbon**	**Graphite**	**Boron**
Breaking tenacity, 20°C 65% RH (cN/tex)	4-18	26,5-53	53-62	118-26,5	35-80	14,1	35-44	4,5-13,2	62	26,5-247	26,5-26
Moisture absorption 20°C 65% RH (%)	10-15	6-10	6-10	none	4-5	none	none	none	2-14	none	none
Heat endurance (°C)	Chars at 265	Chars at 300	Flammable	1500	Yellows at 300	400	600	500	4 500	4 500	4 500
Typical size Length (mm) Width (μm)	 12-381 10-60	 9,5-63,5 12-25	 up to 2134 10-30	 3,2-76 0,02	 filament 10-40	 filament any	 filament 1-4	 filament any	 filament 8-10	 filament 6-9	 filament 6-10

$$\text{tenacity (gf/denier} = \frac{\text{psi}}{12\,800 \times \text{density}},$$

where density is in g/cm^3 or else relative density (specific gravity) can be used

$$\text{Tenacity (cN/tex)} = \frac{6{,}89 \times 10^{-4}\ \text{psi}}{\text{density}}.$$

For cotton cN/tex = 0,486 (psi in 1000's)

also Tenacity (cN/tex) = $9{,}8 \times 10^{-3} \times \rho^{-1} \times (\text{kgf/cm}^2)$

ρ = density (g/m^3)

cN/tex = 8,83 x gf/denier

The strength of Kevlar is $\simeq$ 191 cN/tex which is more than twice that of the strongest nylon[49].

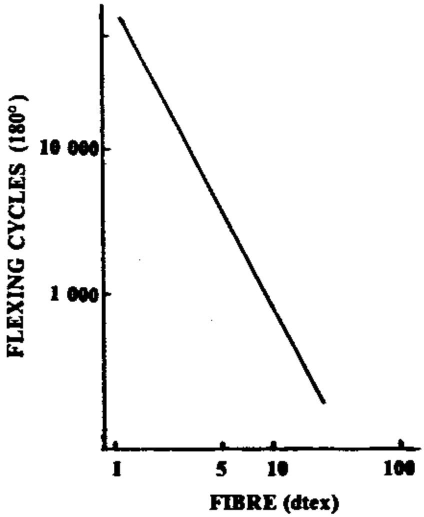
COMPARISON OF PHYSICAL AND MECHANICAL PROPERTIES OF PRINCIPAL FIBRES[43, 50]

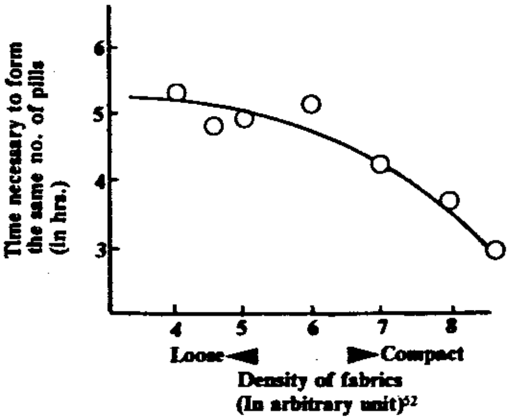
Fibre	Relative Density	Tensile Strength (kg/mm^2)	Tenacity (cN/tex)		Elongation %		Wet/Dry Strength (%)	Elastic Recovery	Bending Strength	Abrasion Strength	Softening Point (°C)	Melting Point (°C)	Effect of Acids	Effect of Alkalis	Weathering Resistance	Resistance to Washing (relative units)	Dyeability	Moisture regain at 20°C and 65% RH
			Dry	Wet	Dry	Wet												
Wool	1,26-1,33	9-25	8,3-13	7-12	6-10	30-60	76-94	Excellent	S	W	—	—	S	W	SW	430	Excellent	16
Cotton	1,52 1,54-1,55	22-45	22,5-27	26-29	25-55	9-12	102-110	Passable	S	FS	—	—	W	S	SW	50	Good	7
Flax	—	60-95	—	—	2-3	20-25	—	—	—	—	—	—	—	—	—	—	—	—
Silk	1,33-1,45	26-35	—	—	15-25	—	—	—	—	—	—	—	—	—	—	—	—	—
Vinylon	1,26-1,30	33,3-84	—	—	9-26	—	70-90	Good	S	S	220-239	—	FS	S	S	—	Good	3,0-5,0
Nylon 6	1,14	35-84	31-45	26-39	16-60	25-90	83-92	Excellent	S	S	—	215-220	FS	S	SW	640	Excellent	3,5-5,0
Polyvinilidene cyanide	1,70	8-23	—	—	18-33	—	100	Excellent	S	S	145-165	165-185	V. strong	S	S	—	Passable	0
Polyvinyl chloride	1,39 1,50	17,5-40	18-25	18-25	15-90	20-40	100	Fairly good	S	S	60-110	200-210	S	S	S	34	Fairly good	0
Polyester	1,38	38-80	31-39	30-39	7-60	20-60	100	Excellent	S	S	238-240	255-260	S	S	S	290	Fairly good	0,4-0,5
Acrylics	1,14-1,17	20-40	23-29	21-27	12-50	16-30	80-100	Excellent	FS	FS	190-240	—	Very S	S	S	53	Fairly good	1,2-2,0
Polyethylene	0,94-0,96	44-80	—	—	8-35	—	100	Excellent	S	S	110-115	125-135	S	S	SW	—	Passable	0
Polypropylene	0,91	22-80	—	—	15-60	—	100	Excellent	S	S	140-160	165-173	S	S	SW	—	Passable	0
Acetate (Cellulose)	1,32	10,5-60	10-13,2	7-9	17-35	28-35	60-67	Good	W	W	200-230	260	SW	SW	SW	50	Good	6,0-7,0
Triacetate (Cellulose)	1,28	—	10,3-11	6-7	25	28-30	—	—	—	—	—	—	—	—	—	—	—	—
Rayon	1,50-1,52	16-78	13-22	7-11	7-30	25-35	45-80	Passable	W	W	—	—	W	SW	SW	79	Excellent	12-14

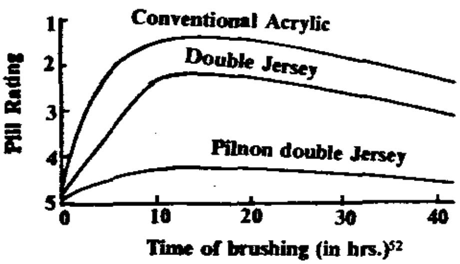
Key:
S — Strong
FS — Fairly Strong
W — Weak
SW — Somewhat weak

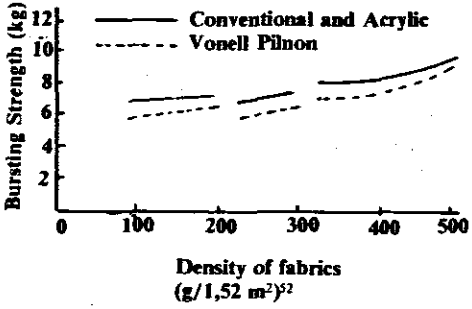
Fibre Flex Life

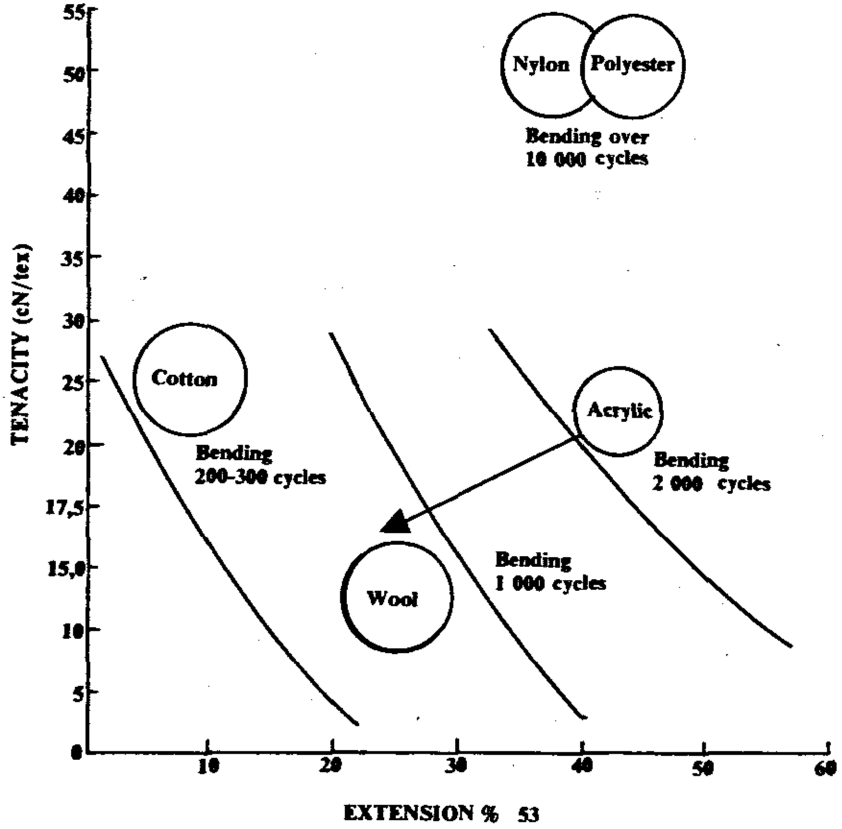
The resistance to flex abrasion of a fibre is important in determining its wear life and also its pilling propensity. This is illustrated in the figures below and illustrates how a pill resistant fibre is often engineered. The following graph relates flex life to fibre fineness (denier of dtex)[51].






Conventional Acrylic
Double Jersey
Pilnon double Jersey
Pill Rating
1
2
3
4
5
0
10
20
30
40
Time of brushing (in hrs.)52


Conventional and Acrylic
Vonell Pilnon
Bursting Strength (kg)
12
10
8
6
4
2
0
100
200
300
400
500
Density of fabrics
(g/1,52 m²)52


Nylon
Polyester
Bending over
10 000 cycles
Cotton
Bending
200-300 cycles
Acrylic
Bending
2 000 cycles
Wool
Bending
1 000 cycles
TENACITY (cN/tex)
55
50
45
40
35
30
25
20
17,5
15,0
10
5
0
10
20
30
40
50
60
EXTENSION % 53

Fibre Regain Values:

The following tables have been given for the regain of different fibres[54,55,56].

FIBRE REGAIN OF DIFFERENT FIBRES AT 24° C[54]

Material		Description	% Relative humidity								
			10	20	30	40	50	60	70	80	90
Natural fibres	Cotton	Roving	2,5	3,7	4,6	5,5	6,6	7,9	9,5	11,5	14,1
	Cotton	Woven fabric	2,6	3,7	4,4	5,2	5,9	6,8	8,1	10,0	14,3
	Cotton	Treated	4,8	9,0	12,5	15,7	18,5	20,8	22,8	24,3	25,8
	Wool	Merino-Wool (hank)	4,7	7,0	8,9	10,8	12,8	14,9	17,2	19,9	23,4
	Silk	Raw Silk (hank)	3,2	5,5	6,9	8,0	8,9	10,2	11,9	14,3	18,3
	Linen	Table Cloth	1,9	2,9	3,6	4,3	5,1	6,1	7,0	8,4	10,2
	Linen	Dry spun linen yarns	3,6	5,4	6,5	7,3	8,1	8,9	9,8	11,2	13,8
	Jute	Jute average quality	3,1	5,2	6,9	8,5	11,2	12,2	14,4	17,1	20,2
	Hemp	Canvas from Manila and Sisal-Hemp	2,7	4,7	6,0	7,2	8,5	9,9	11,6	13,6	15,7
Chemical fibres	Viscose Nitrocellulose	Average Hanks	4,0	5,7	6,8	7,9	9,2	10,8	12,4	14,2	16,0

REGAIN OF WOOL AT DIFFERENT TEMPERATURES AND RELATIVE HUMIDITIES[55]

RH	25° C	30° C	35° C	40° C	45° C	50° C	55° C	65° C	70° C	75° C
10,0	4,15	4,05	3,95	3,80	3,70	3,55	3,40	2,95	2,80	2,65
20,0	6,00	5,80	5,65	5,60	5,30	5,15	5,00	4,50	4,75	4,05
30,0	7,84	7,60	7,30	7,10	6,95	6,75	6,55	6,00	5,70	5,40
40,0	8,65	9,30	9,00	8,80	8,55	8,30	8,05	7,45	7,15	6,80
50,0	11,50	11,05	10,65	10,40	10,05	9,80	9,45	8,95	8,60	8,30
60,0	13,50	12,95	12,50	12,15	11,75	11,40	10,95	10,50	10,10	9,90
70,0	15,60	15,05	14,65	14,15	13,85	13,35	12,95	12,75	11,85	—
80,0	18,30	17,60	17,25	16,85	16,50	16,15	15,75	14,90	—	—
90,0	22,25	21,30	21,10	20,50	20,15	20,10	19,80	19,80	—	—
95,0	25,60	24,35	24,20	23,70	23,20	23,30	23,20	23,20	—	—
97,0	27,95	26,60	26,40	26,10	26,90	26,30	26,90	—	—	—

The following regain values have also been given (at 24° C)[56]:

			RELATIVE HUMIDITY – PER CENT								
	Material	Description	10	20	30	40	50	60	70	80	90
Natural Textile	Cotton	Sea Island-roving	2,5	3,7	4,6	5,5	6,6	7,9	9,5	11,5	14,1
	Cotton	American cloth	2,6	3,7	4,4	5,2	5,9	6,8	8,1	10,0	14,3
	Cotton	Absorbent	4,8	9,0	12,5	15,7	18,5	20,8	22,8	24,3	25,8
	Wool	Australian merino skein	4,7	7,0	8,9	10,8	12,8	14,9	17,2	19,9	23,4
	Silk	Raw chevennes skein	3,2	5,5	6,9	8,0	8,9	10,2	11,9	14,3	18,8
	Linen	Table cloth	1,9	2,9	3,6	4,3	5,1	6,1	7,0	8,4	10,2
	Linen	Dry spun yarn	3,6	5,4	6,5	7,3	8,1	8,9	9,8	11,2	13,8
	Jute	Average of several	3,1	5,2	6,9	8,5	10,2	12,2	14,4	17,1	20,2
	Hemp	Manila and sisal rope	2,7	4,7	6,0	7,2	8,5	9,9	11,6	13,6	15,7
Rayons	Viscose Nitrocellulose	Average skein	4,0	5,7	6,8	7,9	9,2	10,8	12,4	14,2	16,0
	Cupramonium Cellulose Acetate	Fibre	0,8	1,1	1,4	1,9	2,4	3,0	3,6	4,3	5,3
Paper	M.F. Newsprint	Wood pulp 24% ash	2,1	3,2	4,0	4,7	5,3	6,1	7,2	8,7	10,6
	H.M.F. Writing	Wood pulp 3% ash	3,0	4,2	5,2	6,2	7,2	8,3	9,9	11,9	14,2
	White Bond	Rag 1% ash	2,4	3,7	4,7	5,5	6,5	7,5	8,8	10,8	13,2
	Com. Ledger	75% rag, 1% ash	3,2	4,2	5,0	5,6	6,2	6,9	8,1	10,3	13,9
	Kraft Wrapping	Coniferous	3,2	4,6	5,7	6,6	7,6	8,9	10,5	12,6	14,9
Misc. Organic Materials	Leather	Sole oak tanned	5,0	8,5	11,2	13,6	16,0	18,3	20,6	24,0	29,2
	Catgut	Racquet strings	4,6	7,2	8,6	10,2	12,0	14,3	17,3	19,8	21,7
	Glue	Hide	3,4	4,8	5,8	6,6	7,6	9,0	10,7	11,8	12,5
	Rubber	Solid tyre	0,11	0,21	0,32	0,44	0,54	0,66	0,76	0,88	0,99
	Wood	Timber (average)	3,0	4,4	5,9	7,6	9,3	11,3	14,0	17,5	22,0
	Soap	White	1,9	3,8	5,7	7,6	10,0	12,9	16,1	19,8	23,8
	Tobacco	Cigarette	5,4	8,6	11,0	13,3	16,0	19,5	25,0	33,5	50,0
Food-stuffs	White bread		0,5	1,7	3,1	4,5	6,2	8,5	11,1	14,5	19,0
	Crackers		2,1	2,8	3,3	3,9	5,0	6,5	8,3	10,9	14,9
	Macaroni		5,1	7,4	8,8	10,2	11,7	13,7	16,2	19,0	22,1
	Flour		2,6	4,1	5,3	6,5	8,0	9,9	12,4	15,4	19,1
	Starch		2,2	3,8	5,2	6,4	7,4	8,3	9,2	10,6	12,7
	Gelatine		0,7	1,6	2,8	3,8	4,9	6,1	7,6	9,3	11,4
Misc. Inorganic Materials	Asbestos fibre	Finely divided	0,16	0,24	0,26	0,32	0,41	0,51	0,62	0,73	0,84
	Silica gelatine		5,7	9,8	12,7	15,2	17,2	18,8	20,2	21,5	22,6
	Domestic coke		0,20	0,40	0,61	0,81	1,03	1,24	1,46	1,67	1,89
	Activated charcoal	Steam activated	7,1	14,3	22,8	26,2	28,3	29,2	30,0	31,1	32,7
	Sulphuric Acid		33,0	41,0	47,5	52,5	57,0	61,5	67,0	73,5	82,5

The following table compares the regain and water retention levels for various fibres[57]:

Fibre	Relative Density	Regain (65% RH, 20° C) %	% Water Retention* (DIN 53814)
Cotton	1,50	7,0	40-45
Linen	1,50	8,0	ca.50
Wool	1,32	13-15	42
Rayon	1,50	13	80-120
Acetate	1,30	6,5	20-25
Triacetate	1,30	3,2	12-18
Polyamide 6.6	1,14	4,0-4,5	8-12
Polyamide 6	1,14	3,5-5	10-12
Polyurethane Elastomeric	1,1-1,18	1,3	ca.6
Polyester	1,38	0,3-0,4	3-9
Polyacrylic	1,15-1,18	1,0-1,15	4,5-6

* wetted out with a wetting agent and centrifuged.

The following table has been presented for the regain and water retention of different fibres[58]:

	Regain (65% RH, 20° C) (%)	Water Retention (%)
Hydrophilic Fibres		
Cotton	7-8	40-45
Wool	13-18	20-30
Silk	9-10	30-40
Viscose	13-14	80-120
Hydrophobic Fibres		
Polyester		
Polyethylenterephthalate	0,4	2-5
Poly-dimethylcyclohexanterephthalate	0,2	2-5
(Kodel Eastman)		
[Vestan 1 Bayer)]		
Polyamide		
Polyamide 6.6	3,5-3,8	10-15
Polyamide 6	4,0-4,5	
Qiana (Du Pont)	4,5-4,9	
Aromat, Polyamide		
[Nomex. (Du Pont)]		
Polyacrylonitrile	1,0-2,5	5-10
Polyurethane-Elastomer	1,0-1,3	
Polypropylene	0	
Polyvinyl chloride	0	2-3

Fibre Swelling:

The following table has been given for the swelling of fibres in water[59]:

Fibre	Transverse Swelling (%)		Axial Swelling (%)	Volume Swelling (%)
	Diameter	Area		
Cotton	20 ; 23	40; 42; 21		42; 44
Linen		47	0,1 0,2	
Jute	20; 21	40		
Mercerised cotton	17	46 24	0,1	
Mercerised linen			5,6	
Viscose rayon	25; 35; 52	50; 65; 67 66; 113; 114	3; 7 4; 8	109; 117 115; 119 123; 126 74; 122 127
Lilienfeld viscose rayon		45; 83; 90	0,1 0,7 to 1,3	85; 92
Cuprammonium rayon	41; 53 32	62 56	3,6 2,2-4	68; 103; 107
Fortisan		22		
Ordinary acetate rayon	9; 11; 14 0,6	6 8	0,1 0,3	
Wool	14,8-17	25; 26		36; 37; 41
Silk	16,5 16,3 to 18,7	19	1,6; 1,3	30; 32
Nylon	1,9 to 2,6	1,6; 3,2	2,7 to 6,9	8,1 to 11,0

FIBRE CIRCULARITY

THE VARIATION IN CIRCULARITY OF DIFFERENT TEXTILE FIBRES[60]

No.	Fibres	Range of Circularity Values	Mean Circularity	CV %
1	2	3	4	5
	Man-made			
1.	Nylon	0,932 ... 1,048*	0,983	2,0
2.	Dacron	0,835 ... 1,001*	0,945	3,2
3.	Ardil	0,822 ... 0,989	0,941	2,6
4.	Casein	0,800 ... 0,995	0,937	3,5
5.	Viscose Rayon	0,515 ... 0,885	0,744	10,1
6.	Acrylic	0,576 ... 0,852	0,707	7,2
7.	Orlon	0,566 ... 0,966	0,677	8,8
8.	Dynel	0,343 ... 0,811	0,440	13,6
	Natural			
9.	Tussah Silk	0,267 ... 0,810	0,520	20,4
10.	Wool	0,526 ... 1,008*	0,831	13,4
11.	Ramie	0,464 ... 0,968	0,744	13,8
12.	Cotton: Auburn 3 (65% maturity)	0,576 ... 0,990	0,661	21,6
13.	Cotton: NC 14 (25% maturity)	0,184 ... 0,920	0,533	31,3

* These values are within the limits of error in measurement.
The circularity values (C), have been determined employing Schloemer's formula, $C = 4\pi A/P^2$, where A is the area of cross-section measured with a polar planimeter and P, the perimeter measured with a map measurer. Measurements on one hundred cross-sections of each type of fibre were made[60].

Fibre Bending and Stiffness Properties:

Fibre Flexural rigidity (G) $= \frac{1}{4\pi} \quad \frac{\eta E T^2}{\rho} \times 10^{-3}$ N.mm^2

where η is the shape factor[61]

E is the initial (or specific) modulus in N/tex

T is the fibre linear density in tex

and ρ is the fibre density in g/cm^3

We have, however,

$$T = 7{,}854 \times 10^{-4}\, d^2\, (1 + 0{,}0001\, V^2)\, \rho$$

where d is the fibre diameter in μm

and V is its coefficient of variation in %.

It therefore follows that:

$$G = \frac{1}{4\pi} \eta\, E\, \rho\, (7{,}854 \times 10^{-4})^2\, d^4\, (1 + 0{,}0001\, V^2)^2$$

$$G = 4{,}9 \times 10^{-8}\, \eta E\, \rho\, d^4\, (1 + 0{,}0001\, V^2)^2$$

If we take $(1 + 0{,}0001\, V^2)^2 = 1{,}1$

i.e. V is assumed to be 22% then

$$G = 5{,}4 \times 10^{-8}\, \eta E\, \rho\, d^4$$

The specific flexural rigidity (i.e. flexural rigidity per unit tex or the flexural rigidity of a one tex fibre) can be calculated as follows:

$$\text{Specific flexural rigidity } R_f = \frac{1}{4\pi} \eta \frac{E}{\rho} \times 10^{-3} \quad \text{N.mm}^2/\text{tex}^2$$

$$= 7{,}96\, \eta \frac{E}{\rho} \quad \text{N.mm}^2/\text{tex}^2$$

$$= 796\, \frac{\eta E}{\rho} \quad \text{cN.mm}^2/\text{tex}^2$$

If d is the mean fibre diameter and V is the *fractional* coefficient of variation of fibre diameter then the average fibre stiffness is approximately proportional to[62]:

$$d^4\, (1 + 6\, V^2 + 3\, V^4).$$

FIBRE FLEXURAL, TORSIONAL, SHEAR AND TENSILE PROPERTIES* (MORTON AND HEARLE)[61]

Fibre	Shape Factor (n)	Specific Flexural Rigidity (cN.mm²/tex²)	Modulus (kN/mm²)		Specific Torsional Rigidity cN.mm²/tex²	Shear Modulus kN/mm²	Shear Tenacity (cN/tex)		Tensile Tenacity (cN/tex)		Extension at Break (%)	Work of Rupture (cN/tex)	Initial Modulus*** (cN/tex)
			Bending	Tension**			65% RH	Wet	65% RH	Wet			
Flax							8,14	7,36	25,5(54)	28,4	3,0	0,8	1800
Cotton		0,053		7,7	0,016	—	8,44	7,65	23,5-32	21,6	6,5	1	560
Jute									-31		1,8	0,27	1720
Viscose rayon	0,74	0,019					6,38	3,14	17,7	6,9	—	—	—
Hemp									47	—	2,2	0,53	2170
Fibro		0,035	10	8,7	0,0058-0,0083	0,84-1,2			21	—	15,7	1,88	650
Ramie									59	—	3,7	1,06	1460
Vincel		0,069	20		0,0097	1,4			—	—	—	—	—
Secondary acetate	0,67	0,008-0,025		4,2	0,0064	—	5,79	5,0	11,8-13	7,8	24	2,16	360
Triacetate		0,025		3,8	0,0091				12,0	—	30	1,8	310
Wool	0,80	0,020-0,024	3,9	5,2	0,012	1,3			12,5	—	40	3,1	230-400
Silk	0,59	0,019-0,060		14	0,016	—	11,58	8,83	31,4-38	24,5	23,4	6,0	730
Casein Fibrolane		0,018		2,3	0,011	—	—	—	—	—	—	—	—
Nylon 6.6 (3 types)	0,91	0,014-0,015 -0,022	2,5-3,6	1,9-3,8	0,0041-0,0060	0,33-0,48	11,18	9,52	39,2	35,3	—	—	—
Polyester fibre Terylene	—	0,030	7,7	6,2	0,0067	0,85							
Acrylic fibre (3 types)	—	0,033-0,048	6,0-8,1	4,9-7,0	0,012-0,018	1,0-1,6							
Polypropylene		0,051	5,2	2,4	0,014	0,75			65	—	17	7,1	710
Glass	1,0	0,089							40(75)	—	1,9(2,5)	0,39(0,98)	2120(2940)
Highly orientated cellulose	0,83	0,044					10,40	9,42	70,6	58,9			
							8,14	7,36	25,5	28,4			
							9,81	9,42	27,5	24,5			
High Tenacity Rayon									41		12	2,8	880
Polynosic									26		7	1,1	1320
Nylon 6.6													
Medium Tenacity									48		20	6,3	300
High tenacity									66		16	5,8	440
Staple fibre									37		43	10,1	100
Nylon 6 (Perlon)									29		46	7,7	60
Polyester (Terylene)													
Medium-tenacity									47		15	5,3	1060
High-tenacity									56		7	2,2	1320
Staple-fibre									47		37	11,9	880
Acrylic (Orlon staple)									27		25	4,7	620
Modacrylic (Dynel)									34		34	6,3	880
Polyvinyl alcohol									17		26	2,4	220
Polyvinyl chloride									24		17	2,3	350
Courlene (low density)									8		20-40	1,1-2,6	90
Courlene X3 (high density)									34		10	1,9	440

* At 65% RH and 20°C unless specified otherwise

To convert cN/tex and cN.mm²/tex² to m/v/tex and mN.mm²/tex² respectively, multiply by 10.

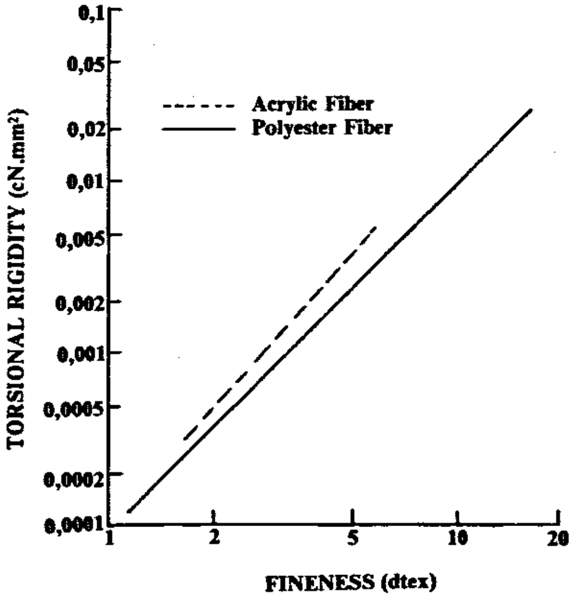
** To convert to cN/tex multiply by $\frac{100}{\text{density}}$

*** Young's modulus

Orlon fibre linear densities (dtex) which give the same fabric handle as various wool qualities are given below[63].

Fibre Crimp type	Commercial Orlon type	Fabric Tactility	Fineness Quality (Wool Scale) as function of Fibre Crimp and Denier		
			3,3 dtex	6,6 dtex	9,9 dtex
Pliant	21	Soft	> 70's	54-64's	48-52's
More rigid	23; 24	Crisp	60-70's	48-54's	44-46's

Fibre torsional rigidity is related to fibre linear density (dtex) in the figure below:[64].



ELASTIC RECOVERY PROPERTIES:

Nylon's recovery from elongation (elasticity or work recovery) improves with increasing humidity and is far superior to that of polyester at relative humidities above about 10%, at high elongations (above about 2% in general and in water[65]:

PERCENTAGE RECOVERY FROM 15% STRAIN[66]

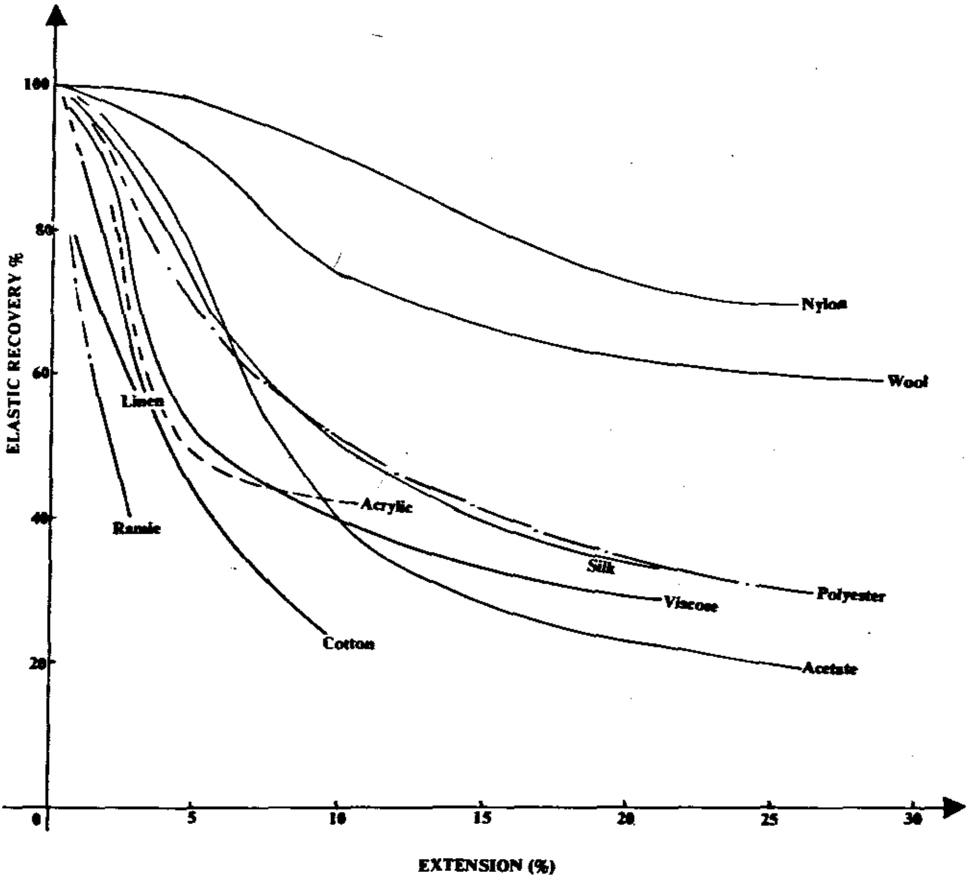
Fibre	Type of strain	
	Bending	Tensile
Nylon	83	72
Courtelle	70	48
Polypropylene·	64	79
Britch Wool	60	63
Evlan	38	32

Data from J.C. Guthrie

Some elastic properties of various fibres are also given below[118].

TENSILE AND WORK RECOVERY																
Material	Tensile recovery (%)								Work recovery (%)							
	60% RH				90% RH				60% RH				90% RH			
Elongation (%)	1	3	5	10	1	3	5	10	1	3	5	10	1	3	5	10
Japan silk	84	60	52	34	78	65	58	45	57	32	23	17	47	30	24	23
Wool 50/56's	99	84	69	51	94	89	82	56	83	58	37	21	67	54	45	25
Wool top 64's	100	81	65	49	98	94	84	62	79	58	41	21	65	59	39	24
Zein fibre	100	74	47	—	85	59	43	28	90	36	22	—	48	31	21	15
Nylon 6.6	90	90	89	86	92	92	90	—	66	57	55	52	68	68	64	—
Casein fibre	90	65	47	30	76	58	43	25	74	45	23	11	53	34	18	9
Polyester (continuous filament)	98	79	65	51	92	75	60	47	82	49	35	24	76	46	30	21
Polyester (staple)	95	75	70	—	92	73	69	—	85	44	37	—	83	43	34	—
Acrylic filament	92	56	50	43	90	55	48	39	64	27	23	21	66	24	21	16
Acrylic (staple)	89	66	51	—	84	62	48	—	63	33	20	—	62	30	19	—
Polyvinylidene chloride (PVC)	89	86	83	70	—	—	—	—	62	60	56	43	—	—	—	—
Polyethylene	80	81	80	78	80	83	83	80	55	52	50	47	63	57	55	51
"Cordura" textile rayon	72	40	31	25	54	35	30	26	49	14	14	10	27	13	13	13
Du Pont viscose rayon	67	38	32	23	60	33	28	27	50	14	11	9	27	12	10	11
Cotton II	91	69	52	—	83	68	59	—	50	37	31	—	42	38	33	—
"Acele" acetate rayon	96	65	46	24	75	50	37	22	80	33	18	9	70	24	14	8
Glass fibre									97							

Some elastic recoveries at various elongations are shown in the figure below[67] for various fibres:



A comparison of some properties are shown for different fibres below[68]:

Properties	Nylon	Polyester	Acrylic	"Source"
Relative density	1,14	1,36	1,17	1,2
Tenacity (cN/tex)	35	9-15	21	35
Toughness (cN/tex)	7,9	5,3	4,4	7,1
* Elastic Recovery — 1st cycle	81	36	37	69
6th cycle	88	79	13	73
Recovery after 6th cycle	75	37	43	72

* 15% strain

Effect of exposure, heat and radiation

The effect of sunlight on curtains[69]:

The following rating has been given for various fibres in order of increasing rate of loss of strength on exposure to sunlight:

Fibreglass

Acrylics

Polyesters

Cellulose diacetate and triacetate
Nylon 6 and 6.6

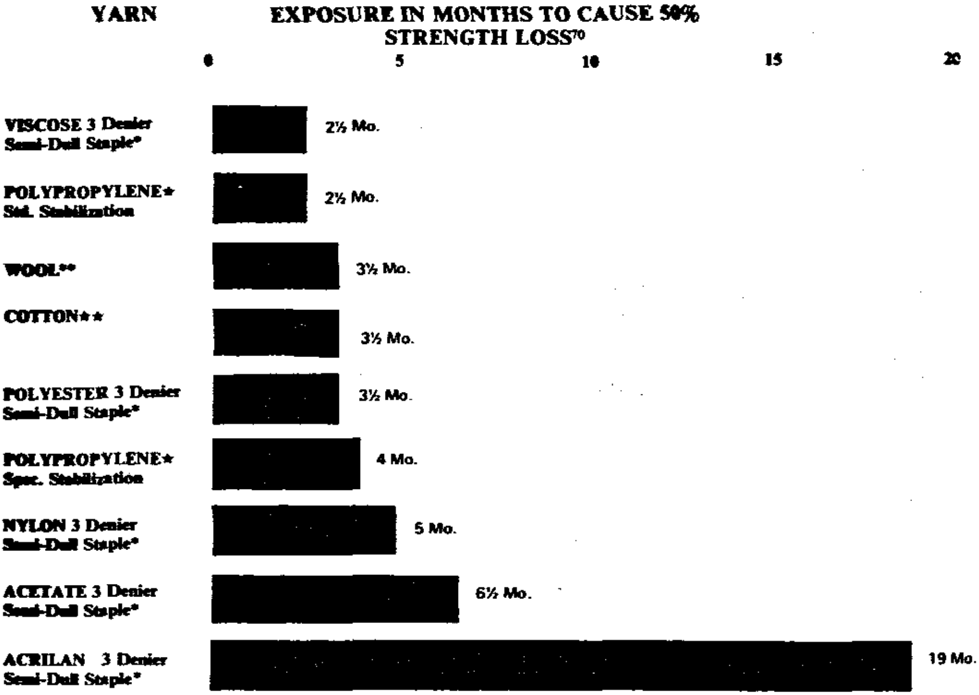
Linen

Cotton

Wool

Silk

One must remember that these fibres have very different initial strengths, which must be taken into account as well as the rate of strength loss, when trying to decide on the best buy from the point of view of light stability.



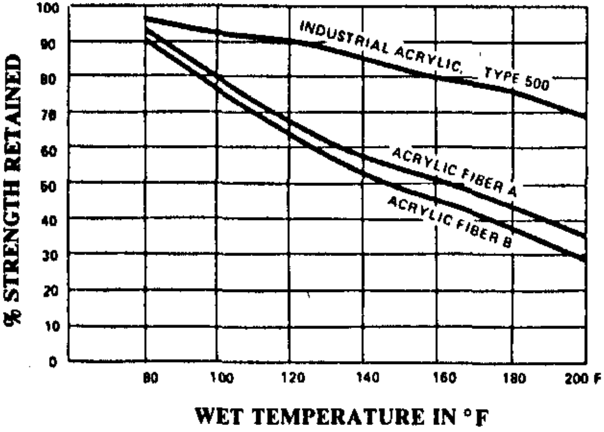
*2½ inch staple, 30/2 yarn

★ Data obtained from "Proceedings, Symposium on Polyproplene fibers", sponsored by Southern Research institute.

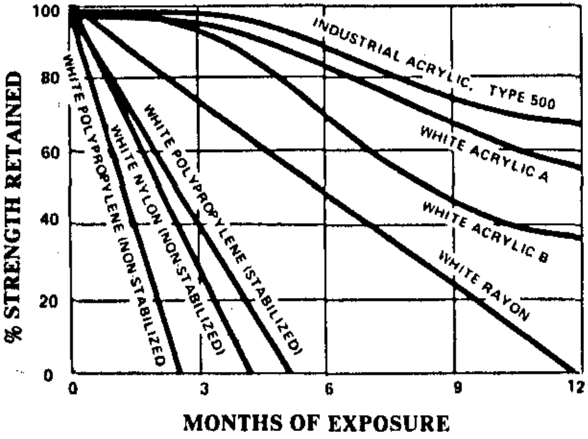
** 64s cut 2½ inch, 16/2 yarn

★★ Combed cotton, 30/2 yarn

Comparative resistance of yarns to Florida outdoor exposure (Monsanto).



Effect of wet heat on acrylic fibers (Dow Badische): 70



Sunlight degradation of textile fibers (Dow Badische): 70

Percent loss in original breaking load (yarn breaking loads were measured on an Instron at 100 mm/min constant rate of extension from a 100 mm-gauge length), 10 tests were made on each exposed and unexposed sample[42]:

	Daylight (behind glass)			**Xenon Arc samples exposed 2 mm from the filter**		**Carbon arc**
	UK 6 mths	**UK 6 mths**	**Florida 21 000 Lang-leys**	**200 hr**	**400 hr**	**200 hr**
Bright Nylon type 6.6	34	47	28	34	45	40
Semi-dull Nylon 6.6 no additive	71	95	—	65	85	—
Semi-dull Nylon 6.6 with additive	14	21	38	15	20	66
Semi-dull Nylon type 6	—	—	65	—	—	80
Extra-dull Nylon 6.6 No additive	85	(100)	—	(100)	(100)	—
Extra-Dull Nylon 6.6 With additive	43	58	59	20	25	43

Some temperatures for cars in direct sunlight are given below for various localities[42]:

Location	Ambient Temps		Humidity (RH %)		Car Temperatures — Max. in Full Sun										Max. Ambient during *Tests*
	Max. °C	Min. °C	Max.	Min.	Crash Pad *Top*	Instrument *Panel*	Centre Steering *Wheel*	Rear Parcel Tray	Seats	Outside Body Panels		Under Hood Top		Header Bar	
										Light	*Dark*	*Light*	*Dark*		
Singapore	30	23	97	62	74	45	45	56	44	37	44	37	44	47	NA
RHODESIA															
Salisbury	35	-1			81	60	60	66	55	53	55	40	59	59	28
THAILAND															
Bangkok	40	8	100	12	65	44	52	62	45	55	—	44	—	50	34
AUSTRALIA															
Geelong					80	61	62	84	60	55	60	47	58	66	37
N.ZEALAND															
Wellington	36	-7	88	67	52	50	52	55	61	32	34	28	32	52	22
S. AFRICA															
Pt. Elizabeth	52	-5	100	1	95	65	91	86	66	50	55	47	60	63	30
USA															
Michigan					104	91	81	62	86	62	64	50	44	102	51

LOSS OF STRENGTH ON PROLONGED EXPOSURE OF HIGH TEMPERATURES[61]

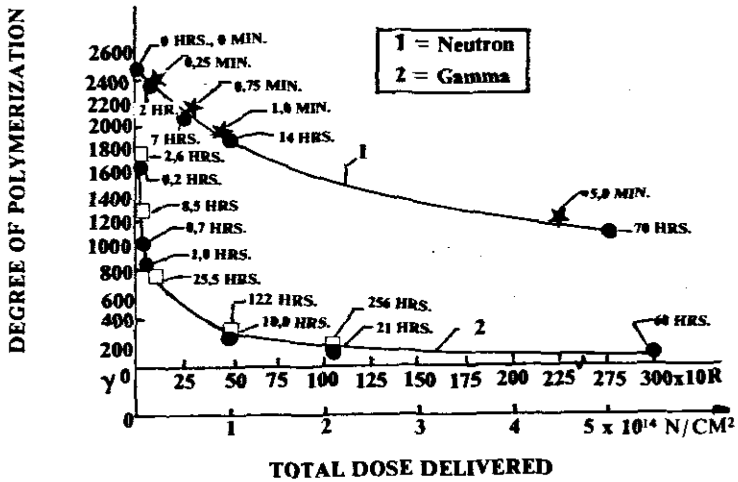
Fibre	Percentage strength retained			
	After 20 days		After 80 days	
	At 100° C	At 130° C	At 100° C	At 130° C
Viscose rayon	90	44	62	32
Cotton	92	38	68	10
Linen	70	24	41	12
Glass	100	100	100	100
Silk	73	—	39	—
Nylon	82	21	43	13
Polyester, Terylene	100	95	96	75
Acrylic, Orlon	100	91	100	55

Some details of the effect of *radiation* on textiles are given in the table and figures below[71]:

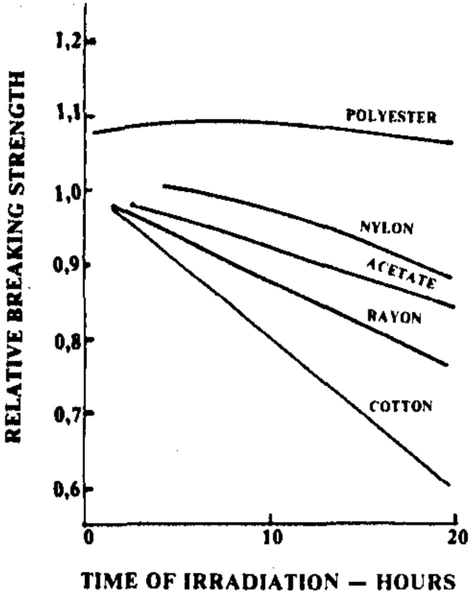
	Radiation Tolerance of Textiles in Air Below 95F*		
	Dose (Mrad)		
	Where loss in strength becomes significant	Where viscosity is changed significantly	First complete destruction of fibrous properties **
Cotton	0,1	0,055	30
Rayon	0,8	0,5	80
Acetate	1	1,3	100
Wool	5	—	100
Nylon 6 or 66 (polyamides)	2	1,1	100
Dynel (modacrylic)	4	—	—
Orlon (acrylic)	8	—	1 000
Dacron (polyester)	25	—	10 000

• Data of Bolt and Carrol (11)

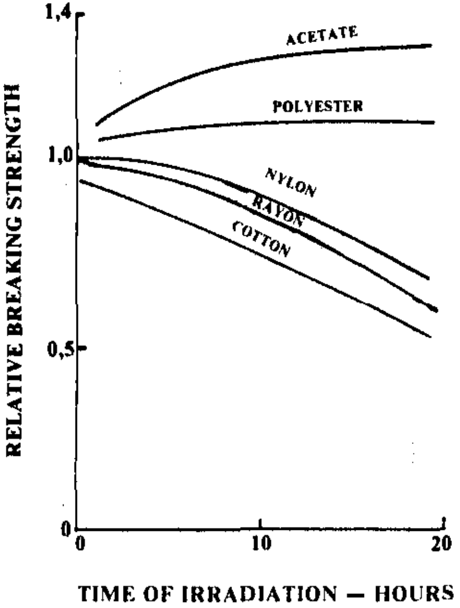
•• Estimated by extrapolation; values may not be realistic.



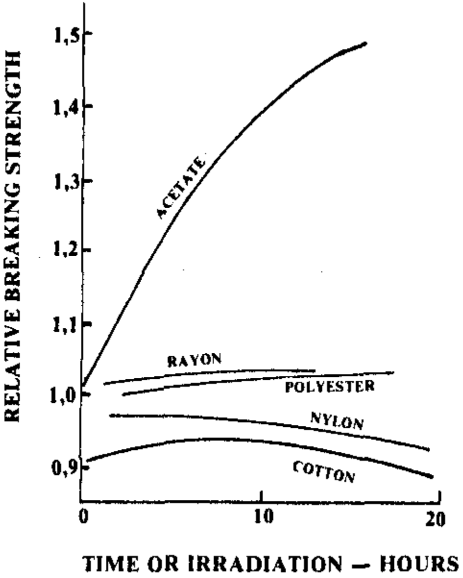
Dependence of change in degree of polymerization of cotton on total dose of radiation.



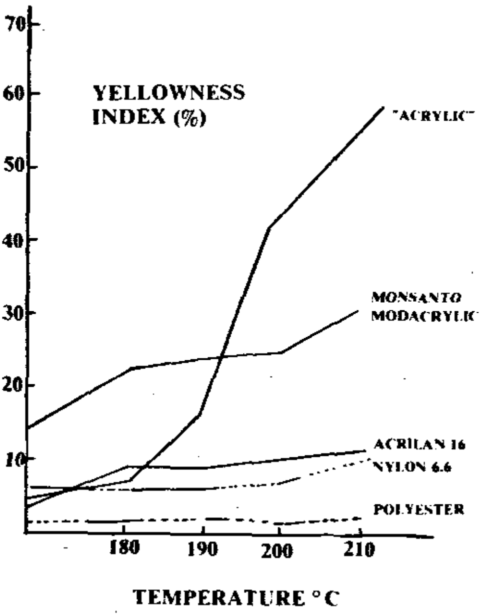
Breaking loads, relative to unirradiated materials, of yarns after exposure to γ-radiation for different periods of time in an atmosphere of nitrogen saturated with water at 21°C. Dose rate, 3 x 10^5 r hr.



Breaking loads, relative to the unirradiated materials, of yarns after exposure to γ-radiation for different periods of time in an atmosphere of nitrogen containing 10% acrylonitrile and 2,2% water at 20°C Dose rate, 3,8 x 10^5 r/hr.



Breaking loads, relative to the irradiated controls (no acrylonitrile), of yarns after exposure to γ-radiation for different periods of time in an atmosphere of nitrogen containing 10% acrylonitrile and 2,2% water at 20°C. Dose rate, 3,8 x 10^5 r/hr.



Effect of time and temperature on base colour of various fibres. [72] *(20s exposure)* [72]

The effect of time and temperature on the base colour of a number of fibres is illustrated in the figure above[72]. It is easy to see that polyester is a good performer showing almost no change in base colour under the conditions of the printing operation. Also, the good performance of Acrilan is demonstrated compared to a competitive acrylic fibre. In our experience, the polyester and polyamide fibres always perform similarly to this test, whatever the source. This is not true of acrylic fibres, with results from acceptable to non-acceptable being obtained under the conditions of this test dependent on the source of the fibre.

The Percent Yellowness Index has been calculated as follows:[72]

The Yellowness Index has been calculated as follows:[72]

$$YI\,(\%) = \frac{1{,}28\,X - 1{,}06\,Z}{Y} \times \frac{100}{1}$$

where X, Y and Z are the CIE tristimulus values.

SOME POLYESTER FIBRE PROPERTIES

The following physical properties have been given for some Japanese synthetic fibres and yarns[73]:

SOME DETAILS FOR TETORON STAPLE POLYESTER[73]

Type	Lustre	dtex	Fibre length (mm)	Uses
T301	Super Bright	1,1	38	T/C, T100
		1,37	44	T100
T302	*Super-Bright*	*1,67*	*35*	*T/C for open end spinning*
T303	Super-Bright	1,33	38	T/C T100
T403	Semi-dull	1,33	38	T/C T100
T981	Super Bright	2,2	38,51	T/C T100
		3,3	51,76,89	
			102	T/R, T/W, T/Ram
		6,7	89,102	T/W, T/Ram
E101 (Normal shrinkage type) Anti-pilling	Bright	2,2	64	T100
		3,3	79,89V	T100, T/W
		4,4	89V	T100, T/W
		5,5	76	T100
E104 (High shrinkage type)	Bright	3,3	76,89V	T100
		4,4	89V,102V	T/W
		5,5	76,102V	T100
K261 (Cationic dyeable)	Semi-dull	3,5	76,89V	T100, T/W
		4,4	89V	T100, T/W
K264 (Cationic dyeable)		3,3	102V	T100
		4,4	102V	T100, T/W

KEY: T — Tetoron
W — Wool
R — Rayon
C — Cotton

COMPARISON OF SOME TETORON POLYESTER FIBRE PROPERTIES[73]

FIBRE	TETORON														CATIONIC DYEABLE STAPLE				
TYPE	T301+	T301+	T302*	T303Δ	T304Δ	T981	T981	T981	E101**	E101**	E101**	E104**	E104**	E104**	K261	K261	K164	K164	Regular T201
Property	dtex 1,1	1,37	1,67			2,2	3,5	6,7	3,3	4,6	5,5	3,3	4,4	5,5	3.3	4,4	3.3	4.4	46
Dry tenacity (cN/tex)	60	58	56	61	62	48,5	48,5	48,5	25,6	25,6	2,5	25,6	25.6	25	23.8	23,8	25,6	25.6	4
Dry elongation (%)	25	26	27	25	24	50	50	50	28	28	28	40	40	40	33	33	33	33	44
No. of crimps/cm	5,1	5,3	4,7	5,1	5,1	5,3	5,1	3,9	3,9	3,7	3,5	3,9	3.7	3.5	4.1	3,9	4.1	3.9	3.9-4.3
Shrinkage (%) (Hot air at 180° C)	6,0	6,0	6,0	6,0	6,0	—	6,0	—	• 1 or below	• 1 or below	• 1 or below	• 15	• 15	• 15	• 1 or below	• 1 or below	• 15	• 15	• 0
Relative density	1,38	1,38	1,38	1,38	1,38	—	1,38	—	—	—	—	—	—	—	—	—	—	—	—
Moisture regain (%)	0,4	0,4	0,4	0,4	0,4	—	0,4	—	—	—	—	—	—	—	—	—	—	—	—
Bending strength (flex cycles)	—	—	—	—	—	—	—	—	300	300	300	700	700	700	260	260	450	450	2000+
Degree of crimp (%)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	12-14

+ Hard crepe eyelets are recommended when weaving yarns spun from this fibre

* Specifically used for cotton blending on rotor (OE) machines

● Shrinkage in boiling water

** Super Anti-Pilling Tetoron staple for knitted and woven goods, particularly in blends

Δ Used for sewing threads

SEWING THREAD PROPERTIES (100%) TETORON[73]

Count	80/3		60/2	
Type	T-303	T-403	T-303	T-403
Item				
Tensile Strength (cN)	686	686	588	588
Elongation (%)	22	21	21,5	20,5
Twist plying (turns/m)	1060	1060	1060	1060
Twist Singles (turns/m)	1260	1260	1140	1140
Young's Modulus (cN/tex)	238	253	247	243
Dry Heat Shrinkage (180°C 20 min) (%)	4,0	3,4	3,6	3,0

"AMILAN" TORAY NYLON & "TORAY TETORON" POLYESTER FILAMENT YARN FOR INDUSTRIAL MATERIALS[73]

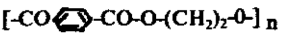
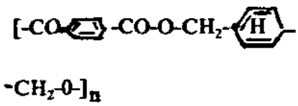
	YARN IDENTIFICATION					PHYSICAL PROPERTIES				Characteristics	Uses
	dtex	Filaments	Turns/m	Twist	Type	Tenacity (cN/tex)	Elongation at break (%)	Boiling water Shrinkage (%)	Hot-air Shrinkage at 150°C (%)		
"Amilan" Toray Nylon	233	24	15	S	700, 730	68,8	25	12	6	Type 700: Bright High tenacity Type 730 : Bright High tenacity Weather-proof Heat-resistant Type 781S : Bright Super high tenacity Weather-proof Heat and fatigue resistant	Fishing net, Tarpaulin
	467	48	15	S	700, 730	68,8	26	11	5,5		Filter cloth
	700	72	15	S	700	67,9	26	11	5		Filter cloth
	933	96	15	S	700	67,0	26	11	5		Filter cloth
	867	192	15	S	700	67,0	26	11	5		Filter cloth
	933	136	20 or 0	Z or 0	781S	80,3	22	11	5		Filter cloth
	1400	204	20 or 0	Z or 0	781S	80,3	22	11	5		Tyre cord, Belt, Rope
	1867	272	20 or 0	Z or 0	781S	78,5	23	11	5		
"Toray TETORON" Polyester	78	24	20	S	300	65,3	14	7	11	Type 300: Bright High tenacity Type 702C: Bright Super high tenacity High and fatigue resistant	Sewing thread
	139	24	20	S	300	64,4	14	7	11		Sewing thread
	167	48	20	S	300	63,5	13	7	10		Sewing thread
	222	24	20	S	300	63,5	13	7	11		Sewing thread
	278	48	20	S	300	63,5	13	7	11		Sewing thread, Tent
	1111	192	0	0	702C	78,5	12	7	11		Filter cloth
	1667	288	0	0	702C	78,5	12	7	11		Tyre cord, Belt hose

+ "Toray TETORON", "Amilan" and "TORAYLON" are registered trademarks of Toray Industries, Inc.

COMPARISON OF DIFFERENT LOW PILLING POLYESTERS[74]

	Grisuten hpa	Trevira 350	Grilene sap	Tesil V31
Fibre fineness (dtex)	4,4	4,8	4,6	4,4
Tenacity (cN/tex)	30	32	29	31
Extension (%)	30	43	32	53
Loop tenacity (cN/tex)	24	28	27	25
Crimp (%)	24	15	11	15
Shrinkage (%)	0,2	1,0	1,0	1,0
Whiteness (%)	80	86	78	76
Loop abrasion cycles (Z)	380	850	300	750

THREE MARKETABLE POLYESTERS[75]

Uses	Structure	Relative Density	Melting Point (°C)	Glass Transition Temperature (°C)
Clothing, home textiles, pure and blended with natural or other chemical fibres	**Normal PES** 	1,36-1,38	250-256	70-80
Non-wovens, tuffing, home textiles	**Kodel** 	1,22-1,23	290-295	60-90
Carrier-free dyeable, for home textiles	PTMT (PBT) 	1,31	-244	40

For other (Unitika) polyester staple fibres the following list of properties has been given:

Fibre	dtex x mm	Tenacity (cN/tex)	Elongation (%)	Thermal Shrinkage at 170° C for 15 min (%)
Bright (626)	1,39 x 51	63,5	25	2,3
Semi-dull (507)	1,44 x 38	59-62	28	2,5-2,8
Semi-dull (506)	1,67 x 38	59-62	28	2,5-2,8
Semi-dull (575)	1,67 x 35	42	55	2,1
Semi-dull (526)	1,67 x 51	64	26	2,5
Semi-dull (536)	2,22 x 51	50	40	2,7
Bright (636)	2,22 x 51	51	42	2,2
Hollow Bright (H635)	2,22 x 51	48	40	2,7
Modified (P634)	2,22 x 51	48	39	2,2
Modified (545)	3,3 x 64/102	45	50	3,5
Anti-pill (555)	3,6 x 64/102	33	52	3,5
Hollow (H38F)	7,9 x 76	34	52	—
Hollow (H38Y)	8,1 x 76	31	54	—

The following table of fibre properties is given[76]:

	Relative Density	Tenacity (cN/tex)	Extension (%)	Regain (%)
Polyester W-type	1,38	40-50	35-60	0,3-0,4
Low Pilling type polyester	1,38	20-35	20-55	0,3-0,4
Acrylic	1,15-1,18	18-32	20-60	1-1,5
Nylon	1,14	32,63	15-70	4-4,5
Cotton	1,5	18-27	18-25	13
Wool	1,32	9-18	25-45	13-15

Trevira type 350 is a pill-resistant polyester[77]. During processing its properties are similar to those of the regular (type 220) and high tenacity (type 121) types but after dyeing the strength of the type 350 decreases to that normally associated with pill resistant fibres. For example, the tenacity and elongation of the type 220 were given as 42,4 cN/tex and 45% respectively, while those for the low-pilling type 350 are 30,9 cN/tex and 40% respectively. More important, however, is the resistance to flexing which is 3500 cycles for the type 121, 3200 for the type 220 and 450 to 750 cycles for the type 350. This is advanced as the reason for its low-pilling character. After dyeing its resistance to flexing drops to 320 to 420 cycles. It can be used in cotton/polyester blends, e.g. 2,8 dtex with a twist factor of 32,5 (3,4 English cotton) in 20 tex yarn[77].

The properties of a new low dyeing type of polyester (Trevira Type 210) are compared with other polyester fibres in the table below[78]:

Service Properties	Trevira 210	W-types	low-pill types
Crease sensitivity	good	very good	good
Abrasion resistance	good	very good	good
Pilling tendency	strong	strong	weak
Pleat stability	good	very good	good
Shape retentivity	very good	excellent	very good

Physical properties	Trevira 210	W-types	low-pill types
Strength (cN/tex)	30-40	40-50	20-35
Elongation (%)	40-58	35-55	20-50
Knife-edge abrasion (revs)	1800-3500	2500-3500	150-2500
Shrinkage at boil (%)	<1	<1	<1
Density (g/cm³)	1,38	1,38	1,38
Melting point (°C)	256	256	256
Glass transition temp. (°C)	~70	~80	
Sonic modulus (cN/dtex)	70	80	
Thermal shrinkage 200°C (%)	~ 9	~ 7	
Rel. knot strength (%)	98	84	
Rel. loop strength (%)	98	84	
Angle of distortion at break (%)	33	44	

PHYSICAL PROPERTIES OF E TYPE TETORON STAPLE POLYESTER[79]

	Wool	E type Tetoron		Regular Tetoron
		E-101	E-104	T-201
Dry tenacity (cN/tex)	9-18	25	26	46
Dry Elongation (%)	25-35	36	42	44
Bending Strength (cycle)	200-400	300	600	more than 2 000
Number of Crimps (crimp/cm)	4,3-5,1	3,9	3,9	3,9-4,3
Degree of Crimp (%)	11-18	13	11	12-14
Wet Shrinkage (%)	0-0,5	0	15,0	0

The following table relates chain length, orientation angle and crystallinity to tensile properties[80] for cellulosic fibres:

Fibre	Crystallinity (%)	Orientation Angle	Tensile Strength	Chain Length (nm)
Flax	70	7°	180	80
Cotton	75	18°-40°	120	1000
Textile Viscose	38	22°	46	125-150
Cuprammonium	35	25°	37	100
Acetate	30-45 (depending on stretch)	15°-40°	24	50
Fortisan	49	5°	143	165

Orientation denotes the average degree of inclination of crystallities to the fibre axis. In this context, the higher strength for Fortisan can be ascribed to its much higher orientation. However, higher orientation means a sacrifice of other properties required in fibres meant for apparel use, such as resilience, pliability and softness to touch. The dye absorption and lateral bending properties of a fibre are determined by its non-crystalline fraction.

Cellulose crystal lattice has at least two common stable forms: Cellulose I in which all natural fibres (with the minor exception of some marine algae) exist, and Cellulose II, the form of all regenerated cellulose fibres and sheets.

Mercerization of natural cellulose causes the crystal lattice to change from Cellulose I to Cellulose II configuration. The change is usually accompanied by swelling and a substantial reduction in the degree of crystallinity. During mercerization the lustre of fibres can be improved by controlling mercerizing stretch. Additionally, however, the degree of orientation and crystallinity are also controlled. Despite the high crystallinity and strength of cotton, which would make the fibre too rigid to be spun ordinarily, like ramie, the spiral orientation causes cotton to retain flexibility during processing and use. Several attempts to spin rayons with a spiral orientation have failed to simulate this quality of cotton. The extra chain length of cotton macromolecules finds expression in its endurance. Successive launderings of textile goods reduce the average chain length, and this is where the extra chain length of cotton acts as a reserve.

Likewise, successive mechanical wear reduces the degree of crystallinity of all celluloses. Thus, while viscose with a degree of crystallinity of 35-40% degrades into powdery shreds after limited use and washing, cotton with twice as high crystallinity wears on. Apart from long chains, secondary interactions between molecules are also essential. In wool the side chains consist of over 20 amino acid residues with sulphur linkages. In cellulose fibres, natural and regenerated OH groups and Van der Waals forces hold the chains together. Without side bonds the material tends to have plastic flow and dimensional instability such as in Polythene.

Side chains also determine such important properties as crease recovery and permanent set. To illustrate this point, the treatment of cellulose fibres with urea-formaldehyde condensates may be considered. This results in side linkages as well as the introduction of a separate phase, consisting of the reagent, and confers a degree of lateral stability on the textile product.

Acetylation of cellulose, on the other hand, introduces CH_3COO-groups instead of lighter OH-groups. The inertia of the side chains thus increases and the material acquires attractive thermo-setting and pleating quality[80].

Vincel has a dry tenacity of 37 cN/tex and when wet is stronger than an American cotton under similar conditions[81].

TYPICAL PROPERTIES OF RAYON STAPLE FIBRES[82]

	Regular	**HWM**	**Prima***	**Polynosic**
dtex (most common)	1,67	1,67	1,67	1,67
Tenacity, conditioned (cN/tex)	25	35	31	39
Wet (cN/tex)	16	23	20	28
Loop (cN/tex)	9	8	7	7
Knot (cN/tex)	13	13	13	15
Elongation (%) Conditioned	18,0	14,0	13,0	10,0
Wet	25,0	18,0	14,0	12,0
Wet modulus (cN/tex)	1,8	4,4	4,4	10,6
Water retention (%)	95	70	80	64
Degree of Polymerisation (DP)	325	400	450	580
Solubility in 6,5% NaOH at 20°C (%)	30	15	10	7,5

* "PRIMA" is ITT Rayonier's Trademark for its high Crimp, High wet Modulus Rayon.

COMPARISON OF PHYSICAL PROPERTIES OF VISCOSE, POLYNOSIC, HIGH WET MODULUS (HWM) AND COTTON FIBRES[83]

Property	Viscose	HWM	Polynosic	Cotton
Cond. tenacity (cN/tex)	19-31	31-53	31-57	17,7-53
Cond. elongation (%)	10-30	8-15	6-12	7-12
Wet tenacity (cN/tex)	4,4-19	22-41	24-40	26,5-57
Wet elongation (%)	22-35	15-22	14-17	13
Wet modulus (cN/tex)	26,5-35	79-221	177-618	61,8-132
Loop test (cN/tex)	2,6-8,8	6,2-26,5	6,2-10,6	8,8-17,7
Moisture regain (%)	11-13	10-12	9-11	7-7,5
Water retention (%)	90-115	60-80	55-75	35-45
Cond. modulus (cN/tex)	530-795	706-971	1060-1590	—
Deg. of polymerisation (DP)	240	320	500	2000
Cross section	Serrated	Round	Round	Bean shaped
Area shrinkage of woven fabrics (%)	20	15	10-11	10-11
Solubility in 10% NaOH at 20° C (%)	51	42	9	2

COMPARATIVE PROPERTIES OF VISCOSE, VISCOSE ACETATE AND CELLULOSE ACETATE FIBRES[84]

Sample	Breaking Strength (cN)	Tenacity (cN/tex)	% Elongation at break
Bright viscose (1,67 dtex)	3,3(1,7)**	20,2	16,0(15,1)**
Viscose acetate (2,4 dtex)	3,4(1,6)**	14,1*	19,3(17,8)**
Viscose acetate (2,4 dtex)	3,9(1,8)**	15,9	16,6(17,6)**
Bright viscose	3,9		18,8
Viscose acetate	3,8		16,7
Bright viscose	6,6		10,2
Viscose acetate	6,6		17,8
Viscose dull	3,5(2,1)**		18,2
Viscose acetate	3,4(2,0)		16,1
Cellulose acetate (dull) (3,3 dtex)	3,5(1,7)**	10,6	34,3(31,7)**

* Tenacity decreases only due to increase in dtex of viscose-acetate due to acetylation.

** Figures in parenthesis represent wet strength of viscose and viscose acetate

COMPARATIVE TABLE OF FIBRE PROPERTIES[86]

	Tenacity (cN/tex)	Extension at Break (%)	Water Imbibition (%)
Fibro	20	20	100
HS Fibro	25	16-17	85
Sarille	19-20	20	100
Vincel	35-36	14	75
HSO (Viloft)	23	15	120-130
Polyester	45-50	38-40	5
Cotton Midd.Am.	25	10	35

HSO is a modified viscose; the HS stands for "hot stretch" which implies increased molecular orientation and, therefore, improved fibre tenacity, and the "O" is a pictorial representation of the tubular form which this fibre takes.

The objective of Courtaulds was two fold: if possible to increase the "cover" given by viscose fibres, and secondly, to incline the handle of fabrics in which the new HSO is used more towards a cotton type handle[86].

The HSO fibre has been named Viloft.

Property	Viloft	Courtaulds viscose	American middling[87] grade cotton
Torsional rigidity (x 10^{-9}) ($Nm^2.tex^{-2}$)	3,7	1,52	3,2
Micronaire, cu.ft/hr	4,7	13,7	8,5
Water imbibition, %	130	100	47
Effective Density (g/cm^3)*	1,15	1,5	1,5

COMPARATIVE PROPERTIES OF VILOFT AND STANDARD VISCOSE (CAURTAULDS)[85]

Property	Viloft[85]	Courtaulds standard viscose[85]
Fibre decitex	1,7	1,7
Air tenacity dry (cN/tex)	22,0	20,0
Air dry extension (%)	14,0	19,0
Wet tenacity (cN/tex)	11,0	10,0
Wet extension (%)	18,0	28,0
Loop tenacity (cN/tex)	9,0	8,0
Knot tenacity (cN/tex)	13,0	15,0
Initial wet modulus	36	30
cN/tex at 100% extension):5%	50	40
Yield point (cN/tex)	7,7	7,3
Yield extension (%)	1,2	2,2
Water imbibition (%)	130	100
Effective density (g/cm^3)	1,55*	1,5
Micronaire ft^3hr^{-1}	4,7	13,7
Torsional rigidity ($cN.mm^2.tex^2$)	0,37	0,152

* This is dependent on the method of measurement[85]

In one test the air permeability through a Viloft fabric was 15,3 ft³/hr compared with 19,4 of a matching all standard viscose fabric, while the percentage of light transmitted through it was only 4,9 compared with 8,1 for the standard viscose cloth. Perhaps even more dramatic was a comparison made between identical 100% Viloft and 100% cotton cloths, with the air permeability being 10,8 ft³/hr for Viloft and 15,1 for cotton, while light transmission was only 1,9 with the new fibre, compared with 3,7 for cotton.

SOME VEGETABLE FIBRE PROPERTIES

COMPARISON OF PHYSICAL CHARACTERISTICS OF YUCCA FIBRES WITH BAST FIBRES[88]

Physical Character	*Flax*	*Hemp*	*Ramie*	*Jute*	*Yucca*
Filament length (mm)	211-1473	1057-3175	102-9271	1588-2743	295
Average diameter (μm)	15,37-26	25,50-37,5	13,5-31,5	20,25-23	40,1
Elongation (%)	1,6	1,6	2,7	2,8	0,3
Tensile strength (kgf/mm²)	83,8	90,0	45,5	44,1	37,9

COMPARISON OF CHEMICAL CHARACTERISTICS OF YUCCA FIBRES WITH BAST FIBRES[88]

Physical Characteristics	Flax	Hemp	Ramie	Jute	Yucca
Cellulose (%)	77,3	83,21	77,7	63,01	77,9
Wax (%)	2,38	0,22	3,48	0,38	0,56
Ash (%)	1,01	2,66	0,82	0,68	0,73

SOME CONSTITUENTS OF JUTE AND WOOD[89]

Constituents	*Jute*	*Wood*
Lignin	12-15	29
Pectic bodies & lignin	12,3-15,3	33
Alpha cellulose	58-63	53
Hemi-cellulose	21-25	14
DP of cellulose	900-1 100	<1 000

PHYSICAL PROPERTIES OF BANANA, MESTA, 'ALOE', MANILA AND SISAL FIBRES[90]

Physical Characteristic	Banana Fibre	Mesta Fibre	'Aloe' Fibre	Manila Fibre	Sisal Fibre
Single-fibre tenacity (cN/tex)	49 (17-77)	42 (7,7-80,8)	36,5 (10,5-67,9)	34-44	37-44
Single-fibre tenacity (cN/tex) (after being wet overnight)	49 (16,9-74)	43 (14-70)	33 (13,6-57,5)	—	—
Single-fibre extension at break (%)	2,5 (1,5-3,4)	1,3 (0,5-2,6)	5,0 (4,0-25,8)	2,0-3,0	2,5-4,5
Single-fibre extension at break (after being wet overnight)	2,3 (2,0-6,0)	1,4 (0,6-2,2)	6,6 (5,8-40,0)	—	—
Fibre-bundle tenacity (cN/tex)	27,8 (21,6-32,7)	22,7 (16,4-30)	23,2 (18,2-28,0)	— 19,6-34	— 21,6-35,3
Fibre-bundle tenacity (cN/tex) (after being wet overnight)	22,9 (17,0-30,4)	17,8 (10,9-27,3)	22,1 (17,5-24,5)	—	—
True density (g/cm³)	1,31	1,47	1,47	1,45	1,45
Apparent density (g/cm³)	0,62	1,21	1,17	1,20	1,20
Fibre porosity (%)	53	18	20,7	17	17
Uncombed linear density (tex) of 2-mm cut length	10,5 (3,0-12,0)	4 (3,5-5,5)	19,2 (18,3-19,7)	20-35	16-35
Flexural rigidity (cN.mm²)	3,3 (2-5)	0,35-0,65	5,9 (5,5-6,5)	15,0-20,0	12,5-17,5
Moisture regain at 65% RH (%)	15,2	12,9	12,4	9,5	11
Length of raw fibre (cm)	85 (45-100)	—	47,2 (5-165)	—	—

Values in parenthesis represent the ranges

CHEMICAL COMPOSITION AND PROPERTIES OF RAMIE

Muller gives the following composition of Ramie[91].

Constituent	Percentage
Ash	5,63
Water	10,15
Aq. extract	10,34
Fat and wax	0,59
Cellulose	61,22
Inter-cellular substances and pectins	12,07
	100,00

The gummy matter consists of pectose, cutose and vasculose. It is a pure cellulose and contains no colouring matter. Degumming followed by hypochlorite (NaC10) and sodium chlorite ($NaC10_2$) bleaching gives milky white fibres. Very good resistance to microbial attack makes ramie a prominent fibre among natural cellulosic fibres.

Ramie is the king of the natural cellulosic fibres due to its length, strength, durability, colour and purity. It is eight times stronger than cotton and has an enhanced wet strength. Wet ramie is 160% stronger than dry. In lustre, it is next to rayon and silk. Ramie is a highly orientated fibre, has an orientation nearly parallel to the axis of the fibres (specific index of birefringe is + 0,068). It has an enormous tensile strength but lacks torsional strength and ability to stand a knot.

Ramie has less cohesion force and so is less spinnable. The hairiness of the fibre makes it difficult for spinning. At least 25% moisture is required for its spinning. Processing in a spun silk mill or jute/flax machinery is advisable. The bast cells are 75 mm-228 mm long, the average being 203 mm-228 mm. The diameter of the cells is not uniform, thick and thin places occurring at random.

The specific index of birefringences of ramie, as stated already is + 0,068, resulting in properties like (i) High tenacity, (ii) Low elongation, (iii) increased lustre, (iv) Low moisture absorption, (v) High chemical stability and (vi) Low dyeing affinity.

Due to the high orientation of the molecular structure of ramie fibres, the following differences in physical properties of flax, cotton, silk and ramie will be observed:

Fibres	Tensile Strength	Elasticity	Torsion
Ramie	1	1	1
Flax	4 times less	1,5 times less	1,2 times less
Cotton	8 times less	1 (same as Ramie)	4 times more
Silk	7 times less	4 times more	6 times more

As a bast fibre, if flax is compared with ramie, from the spinning point of view the following differences can be observed.

	Ramie	Flax
1. Tensile strength	Superior to flax	—
2. Cohesiveness	—	Superior to Ramie
3. Fineness	-do-	—
4. Uniformity	—	-do-
5. Pliability	—	-do-

The durability of the ramie fibre makes it a very prominent fibre among cellulosic fibres. After washing 30 times in a fixed percentage of soda and soap, ramie, flax and cotton yarn of the same count show a decrease in tensile strength to the extent of 6%, 64% and 15%, respectively[91].

PROPERTIES OF DIFFERENT VARIETIES OF RAMIE FIBRE[92]

Variety	Gum content (%)	Bundle tenacity* (cN/tex)	Fineness* (tex)
R 1411	21,6	34,4	0,66
R 1449	25,4	33,2	0,56
R 1450	23,6	34,9	0,42
R 1452	25,0	35,7	0,62
R 50-59 (R 1453)	25,2	31,4	0,46
E 53-42 (R 1412)	23,7	34,5	0,55
P.I. London	24,5	31,2	0,44
Local	27,3	30,8	0,44

* Degummed Fibre

PROPERTIES OF YARN

Variety	R1412			R1449		R1450			R1452			R1452 Top Ends		
Yarn count (tex)	74	57	36	81	52	72	58	39	77	59	33	96	100	91
Tex Twist factor	26	27	27	26	26	26	28	25	27	28	27	25	28	31
Tenacity (cN/tex)														
Dry	18,7	19,1	18,8	17,2	12,9	16,0	16,1	15,3	22,1	20,1	17,0	7,5	10,1	11,4
Wet	31,4	31,9	28,5	26,1	25,1	26,2	29,1	25,5	32,4	30,8	30,9	16,0	16,9	15,9
Strength CV%														
Dry	19	30	38	21	30	24	31	37	18	24	38	61	40	30
Wet	21	22	28	24	23	18	27	31	16	23	27	29	28	23
Spinning frame draft	10,4	7,3	12,0	9,2	7,7	10,4	7,0	9,6	9,2	6,5	10,4	—	—	—
Doubling	2x1	1x1	1x1	2x1	1x1	2x1	1x1	1x1	2x1	1x1	1x1	—	—	—

PHYSICAL PROPERTIES OF PINEAPPLE LEAF FIBRE, JUTE AND COTTON[93]

Property	Pineapple leaf fibre	Jute	Cotton
1. Ultimate cells			
Length (mm)	3-9	0,8-6,0	15-60
Breadth (μm)	4-8	5-25	15-20
L/B ratio	450	110	1300
2. Filaments			
Gravimetric fineness (tex)	1,54	1,25-5,0	0,10-30
Tenacity (cN/tex)	50	35-50	20-45
Extension at break (%)	2-6	1,0-2,5	6,5-7,5
Modulus of torsional rigidity (X 10^{10} dyne/cm^2)	0,36	0,25-1,30	0,8-1,20
Flexural rigidity (dyne/cm^2)	3,8	4,0-6,0	0,30-1,0
Transverse swelling in water (%)	18-20	20-22	20-22
3. Bundle			
Tenacity (cN/tex)	26,0	13-31	—
True Density (g/cm^3)	1,48	1,45	1,55
Apparent Density (g/cm^3)	1,35	1,23	—
Porosity (%)	9,0	14,0	—
Moisture regain at 65% RH	11,8	12,0	7,0
at 100% RH	41,0	36,0	24,0

PROPERTIES OF SILK AND SILK-TYPE FIBRES

PHYSICAL PROPERTIES OF BELIMA AND SIDEREA (SILK-LIKE FIBRES)[94]

Properties	Belima	Siderea	Silk	Polyester	Polyamide
Filament linear density (dtex)	0,56-1,67	2,2-5,6	1,1-2,2	2,2-5,6	2,2-5,6
Relative Density	1,32	1,20	1,40	1,38	1,14
Tenacity dry (cN/tex) wet	40-44 40-44	40-53 37-49	26-35 18-26	40-49 40-49	40-57 35-53
Elongation dry (%) wet	25-33 25-33	20-32 22-34	15-25 27-33	20-32 20-32	28-42 36-52
Young's modulus kgf/mm^2 cN/tex	 800-1 200 594-891	 600-1 200 490-980	 650-1 200 455-840	 1 100-2 000 788-1 420	 200-450 172-387
Elastic Recovery at 5% Elongation (%)	95-97	98-100	60-70	95-97	97-99
Heat Shrinkage	5-10	6-18	1-2	5-10	8-22
Resistance to sunlight	Slightly lower in tenacity after long time exposure	Similar to Belima	Remarkably lower in tenacity, deteriorates to 55% after 60 day exposure	Slightly lower in tenacity, after long time exposure	Yellowing and lower in tenacity after long time exposure

In developing Chinon, Toyobo staff started with a basic study of silk fibre[95]. The natural fibre is a polymer formed of blocks of crystallisable fibrin and non-crystallisable plastin. Characteristics of silk, including its lovely look and feel, are created mainly by the non-crystalline part[95]. In producing Chinon, casein — the same protein as that of silk — was therefore used for the non-crystalline part, while acrylonitrile was adopted for the crystalline part.

CHINON: PHYSICAL PROPERTIES COMPARED WITH SILK[95]		
	Chinon	**Silk**
Dry tenacity (cN/tex)	31 to 40	26 to 35
Dry elongation (%)	15 to 25	15 to 25
Wet tenacity (cN/tex)	28 to 37	19 to 25
Moisture regain (%)	4,5 to 5,5	9
Relative Density	1,2	1,33 to 1,45

COMPARISON OF PHYSICAL PROPERTIES[96]				
	Silk	**A-Telluna***	**Benzoate**	**Polyester**
Fibre strength (cN/tex)	26-35	40-42	35-47	44-49
Elongation (%)	15-25	32-33	25-35	32-35
Young's modulus (kg/mm²)	650-1 200	950-1 050	600-900	1 200-1 600
Young's modulus (cN/tex)	455-840	670-743	460-660	847-1 130
Elasticity (at 3%)	54-55 (at 8%)	95-100	95-100	95-100
Melting point (°C)		238	223-228	263
Softening point (°C)	—	228	197-201	256
Shrinkage in heated water (%)				
*normal temperature	— —	8-9	—	7-8
*high temperature	—	20-22	—	10-12
Moisture content (%)	11,0	0,4	0,4	0,4
Density (relative)	1,33-1,45	1,385	1,34	1,388

*Copolymerized polyester with benzoate (simulated silky fibre)

The Melting Point of A-Tell (238° C) is lower than that of polyester (263° C), but it is higher than that of nylon 6 (215-220° C) and near to that of nylon 6.6 (250-260° C)[96].

The comparative properties of oak Tasar, traditional Tasar and mulberry are given in the following table[97]:

Varieties of silk	**Shell ratio (%)**	**Filament thickness (μm)**	**Tenacity (cN/tex)**	**Elongation (%)**
Oak Tasar (A. Proylei)	12-14	20-25	22,1-26,5	25-30
Traditional Tasar (A. Mylitta)	8-12	30-35	13,2-17,6	20-25
Mulberry Silk (Bombyx Morie)	20-24	15-20	29,4-40,2	18-20

From the table it is clear that mulberry silk is superior in respect of all the desirable properties except elongation percentage to both the traditional as well as oak-fed Tasar silk. But out of the two kinds of Tasar, oak Tasar is far superior to the traditional Tasar in respect of filament fineness and mechanical properties, i.e. tenacity and elongation percentage. The higher tenacity of oak Tasar silk may be due to higher orientation or longer molecular chain length. The finer filament of oak Tasar can be well utilised for qualitative good preparation with softness and lustrous effect. The higher tenacity will also contribute much in different stages of processing[97].

Although the mulberry silk is finer than oak Tasar and has better strength, there are certain limitations. For mulberry silk production on industrial scale, a substantial farm area will be required. To produce only 100 kg of silk about $1\text{-}1^{1}/_{2}$ hectares of mulberry field will be necessary. With the increase in world population, the demand for food is also increasing. All the irrigated land will be needed for food production to meet the world's food crisis. Therefore, expansion of mulberry silk has some limitation. From the above point of view it is far better to cultivate wild Antheria Proylei Tasar silk-worms which can eat the leaves of wild oak plants readily available on hill ranges[97].

The most important process before actual reeling or unwinding of silk from oak Tasar is cooking. The purpose of cooking is to soften the glutinous substance, sericin, present in the cocoon shell. The cooking of mulberry cocoons is very easy and is generally done by boiling in water for a few minutes. Due to the different nature of the sericin content, oak Tasar cocoons require prolonged treatment of boiling and steaming as compared to mulberry cocoons. Some chemical treatments are also required in addition to boiling and steaming.

It has been found that a combination of boiling, steaming and soaking is better than all the other methods[97].

COMPARATIVE STRENGTH AND MOISTURE REGAIN OF SILKS AND SOME OTHER TEXTILE FIBRES[98]

Fibre	Tenacity (cN/tex) Air dry (65% RH)	Tenacity (cN/tex) Wet/Water	Moisture regain (%) at 65% RH
Silk	36	33	10,0
Cotton	35	39	7,0
Wool	15,5	10,8	17,0
Nylon 6.6	51	44	4,3
Polyester	50	50	0,4

Source: Fibre Data Summaries (Shirley Institute Pamphlet No. 91)

Note: The strength of fibres and filaments varies over a wide range from sample to sample and, in the case of man-made or synthetic fibres, according to the end-use requirements, e.g. fibres are produced with high or medium tenacity, high modulus, etc. The above figures are fairly typical of fibres for apparel uses.

SOME DETAILS OF PROPERTIES OF DIFFERENT SPIDER WEBS[99]
BLACK WIDOW'S WEB HAS HIGHEST TENSILE STRENGTH

	Breaking Load (cN)	**Web diameter* (μ m)**	**Elongation (%)**
Brown house	0,4-0,8	7,5	40
Golden garden	5,7-6,85	0,4	36,4
Black widow	0,4-0,8	3,8	22
Woods (Araneus)	2,3-2,67	0,1	51,2
* Single filament			

POLYPROPYLENE AND POLYOLEFIN

Both drawing ratio and temperature have a considerable effect on the tensile properties and shrinkage of polypropylene. Low shrinkage types (0 to 0,5% shrinkage) are on offer[100], e.g. for draw ratios increasing from 4:1 to 12:1, tensile strength trebled, extension decreased from about 100% to about 10% and the shrinkage decreased from about 15% to about 7%[100].

Polypropylene's melting point lies between 160 and 170° C compared to that of about 125 to 135°C for polyethylene[100]. It becomes plastic at approximately 140° C, softens at approximately 150° C (140° to 160° C) and melts at approximately 170° C (165° to 175° C).

Tumbling olefin sweaters for 10 minutes at 88° C should induce relaxation shrinkage[101]. This olefin (Marvess III) softens at temperatures above 149° C and tumbling temperatures should be kept below 93° C. Home laundering at 65° C and tumbling at about the same temperature are recommended. Shrinkage is less than 1% in length 5% (reversible) in width after 5 machine washings and tumble drying cycles if the sweater has been finished correctly[101]. Dry cleaning should not be used since certain solvents e.g. perchloroethylene, makes olefin hard.

Compared with polyethylene, polypropylene shrinks less at a given temperature, has higher tensile strength, is more inclined to split, and displays better mechanical properties thanks to the particularly marked capacity for molecular orientation of polypropylene[102]. Its melting point lies between 160 and 175° C, which is substantially higher than the 125 to 135° C of polyethylene. On the other hand polyethylene is softer, more supple and more extensible than polypropylene and therefore more *amenable* to processing. It bonds easier to coating materials, bonding agents or printing pastes, and has better resistance to ultra-violet light. Even very thin flat yarns of polyethylene show little proneness to splitting, so that surface-covering fabrics can be produced from this material with lighter mass and therefore cheaper than from polypropylene. From this it follows that carpet backings are made exclusively from polypropylene, whereas polyethylene is used chiefly for textile applications, for carpets and household textiles, fabrics for the garden, leisure and camping, etc.[102].

The following table and figure have been given for the physical properties of various ropes[103]:

SOME PHYSICAL PROPERTIES OF ROPES (DIAMETER 8 mm)

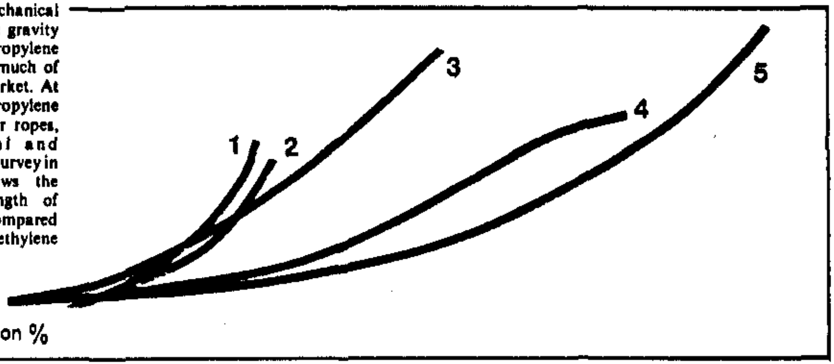
	Linear Density (ktex)	Breaking load (N)	Tenacity* (cN/tex)	Ratio Tenacity *to* manilla
Nylon (monofilament)	42	13230	31,4	3,2
Polypropylene	30	9410	31,4	3,2
Polyethylene (monofilament)	31,5	6860	21,6	2,2
Manilla	54	5292	9,8	1,0
Sisal	54	4802	8,8	0,9

• Breaking load divided by mass per metre

Ropes and twines[103]

The extremely good mechanical properties, low specific gravity and low price of polypropylene enable it to penetrate much of the rope and twine market. At the moment, polypropylene film fibres are used for ropes, cords, agricultural and packaging twines. The survey in Table 1 clearly shows the excellent tensile strength of polypropylene as compared with manilla, sisal, polyethylene and nylon.

Elongation of rope under load



1 = manilla, 2 = sisal, 3 = polypropylene, 4 = polyethylene, 5 = nylon.

As shown above, the elongation of polypropylene lies nearest to that of sisal and manilla.

Tensile strength of wet rope

Rope often becomes wet when used, so the tensile strength ratio between wet and dry cordage is very important. The tensile strength of polypropylene yarn is identical with that of dry yarn, because it does not absorb water, as do vegetable fibres and nylon. With these, ten to thirty per cent of the original strength is lost as a result of moisture absorption.
Vegetable fibres also rot, giving greater break liability, whereas polypropylene yarn does not suffer from this danger — nor does it suffer from ice formation problems. Ice on rope can just be shaken off[103].

An entirely new family of low cost fibres and yarns made from film have thus come into commercial usage combining a relative simple film and fibre forming operation with the excellent chemical, physical and mechanical properties of polypropylene — itself a low cost fibre forming material.

Fibrillation techniques are also being refined further to give novel types of polypropylene film fibres and yarns: they are also being developed for polyamides and polyesters.

ACRYLIC AND MODACRYLIC

The most significant advance in acrylic fibres of late has been the introduction of second-generation bicomponent fibres[104]. Such fibres should not be confused with biconstituent fibres. A bicomponent fibre is composed of two derivatives of the same genetic polymer. Biconstituent fibres are composed of two generically different polymers spun side by side into the same fibre.

First-generation acrylic fibres are crimped by mechanical deformation followed by heat setting, generally in a stuffer-box type of operation. The crimp so formed is usually of the planar, semi-permanent zig-zag type. Second-generation bicomponent acrylic fibres are composed of two polymers spun side by side in the same fibres; in some varieties the distribution of the two polymers is the same in all fibres, in others it is random. The two polymers are almost identical in all respects except thermal properties[104].

The crimp development mechanism is much the same as that operating in a bi-metallic strip, where, on heating, the two sides expand at different rates causing the strip to bend. When subjected to dry heat, boiling water or steam, the two segments comprising each fibre, shrink to different degrees introducing a helical three-dimensional permanent crimp[104].

The fibre bulk associated with such a crimped acrylic fibre approximates to the volume of a cylinder enclosing a helical coil rather than the volume of the fibre itself. When the distribution of the two polymers within the fibres is random, there is the additional advantage that the relatively low-crimp fibres composed of either of the two polymers prevent crimp register and intermeshing between the fibres of higher crimp, thus promoting maximum bulk and cover[104].

Owing to large recovery forces, helical, bicomponent crimp resists deformation more, and recovers more easily from deformation, than mechanically crimped fibres[104].

Bicomponent acrylic fibres were initially developed for piece-dyeing end uses. Historically, crimp wash-out is the principal reason preventing the production of piece-dyed carpet from acrylic fibres. With carpets made from bicomponent acrylic fibre, virtually all the crimp washed out during dyeing is recovered in finishing. One problem facing fibre manufacturers is to restrict the crimp development to a level that will allow the fibre to be spun without excessive breakage. With bicomponent fibres, approximately 75% of the bulk is developed during hank dyeing and the remainder during finishing. Total shrinkage is around 11% compared to 2-3% for a monocomponent fibre. An acrylic fibre must have a polymer composition of more than 85% acrylonitrile, whereas a modacrylic fibre may have a low acrylonitrile content of between50 and 85%[104]. Flame-resistant acrylic fibres have various halogen compounds incorporated in them at relatively low percentages, where as modacrylic fibres have compounds such as vinyl or vinylidene chloride in them, in considerably higher proportions.

The physical properties of both the flame-resistant acrylic fibres and the modacrylic fibres are similar to those of the standard acrylic fibres. Dyeing properties are slightly different. As the halogen level increases, the thermal stability decreases. In general, fibre yellowing owing to thermal degradation also increases as the halogen level increases. Dyes and dyeing auxiliaries have no appreciable effect on the thermal stability, or on flammability. Dyeing is more difficult as there are fewer dye-sites in the polymer and a careful selection of basic dyes must be used[104].

High shrinkage is a property which can be imparted to any acrylic fibre, whether it be first, second or third generation. Normal shrinkage is approximately 2-3% for a monocomponent fibre and 11% for a bicomponent fibre. High-shrinkage fibres can have a shrinkage ranging from 25 to 40% depending upon the end use of the fibre. The fibres can either be used in blends, with normal shrinkage mono-/or bicomponent fibres or in 100% form, blending with monocomponent fibres of normal shrinkage properties increases the bulk and cover. The mechanically crimped monocomponent fibre minimises intermeshing of the highly crimped high-shrinkage fibre, imparting extra bulk and cover[104].

Different effects can be achieved in blends by either stock dyeing or skein dyeing. If the high-shrink fibres and regular fibres are blended and spun after stock dyeing, then a bulky yarn will result. If, however, the two fibres are blended undyed, tufted into cut-pile carpet and piece-dyed, one component will shrink more than the other, imparting a special kind of effect. Furthermore, if one component is acid-dyeable and the other basic-dyeable the tip of the tuft appears as one colour and the base as another.

High-shrinkage fibres also have an application in woven carpets since they can be used to introduce sculptured effects which could not otherwise be achieved. Two yarns of different shrinkage are used to obtain this type of effect[104].

A number of polyacrylic fibres have been introduced which are co-polymers of vinyl cyanide with other vinyl compounds. A modified acrylic fibre is marketed which, while having a high proportion of acrylonitrile in the polymer is not a co-polymer in the usual sense. The co-monomer itself is, polymerised before a co-polymerisation with the acrylonitrile. The result is a type of block co-polymer and has been called by the makers, a "nitrile alloy". The presence of the block in the polymer disturbs the regularity of the packing of the acrylonitirile chains and opens up the molecular spacing. The alloy structure is essentially a continuous hydrophobic polyacrylonitrile backbone, containing discreet volumes of a hydrophilic dye-receptive polymer[104].

The acrylics have the best resistance to sunlight and weathering of all commonly used textile fibres[70]. In comparative Florida outdoor sunlight tests, it took 19 months for acrylic fibres to lose 50% of their tensile strength, while cotton and polyester fibres reached the 50% strength loss level in only $3^1/_2$ months[70].

Military sandbags are another application for acrylic fibres. During the Vietnam conflict, they proved to have better durability than those made from polypropylene ribbon yarns. The most commonly used acrylic was a 6,7 dtex 76 mm green-pigmented fibre for the bags and a 6,7 dtex, 150 mm fibre for sewing thread and tie strings.

Cotton fabric, in a mass range of 16-22 m/kg has been the traditional material used for tobacco shade cloth. Acrylic fibre is also now used, and has the advantage of lasting a year longer, because of its superior sunlight and weathering resistance.

Acrylic fibres are used in industrial filtration applications because of their combination of good resistance to heat degradation under wet and dry conditions and their resistance to hot, acid environments. Good resistance to a wide range of organic solvents and chemicals is also an important property.

Acrylic fibres of the *100% polyacrylonitrile type* like Dow Badische's Type 500 and Bayer's Dralon T have superior resistance to chemicals and heat when compared to the copolymer and terpolymer acrylic fibres. Acrylic-fibre filters can be based on needle-felt constructions or can be woven from yarn spun on the cotton or woollen systems[70].

Fine Acrylic[105]

A 1,3 dtex Acrilan Type B-16 introduced by Monsanto Textiles obviously falls in the category of replacement-for-cotton fibres: Its announced usage is for topweight broadwovens and fine-cut knits.

The spin limit of the new staple is rated at 10 tex. This may be contrasted with a limit of 24 tex for 3,3 dtex acrylics. Aside from characteristic acrylic hand, lustre and easy-care performance, the 1,3 dtex Acrilan yarns spun 100% and in blends *permit manufacture of fine-cut single knits for shirts*, blouses and dresses; fine-cut interlock and double knit for sportswear, shirts and blouses; and lightweight broadwovens for shirts, blouses and dresses. These are spring and summer products.

A 12 tex yarn spun from the 1,3 dtex fibre has a skein break factor of 2273, a 24% elongation, and exhibits boiling water shrinkage of 6,0%[105].

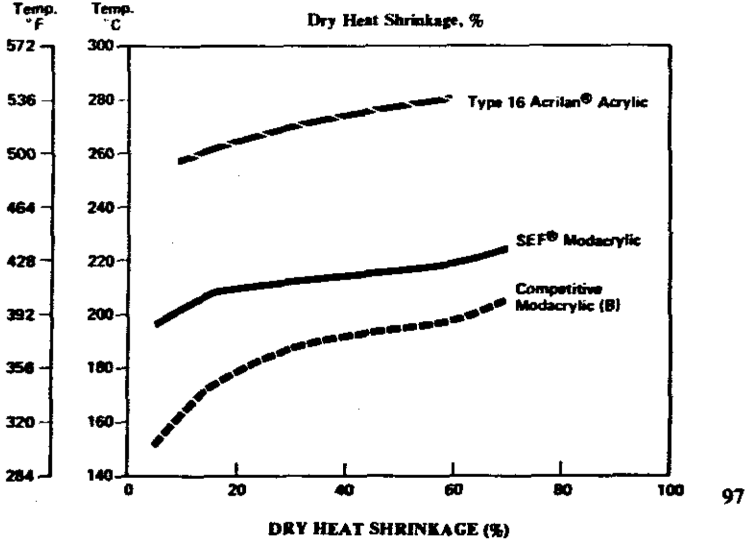
In the U.S. acrylic fibres are defined as containing 85% or more acrylonitrile, while modacrylics contain between 35 and 85%[106].

PHYSICAL PROPERTIES OF TORAYLON (TORAY ACRYLIC)[107]

Physical Property	**Unit**	**T-962F (3,3 dtex)**	**T-106F**	**T-176F**
Tenacity	cN/tex	33,6	33,6	31
Elongation	%	33,0	39,6	17,5
Number of Crimps	per cm	4,3 (8,7)	3,8	2,8
Degree of Crimp	%	15,0 (26,0)	10,6	13
Shrinkage in Boiling Water	%	3,0	0,9	22
Relative Density	—	1,17	1,17	1,17
Moisture Regain	%	2,0	2,0	2,0
Lustre	—	Bright	Bright	Bright
Linear density	dtex	3,3	5,6	5,6
Fibre Length	mm	102	102	102

NOTE: the figure in parenthesis denotes the value after treatment in boiling water

FIBRE DRY HEAT SHRINKAGE[108]



SECOND-ORDER TRANSITION TEMPERATURE FOR ACRYLIC FIBRES[109]

Method	Glass Transition Temperature (° C)		
	Dralon	**Euroacril**	**Courtelle**
Differential calorimetry			
Range	*80,2-108*	*76,3-105*	*80-109*
Mean	94,2	91	94,5
Dilatometry	90	87	93

NYLON

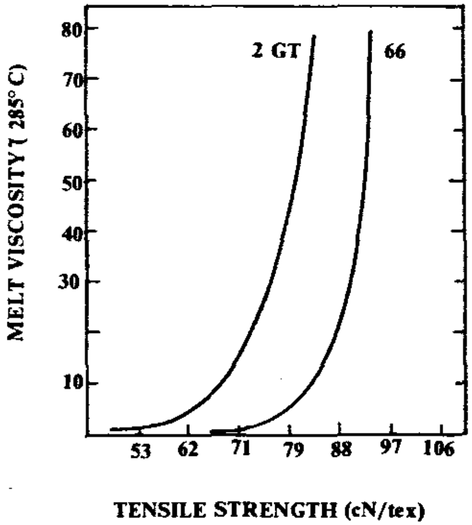
Nylon's recovery from elongation (elasticity or work recovery) improves with increasing humidity and is far superior to that of polyester at RH's above about 10%, at high elongations (above approximately 2%), in general, and in water[65].

Zimmerman[110] states that, for a given synthetic fibre, increased tensile strength through increased orientation is generally accompanied by a loss in toughness and extension. Furthermore, frequently

$$TE^n = \text{Constant}$$

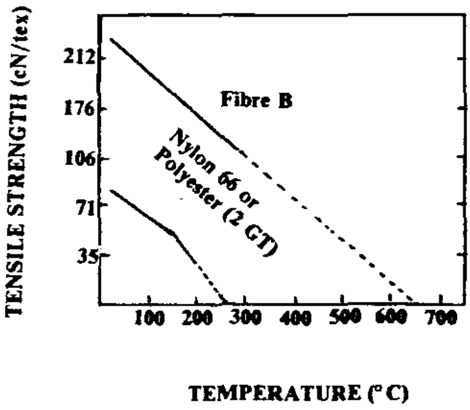
where T is tensile strength, E is elongation (extension) and n is of the order of 0,5.

Zimmerman gives the following figure to illustrate the effects of melt viscosity on tensile strength[110]:



To achieve major increases in tensile strength of industrial yarns, it has been necessary to move to a new type of polymer (e.g. Du Pont's Fibre B, DP-01 aromatic polyamide, where 176-194 cN/tex is normal). The slope of the tensile strength vs temperature curve is mainly dependent upon the melting point of the polymer[110].

The following curve[110] is an example:



Abrasion resistance of yarns, as placed in a fabric before extensive use, depends strongly on molecular weight and, to some extent, on fibre orientation and morphology[110]. It can also depend upon the dtex (or denier) per filament, fabric construction, nature and stress of the abrasive process and the coefficient of friction. For the normal melt-spun fibres, an increase in the average chain length from 80 nm to 120 nm has given an approximate two-fold increase in abrasive cycles to destruction in several standard abrasion tests. Fibre flex abrasion resistance is also strongly dependent upon molecular weight but is adversely affected by filament diameter (in contrast to flat abrasion). It is common to use a 0,6 gf/denier (5,3 cN/tex) tension for single fibre flexing.

Durability is often strongly affected by degradation (e.g. photodegradation) during use, which reduces the molecular weight. A reduction of only 20% in average molecular weight can reduce tensile strength by 50%, a much greater reduction than if the original molecular weight had been 20% less. All fibres are susceptible to strength loss when exposed to oxygen at elevated temperatures, some more than others. Unprotected, aliphatic polyamides are particularly vulnerable to free radical attack at the carbon adjacent to the amide nitrogen. Addition of small concentrations of Cu-based anti-oxidants can have a marked effect on inhibiting degradation[110]. Nylon industrial yarns contain Cu levels which give them a stability 40 or more times greater than that of unprotected nylon. Unprotected polyester yarns are considerably more stable than unprotected nylon 6.6 and have similar stability to commercial nylon tyre yarns. All-aromatic polyamides (e.g. Fibre B or Nomex) are inherently much more stable to oxidation than aliphatic polyamides and are superior to polyester and protected nylon 6.6[110].

Caustic degradation of polyester 0,25 N NaOH at the boil — 7/8 hours.

	Homopolymer	**Copolymer**
Strength loss (%)	20	80
Mass loss (%)	11	70
RV loss	0	0

Aliphatic polyamides (e.g. nylon 6.6), when subjected to high energy electron irradiation, in the absence of oxygen, retain 65% of their strength with little change in break elongation after 200 Mrad exposure. However, for the same radiation dose in air, strength retention is only about 20% while break elongation decreases drastically (e.g. from 19% to 7%). In contrast, all-aromatic polyamide yarns such as *Nomex* or *Fibre B* retain 75 to over 90% of their strength after 600 Mrads exposure in air (depending on the dose rate, the higher values for higher dose rates). This high stability of aromatic polyamides is not paralleled by a correspondingly high UV stability which is about the same as that of unmodified nylon[110]. Nomex is a heat resistant fibre which melts at 371°C, shrinks by only 2% when heated to 260°C and loses only half its strength when heated to 300°C for a week[113]. Qiana has a setting temperature of 140°C dry[113].

Nylon 6 melts at 210°C
Nylon 6.6 melts at 250°C.

These values can be reduced by as much as 70°C in the presence of moisture. Nylon 6 has somewhat better elastic recovery, fatigue resistance and resistance to degradation by light than nylon 6.6 Nylon retains 15% by mass of water after spin-drying compared with about 50% for cotton and 40% for wool. Wearer trials have shown that the addition of about 20% of nylon to wool increases the life of a stair carpet by about 50%[112].

COMPARISON OF SOME PHYSICAL PROPERTIES OF QIANA NYLON, NYLON 6.6 AND A POLYESTER[114]

	"Qiana" Nylon	6.6 Nylon	"Dacron" Polyester
Relative density	1,04	1,14	1,37
Interlace	5 to 10 cm	6 to 19	10
Elongation (%)	30 to 35	25 to 45	24 to 33
Tenacity (cN/tex)	26,5 to 30	44 to 53	25,5 to 30
Modulus (cN/tex)	283	336	795

COMPARISON OF PROPERTIES IMPORTANT TO DYEING AND FINISHING[114]

	"Qiana" Nylon	6.6 Nylon	"Dacron" Polyester
Shrinkage (BO-4MG/D)	5-6%	4,8%	7,0%
(BO+HS-16 MG/D)	9-10	0	1,0%
DFL	4-5%	0	0
Temperature			
Melting Point	280°C(536°F)	258°C(496°F)	249°C(480°F)
Stick point	230°C(446°F)	230°C(446°F)	230°C(446°F)
TG	135°C(275°F) 170°C(338°F)	47°C(117°F)	90°C(194°F)
Chemical Resistance			
Acid (10%-93°C)	Insoluble	Soluble	Insoluble
Alkali (40-50%-93°C)	Insoluble	Insoluble	Soluble
Colour ("b" value)	+ 1,0	+ 2,0	+ 0,8
Dye Responses			
Types	Disperse Acid	Disperse Acid	Disperse
Carrier	Yes	No	Yes

NB: Gray Fabric to Finished Fabric

FIBRE PROPERTIES[115, 116]

	Nylon 6.6	Polyester
Softening Point	234° C	234° C
Melting Point	250° C	250° C
Modulus at 65% RH-20° C (cN/tex)	309	538
Modulus at 93% RH-21° C (cN/tex)	141	645
Modulus at 93% RH-149° C (cN/tex)	71	26,5
Relative Density	1,14	1,38
Moisture Regain	3,8-4,2%	0,4%
Tenacity (cN/tex)	35-53	26,5-44

SETTING CONDITIONS[115]

	Nylon 6.6	Polyester
Dry Heat	204° C	138° C to 177° C
Steam	98° C(130° F)	116° C
Water	98° C	116° C

Nylon is generally set before dyeing and polyester after dyeing since the carrier and high temperature dyeing generally override much of the effect of presetting.

Some properties of different polyamides (nylons) are given in the table below[117]:

	Melting Point (° C)	Relative Density
Polyamide 3	340	1,33
Polyamide 4	256	1,25
Polyamide 5	260	1,13
Polyamide 6	215	1,12
Polyamide 6.6	255	1,13
Polyamide 6.10	193	1,10
Polyamide 7	225	1,10
Polyamide 8	200	1,09
Polyamide 9	210	1,09
Polyamide 11	190	1,08
Polyamide 12	180	1,08
Arom. Polyamide	(Chars at 430°)	1,38

MOST IMPORTANT PROPERTIES AND USAGE OF SOME POLYAMIDE (PA) TYPE FIBRES

	PA 3	**PA 6**	**PA 6.6**	**PA 11**	**Aromat PA**
Melting point, °C	300	215-220	255-260	190	Decomposes at 370-410° C
Regain (20° C, 65% RH)	7,7	3,5-4,5		1,2-1,3	4,5-7,0
Water retention (%)	22,1	10-15		6,5	unavailable

MOISTURE REGAIN OF:[119]

Nylon 6.6	4%
Nylon 6	4,5%
Nylon 4	7 to 8%

Holfeld and Shephard[111] presented the following review of the function of water as a carrier for nylon:

With today's nylons, barré due to variations in amine ends or dye sites is rare[111]. Most dye-related barré problems are now due to differences in fibre "porosity" which determine *accessibility* of the dye sites. Porosity is determined by the total tension-temperature history of the fibre-fibre manufacturing, plus texturing, heat setting, dyeing and finishing. Variations in porosity determine the *rate* of dyeability with dyes such as the milling and direct types. These are large molecules sensitive to differences in porosity and, therefore, are barré-prone. Because of the increased fashion demands for bright colours and good washfastness, the dyer is often forced to use sensitive dyes. Therefore, our work emphasizes the mechanisms involved in dye-rate barré with bright, "fashion colours" which are often based on rate sensitive dyes[111].

Water has profound effects on the processing and performance of nylon. For instance, nylon fabrics can be set with moist heat at 93 to 121° C; 80° C, or more below the 196 to 210° C necessary to set the same fabrics with dry heat! In sharp contrast, water (moisture) has very little effect on the heat setting of PET (polyester) which is generally frame-set at 163 to 177° C. Furthermore, once set, nylon, for all practical purposes cannot be set repeatedly by using successively higher temperatures[111].

Why should nylon and PET differ so dramatically in their responses to moisture and heat setting, when their softening (235° C) and melting points (250° C) are virtually identical? Nylon, of course, has moisture sensitive hydrogen bonds which are absent in PET. But just what is the rôle of moisture in the behaviour of nylon in heat setting, in dyeing and in fibre manufacture?

In this article data is presented to support the following conclusions:

- Nylon and PET fibre properties and responses are surprisingly similar when measured in the absence of moisture.
- Water is a potent carrier for nylon.
- Water, at least by itself, is not an effective carrier for PET.
- Water provides "chemical energy" which is equivalent to about 100° C of thermal energy in its effects on a variety of nylon fibre properties.
- The dyeing of nylon in water is equivalent to dyeing polyester in 100% carrier i.e. solvent dyeing.

The present consensus is that carriers lower the Tg (glass transition temperature) of a fibre, thereby increasing polymer-chain segmental mobility which increases dyeability (dye rate). Since free volume is temperature dependent, one explanation of carrier effects is that they reduce the thermal energy needed to achieve adequate free volume for dyeing. Water provides "chemical energy" equivalent to about 100° C of dry thermal energy in its effects on a variety of nylon fibre properties. Water has much less effect on PET, generally equivalent to about 20° C of thermal energy. The Tg of Nylon 6.6 at 0% RH is about 80° C based on measurements of films. At 100% RH, Tg is depressed to -10 to -20° C. Thus, water vapour lowers Tg of nylon by 90-100° C. Results show that Tg is extremely sensitive to trace amounts of residual moisture. In contrast, water lowers Tg of PET by only about 10-30° C[11].

Water, even water vapour, increases the segmental mobility of nylon automatically reducing its modulus by merely changing RH (relative humidity) at room temperature. In contrast, a dry air temperature of about 120° C is required to reduce the modulus to the level measured in water at 21° C. Thus, water provides chemical energy equivalent to about 100° C of thermal energy in its effect on lowering fibre modulus. The effect of water on PET modulus is minimal.

It has been shown that, in general, carriers which are effective in promoting the disperse dyeing of PET also caused significant fibre shrinkage.

SHRINKAGE OF NYLON AND POLYESTER AT DIFFERENT TEMPERATURES

Yarn	dtex	% B.O.S.*	% Dry Heat Shrinkage				
		100° C	100° C	160° C	177° C	196° C	225° C
Nylon	933	9,5	1,3	5,9	7,5	9,0	12,4
Nylon	233	7,9	1,1	5,0	6,4	7,6	10,0
Nylon	933	6,9	0,2	3,1	4,6	6,7	10,5
Nylon	933	5,8	0,1	2,6	4,6	6,2	10,2
Nylon	933	2,9	0,3	1,3	1,9	3,1	5,7
Nylon	933	1,9	0,0	0,5	0,9	1,6	4,5
Polyester	1111	1,5	0,5	3,1	4,5	5,9	12,2
Polyester	1111	1,1	0,3	2,1	3,1	5,1	14,0
Polyester	1111	—	1,1	10,0	14,0	18,0	37,0
Polyester	1222	3,5	0,6	8,8	11,9	14,5	21,0
Polyester	933	—	1,5	12,7	14,0	15,8	28,3

*Boil-off Shrinkage

Water meets this criterion for nylon. The shrinkage of a range of nylon fibres in water at 100° C is virtually identical to the dry heat shrinkage of the same yarns at 196° C. The data again shows that water has very little chemical energy effect on PET, equivalent to only about 10-20° C of thermal energy (see above table).

In air, nylon 6.6 melts at about 250-255° C. In water, it "melts" at about 160-170° C. Thus water again provides chemical energy equivalent to about 100° C of thermal energy. Data for polyester were not available.

Humidity reduces WE (work to elongate) for nylon from 16,8 in air (8% RH) to 3,5 cN cm/tex cm x 100) in water at 21° C. In dry air, a temperature of about 130° C is required to reduce WE to 3,5. Thus water provides the chemical energy equivalent of at least 100° C of thermal energy. Water has little effect on WE for PET : 21,2 in air and 21,1 in water at 21° C. The WE for polyester and nylon in dry air are equivalent to 150° C, indicating again that nylon and PET behaviour is similar when properties are measured in the absence of moisture.

Water reduces the stress value for nylon from 7,9 (cN/tex) in air at 8% RH to 2,6 (cN/tex) at 21° C in water. There is no effect on polyester: 9,7 in air and 9,7 in water. In dry air, about 140° C is necessary to reduce stress to the 2,6 value obtained in water at 21° C. Again, the value for PET in air is virtually identical to that of nylon above about 100° C, where residual moisture would be negligible.

The dependence of fibre properties on temperature is a general characteristic of polymers. As temperature rises, interchain distances increase.

This decreases interchain bonding forces and causes the loss in modulus and other properties. However, the overall effect of water is more complicated as indicated by the response of recovery properties to water. The work recovery of nylon increases with increasing RH. In contrast, there is very little effect on PET. This difference between nylon and PET is magnified when fibre recovery is measured in water. Nylon work recovery increased to 95% and tensile form recovery is as high as 98% when water temperature is increased, while PET recovery decreases significantly! Again, the general response of PET in water is very similar to its response in air and strikingly different from that of nylon. This improvement in nylon recovery properties suggests that water not only substitutes for thermal energy but also reduces internal "friction" for nylon. Therefore, we suggest that effective carriers, like water for nylon, help achieve equilibrium dyeing by a dual mechanism:
(1) they provide chemical energy which helps the system reach thermodynamic equilibrium and (2) they function as a "molecular lubricant", which facilitates kinetic or rate processes. This combined effect is clearly lacking with water on PET. The difference in response of nylon and PET to moisture has generally been considered only a difference in degree, attributed to the lower absorption of PET. Thus, e.g. PET absorbs only about 0,4% vs 4,0% for nylon 6.6 at 65% RH, 24° C. However, the strikingly different responses of nylon and PET recovery properties to increases in RH and water temperature indicate that moisture operates on nylon by a fundamentally different mechanism: water is a potent carrier for nylon but is, at best, a very weak carrier for PET[111].

Nylon 4's melting point is slightly higher than that of nylon 6.6[119].

Thermal degradation and yellowing of nylon[120]

The mechanism of thermal degradation and photodegradation of nylon fibres are broadly similar in that they include free — radical chain reactions in which methylene groups adjacent to carbonyl groups are attacked by peroxyl radicals or activated oxygen. Nylon is susceptible to direct attack by the activated oxygen because the marked degradation occurring on exposure in dry air does not increase significantly on increasing the humidity. Yellowing of nylon caused by thermal degradation is very difficult to remove. Sometimes spin finishes or coning oils are responsible for yellowing of nylon. In this, the lubricants applied to yarns while processing, decompose slowly and their decomposition products are mainly responsible for yellowing of nylon. This decomposition process is enhanced in presence of humidity, temperature and duration. Such yellowing, which is formed by decomposition of spin finishes or coning oils, can be removed to a great extent by certain treatments[120].

BI-COMPONENTS

Bi-components are fibres containing two different polymers arranged side by side along the length of a fibre and is obtained by extruding the two polymer solutions or melts through a common spinnerette hole[12]. After extrusion, they are cooled by a current of cool air, wound on bobbins and stretched on draw-twist machines.

Bi-component fibres consist of two components divided along the length of the fibre, into two more or less distinct regions[12]. There are two types of bi-component fibres manufactured (Side-by-side bi-component fibres and sheath-core bi-component fibres). It is possible of course that a bi-component fibre may vary in the lateral distribution of two components along the fibre length. It is also possible to prepare yarns consisting of mixtures of bi-component fibres and mono-component fibres.

Side-by-side bi-component fibres are those in which the two components, either solutions or melts are fed directly to the spinnerette orifices, being combined into bi-component fibres at or near the orifices. The bi-component fibre "Creslan" made by Cynamid International used for carpets is an example of the side-by-side bi-component fibre.

In sheath-core fabrics, one of the components is surrounded by the second component, the arrangement may be concentric or eccentric. For manufacturing such fibres, special types of spinnerettes are used. The core component is supplied from a reservoir and sheath component is supplied from another reservoir to surround the core component as extruded at the outer orifice. Kanegafuchi Spinning Company produces fibre WN 8, a sheath-core bi-component fibre (the sheath is nylon 6 and the core is polyester).

EF-121 is a nylon/polyester (70/30%) bi-constituent fibre (Matrix fibril system) which was specifically tailored for the tyre cord market in 1964.

Examination of the data shown below shows that EF-121 at room temperature has a higher tensile strength, modulus and yield point than nylon. Otherwise, toughness, crystallinity, crystal orientation and zero strength are equivalent to those of nylon 6.

COMPARISON OF A BI-COMPONENT NYLON/POLYESTER FIBRE WITH NYLON[68]

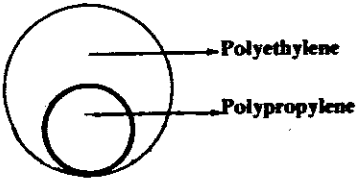
Properties	**EF-121 Fibre**	**Nylon 6**
Strength (cN/tex)	84	75
Elongation at Break (%)	15,5	20,0
Yield point (cN/tex)	9,7	6,0
Initial modulus (cN/tex)	662	397
Crystalline Orientation	93,0	94,0
Zero strength Temp (°C)	233-235	230-232

Property	**Rayon bi-component C-311**	**Orlon bi-component T21**
Tensile strength (cN/tex)	28,2	16,8
Tensile strength (wet) (cN/tex)	26,5	15,9
Elongation, dry (%)	11,0	38,0
Elongation, wet (%)	14,0	40,0

The melting points do not vary much and usually have a value intermediate between those of the components. For example melting point of Orlon T-21 is 250° C while that of ordinary Orlon is 255° C. Information is now available about the bi-component thermal-bonding fibre being introduced into various international markets by Chisso Polypro Fiber Co.[135].

There are significant differences between the Japanese fibre and the heterofil fibres produced by ICI Fibres. The latter have a sheath-core configuration, whereas it is understood that the Chisso items have a basically round cross-section formed by a core of polypropylene 'capped' for a large proportion of the circumference by a layer of polyethylene (see diagram right[135].:

The fiber producer states that the polyethylene layer has a melting point of 130°C and acts as the thermal bonding agent. The polypropylene maintains its original form during and after the bonding[135].



FIBRE PROPERTIES OF THE STANDARD CHISSO ES FIBRE[135]

Tenacity (cN/tex)	22~ 31
Elongation (%)	40~ 120
Crimp/cm	3,9 - 5,1
Moisture Regain 65% RH, 25°C	less than 1,0%
Shrinkage 105°C, Dry heat	less than 1,0%
Softening Point	110~ 120°C and 150~ 160°C
Chemical Resistance	excellent

WATER-SOLUBLE FIBRES
GENERAL PHYSICAL PROPERTIES OF SOLVRON (WATER-SOLUBLE POLYVINYL ALCOHOL FIBRE)[122]

Property	Type						
	SH	SM	SL	SX	SS	MH	ML
Dry Strength (cN/tex)	35-53	17,5-26,5	17,5-35	17,5-35	17,5-26,5	26,5-35	17,5-35
Dry Elongation (%)	10-14	28-35	15-25	15-28	30-40	17-25	17-25
Wet Strength (cN/tex)	16,5-26,5	4,4-8,8	—	—	—	17,5-26,5	—
Wet Elongation (%)	22-24	25-30	—	—	—	30-40	—
Dry Knot Strength (cN/tex)	26,5-35	17,5-26,5	17,5-26,5	17,5-26,5	17,5-26,5	17,5-26,5	17,25-26,5
Dry loop Strength (cN/tex)	35-53	26,5-44	35-44	44-53	17,5-26,5	17,5-26,5	17,5-26,5
Moisture regain (%)	3-4	4-5	5-6	5-6	10-13	7-8	7-8
Young's Modulus (kgf/mm²)*	1300-1800	600-800	500-700	600-1 000	300-400	400-600	500-600

* To convert kgf/mm² to cN/tex multiply by 0,98/density

	Type	Dissolving Temperature (°C)
Multi-filament	SH	93-95
	SM	88-90
	SL	55-65
	SX	45-50
	SS	10-15
Monofilament	MH	87-89
	ML	52-54
Staple	SL	55-65
	SX	45-50
	SS	10-15

TRANSFER PRINTING TEMPERATURES

APPLICABILITY OF VARIOUS FIBRES TO TRANSFER PRINTING[123]

Classification	Fibre	Softening Point °C	Melting Point °C	Transfer Print
Natural	Cotton	NIL	NIL	NA
	Silk	NIL	NIL	NA
	Wool	NIL	NIL	CA
Regenerated	Rayon	NIL	NIL	NA
Semi-synthetic	Acetate	190-205	260	CA
	Triacetate	200-240	300	A
Synthetic	Polyester	230-240	250-260	A
	Nylon 6	180	215-220	CA
	Nylon 6.6	230	250	A
	PVA	220-230	250-260	A
	PVC	75	185	NA
	Acrylic	190-290	NIL	A-CA
	Polyurethane	175	200-230	CA
	Polypropylene	140-150	160-170	NA

Some recommended temperatures and times for transfer printing different textiles are given below: The transfer print temperatures and times were as follows for Sublaprint[124]:

Material	°C	Seconds
Dicel (Courtaulds)	185	15
Tricel (Courtaulds)	195	25
Tricelon (Courtaulds)	195	20
Courtelle Standard (Courtaulds)	185	20
Courtelle RR (Courtaulds)	195	20 Yellows
Acrilan (Monsanto)	205	20
Orlon 42 (Du Pont)	205	20
Nomex (Du Pont)	250	30 (weak)
Polyester (I C I)	210	20
Polyester/cotton: 70/30 and 80/20	210	20
Lirelle (Courtaulds-polyester)	210	20
Spectran (Monsanto-polyester)	210	20
Polyester/Lycra (Du Pont)	195-200	5
Celon (Courtaulds-nylon 6)	200	20
Ultron (Monsanto-nylon)	200	20
Qiana (Du Pont)	200	20
Nylon 6.6/Lycra (Du Pont)	190	20
Dacron/wool (Du Pont)	200	25
Polyester/cotton: 'Koratron' sensitised	200	20
Self-extinguishing Fibre S.E.F. (Monsanto)	175	25
Basic dyeable Dacron Type 65 (Du Pont)	205	20
Teklan (Courtaulds)	140	40
Aluminium-anodised	220	20-60

The temperatures and times are approximate and depend upon the fabrication of the material.

Transfer Printing times as follows have been given for carpets[125]:

Nylon 6.6	205-210°C
Nylon 6	195°C
Polyester	205-215°C
Acrylics	200-210°C

Printing times ranges between 60 and 120 seconds and even up to 5 min.

The following values have also been given[126]:

Dicel	190-210° C for 15-30 s
Tricel	190-210° C for 20-40 s
Nylon 6	190-200° C for 20-40 s
Nylon 6.6	190-210° C for 20-40 s
Polyester	200-230° C for 20-40 s
Acrilan, Orlon, etc.	200-220° C for 15-30 s
Wool Blends	200-220° C for 20-40 s

In one paper, Barks[127] dealt with the transfer printing of fabrics including tricot power nets containing Lycra, the Du Pont elastomeric fibre. The best results were obtained by keeping the tension in the Lycra low, he said, while in printing it was best to use the lowest possible temperature for the shortest time; typical printing temperatures were:

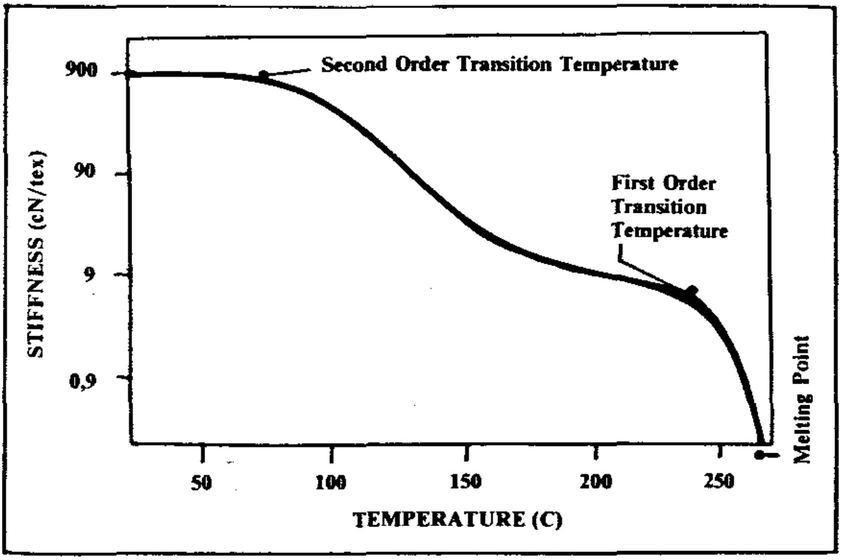
Lycra/nylon	170° C-185° C
Lycra/polyester	180° C-190° C
Lycra/Qiana	195° C-205° C

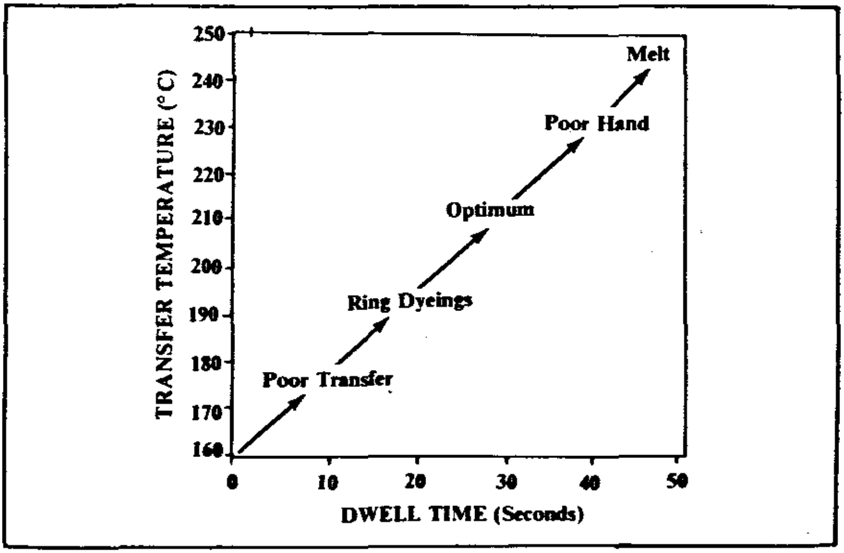
In transfer printing it was necessary to be more careful with fabrics containing Lycra[127].

CONDITIONS OF APPLICATION: GENERAL GUIDE OF RECOMMENDED TEMPERATURES AND TIMES FOR TRANSFER PRINTING[128]

Fabrics	Fabric Softening Temperatures (° C)	Cylinder/Blanket Machines		Suction Type Machines	
		Temperature (° C)	Time (s)	Temperature (° C)	Time (s)
Secondary acetate	190-205	185-195	10-25	185-195	8-12
Triacetate	200-240	185-200	20-30	185-200	10-15
Nylon 6	180	185-195	10-15	185-195	5-8
Nylon 6.6	230	185-195	15-20	185-195	8-10
Acrylic	190-240	185-195	10-15	200-205	10-15
Polyester	230-240	200-230	20-40	210-220	10-20
Polyester-wool		200-230	20-40	200-230	10-20
Polyester-cellulosic		200-230	20-40	200-230	10-20
Triacetate-nylon hetero		185-200	20-25	185-200	10-12
Nylon hetero/nylon type 472 & 473 (Qiana)		200	20-30	200	10-15

The effects of temperature and time on stiffness and transfer printing are shown for polyester in the two figures below[129].





Thermosol conditions for polyester/cotton blends (woven)[130]:

Listed below are the times and temperatures required for the various machines together with the thermosol temperatures for the BASF Palanil and Cottestren dyestuffs. Dyestuffs selection: For polyester/cellulosic blends, as the polyester is almost always dyed with dispersed dyestuffs it is predecided, whilst the most important dyestuff groups for the cellulosic component are:

1. Vat dyestuffs
2. Sulphur dyestuffs
3. Reactive dyestuffs

Without doubt there is a worldwide tendency to utilise vat dyestuffs.

Thermosol Process
Temperature range: 200-225° C
Reaction time: 15 - 60 secs

Mode of Heat Transfer	**Cottestren or Palanil dyes with medium diffusion numbers**		**Cottestren S or Palanil dyes with low diffusion numbers**	
	Temp. ° C	**Time (s)**	**Temp. ° C**	**Time (s)**
Hot air (stenter) (Hot-flue, MM-unit)	200-215	60-30	215-225	60-30
Hot air contact (Fleissner RT-range)	200-215	45-20	215-225	45-20
Contact (cylinder)	215	15-30	220-225	15-30

HEAT SETTING

Some heat setting details are given below for various fibre types[131]:

Type of fibre	**Normal heat setting**		**Rapid heat setting**	
	Temperature (°C)	**Setting time (s)**	**Temperature (°C)**	**Setting time (s)**
Synthetics				100-175 (g/m²)
Polyamide - Perlon	190-192	20	190-195	5-8
Polyamide - Nylon	205-215	18	210-230	5-8
Polyester	220-230	30	190-210	5-8
Blends				150 (g/m²)
Polyester woollen	185-190	30	190-210	10-12
Polyester cellulose	185-190	30	210	10-12

SOME RECOMMENDED PRESETTING CONDITIONS FOR KNITGOODS[132]

Process	Polyamide 6	Polyamide 6.6	Polyester	Polyacrylic
Hydro-setting on beams	125-130°C 15-20 min	125-130°C 15-30 min	125-130°C 15-30 min	–
Saturated steam-setting Vacuum steamer	125-130°C 2,5-3 bar 15-30 min	125-130°C 2,5-3 bar 15-30 min	125-130°C 2,5-3-bar 15-30 min	98°C 30-45 s
Heat-setting Stenter	170-185°C 15-20 s	180-190°C 15-20 s	160-180°C 20-30 s	140°C 15-30 s

THERMAL DATA, OPTIMUM SETTING CONDITIONS[123]

Fibre	Region of softening from slight tackiness to melting °C	Melting Point °C	Optimum setting conditions								
			Hot water		Saturated steam			Hot air		Infra-red selective emitter	
			Temp. °C	Time (min)	Temp. °C	Pressure (kPa)	Time (min)	Temp. °C	Time (s)	Temp. °C	Time (min)
Nylon 6	160-195	213-219	100	120-180	130 ± 4	≈ 14	10-30	190 ± 2	15-30	90-100	15-25
Nylon 6.6	*230-240*	*249-253*	*100*	*120-180*	*130 ± 4*	*≈ 14*	*10-30*	*215 ± 8*	*15-30*	*90-100*	*15-25*
Nylon 11	175	186	100	120-180	130 ± 4	≈ 14	10-30	170 ± 5	15-30	—	—
Co-polymer	—	237	100	120-180	130 ± 4	≈ 14	10-30	—	15-30	90-100	15-25
Polyester	230-240	200-260	100	120-180	140	≈ 14	10-30	210-220	15-30	90-100	15-25
Polyester (Kodel)	220	290-295	—	—	130 ± 4	≈ 14	10-30	210-220	15-30	90-100	15-25
Polyester (Vycron)	170-200	235	—	—	130 ± 4	≈ 14	10-30	185	30-45	90-100	15-25
Acrylic			—	—	—	—	—	—	—	—	—
Nytril	173	—	—	—	—	—	—	—	—	—	—
Vinylchloride/ Vinylidene-chloride	*115-137*	*150-160*	*100*	*30-60*	—	—	—	*90-110*	*15*	—	—
Vinylchloride/ Acrylonitrile	125-135	140-145	95	30-60	—	—	—	115-120	15	—	—
Polyvinyl-chloride	*60-80*	*180-210*	*60-80*	30	—	—	—	*60-80*	*10*	—	—
Polyethylene		110-120	80-82	15	—	—	—	80	10	—	—
Polypropylene (isotactic)	149-155	163-169	—	—	—	—	—	—	—	—	—
Polytetrafluoro-ethylene		400	—	—	—	—	—	—	—	—	—
Triacetate	250	app. 300	—	—	—	—	—	210-230	15-30	90-100	15-25
Diacetate	175-	245-250	80-100	60-180	—	—	—	180-200	10-15	—	—

METHODS OF INDUCING AND RECOVERING FROZEN-IN STRAIN IN FIBRES(13)

Class	Fibre	Induced by:	Recovery
Natural	Wool	(i) Straining above yield point, dry (ii) Straining wet and drying under strain	Wetting under no load
	Silk	Straining wet and drying under strain	Wetting under no load
	Cotton	Small amount by straining wet and drying under strain	Wetting under no load
	Flax	Very small amount by straining wet and drying under strain	Wetting under no load
Regenerated	Viscose rayon	(i) Straining dry (ii) Straining wet and drying under strain	Wetting under no load
	Cellulose diacetate	(i) Straining dry (ii) Straining at 180°C and cooling under strain	Heating to 180°C
Synthetic-polymer	Polyacrylonitrile fibre	(i) Straining cold (ii) Straining dry at 140°C and cooling under strain (iii) Straining in steam and cooling under strain	Steaming or dry heating a 140°C under no load
	Polyvinyl chloride fibre	(i) Straining cold (ii) Straining at 100°C and cooling under strain	Heating in steam or dry heating at 100°C
	Polyester fibre	(i) Straining cold (ii) Straining at 190°C and cooling under strain	Heating to 190°C, no loa
	Polyamide fibre	(i) Straining cold (ii) Straining at 150°C and cooling under strain	Heating to 150°C, no loa
	Polyolefin fibre	(i) Straining cold (ii) Straining at 130°C and cooling under strain	Heating to 135°C, no loa

THERMAL PROPERTIES OF VARIOUS FIBRES[134]

Material	Softening temp. °C	Melting temp. °C	Texturing temp. °C	Crimp contraction 77 dtex (%)
Polyamide 6.6	235	250	210-230	70-80
Polyamide 6	170	215	180-200	70-80
Polyester	230-240	256	200-230	60-70
Polypropylene	150-155	163-175	145-165	45-55
Polyacrilonibile	235-350	Decomposes before melting	150-170	14-20
Triacetate	Adheres at 260°C	300	200-220	10-14
Acetate	175-190	260	160-180	7-11

REFERENCES

1. Anon., Metric Yarn Twist Factors — A New Calculator, Shirley Institute Press Release (1 Dec., 1976).
2. Bayes, A.W., *Text. Inst. Ind.*, **9**, 44 (Feb., 1971)
3. Reader, A.M., *Text. Ind.*, **139**, 55 (Nov., 1975).
4. Grosberg, P., *Text. Inst. Ind.*, **10**, 262 (Sept., 1972).
5. Seyfarth, K., *Int. Text. Bull.* (Spinning), 3/1974, 225 (1974).
6. Martindale, J.G., *J. Text. Inst.*, **36**, T35 (1945).
7. Anon., Uster-Manual of Evenness Testing Part 2: Basic Information and Evaluation, (1961).
8. Balasubramanian, N. and Iyengar, R.L.N., *Indian Text. J.*, 561 (August, 1961).
9. Wegener, W., *Mell. Textilber.*, **56**, 511 (July, 1975).
10. Dyson, E., *J. Text. Inst.*, **65**, 215 (1974).
11. Merritt, R.E., *Knitt. Times*, **47**, No. 1, 34 (2 Jan., 1978).
12. Grover, E.B. and Hamby, D.S., Handbook of Textile Testing and Quality Control, Textile Book Publishers Inc. (Interscience, New York, 1960).
13. Sundaram, V., Ramanathan, S. and Iyengar, R.L.N., *I.S.I. Bulletin*, **24**, No. 3, 2 (1972).
14. 1975 Annual Book of ASTM Standards, Part 32, D1578-67 (Reapproved 1972).
15. Balasubramanian, N., *Ind. Text. J.*, **84**, 73 (Sept., 1974).
16. Ruppenicker, G.F., Kingsberry, E.C. and Little, H.W., *America's Textiles (The Knitter Ed.), AT-4*, 40, (Oct., 1975).
17. Anon, *Kettenwirk-praxis* (English Ed.) **177**, 17 (1977).

18. Suessen Pocket Book (Spindel-fabriek Suessen).
19. Ishida, T., *Japan Text. News, No.* **276**, 109 (Nov. 1977).
20. Holzmann, *Ind. Text. J.*, **87**, 78 (Nov., 1977).
21. Hamby, D.S., The American Cotton Handbook, Vol. I, page 356 (1965). *(Interscience Publishers).*
22. Vaughn, E.A., *Text. World*, **126**, 115 (Oct., 1976).
23. Anon., *Int. Text. Bull.* (Weaving), 1/1974, 34 (1974).
24. Heap, S.A., *OE Report*, 9 (1977).
25. Prentice, A.N., Cotton, Longman Group Ltd., (London, 1972).
26. Feaster, C.V., Principles and Objectives of Cotton Breeding, 42.
27. Laun, D.C., Ph.D. Thesis, University of Texas (Cotton Economic Research), (Oct., 1959).
28. Cotton Testing Service Tests, USDA Publication (May, 1970).
29. Keim, D., *Chemiefasern/Textil-Industrie*, **27/79**, E.68 (May, 1977).
30. Mäder, H., *Wool Record*, **130**, 53 (August, 1976).
31. Carnaby, G.A., *Text. Inst. & Ind.*, **12**, 269 (Sept., 1974).
32. Downes, J.G., *Wool Techn. Sheep Br.*, **22**, No. 2, 44 (Sept., 1975).
33. Müller, H., SABS Symposium: Quality Assurance in Modern Textiles, (Pretoria, 1974).
34. Anon., *Knitt. Int.*, **84**, 54 (May, 1977).
35. Krause, H.W.,*Mell. Textilber.*,**5**, 261 (April, 1975).
36. Riggert, K., *Mell. Textilber.*, **58**, 274 (April, 1977).
37. Rennell, R.W., *Textiles*, **7**, No. 1, 12 (1978).
38. Agnihotri, V.G., *Colourage*, **23**, 41 (4 March, 1976).
39. Pleasance, H.D., *Text. J. Austr.*, **50**, 20 (Oct., 1975).
40. Campagna, F.E. and Sawkney, A.P., *Text.Ind.*, **141**, 64 (Jan., 1977).
41. Arbuckle, A.W., *Int. Dyer Text. Printer*, **155**, 254 (19 March, 1976).
42. Czelny, K.T.J., *Text. Inst. Ind.*, **13**, 103 (April, 1975).
43. Anon., *Japan Text. News*, No. 254, 42 (Jan., 1976).
44. Albrecht, W., *Chemiefasern/Textil-Industrie*, **29/79**, E142 (Oct., 1977).
45. Anon., *Japan Text. News*, No. 211, 26 (June, 1972).
46. Anon., *Man-Made Fibre Desk Book* published by Modern Textiles and Modern Knitting Management, (March, 1976).
47. Agnihotri, V.G., *Colourage*, **23**, 41 (4 March, 1976).
48. Anon., *Machine Design*, No. 6, 214 (17 March, 1977).
49. Moncrieff, R.W., *Int. Text. Dyer and Printer*, **151**, 445 (3 May, 1974).
50. Anon., *Japan Text. News, No.* **252**, 76 (Nov., 1975).
51. Albrecht, W., *Text. Manuf.*, **100**, 39 (Aug., 1973).
52. Ochiai, T., *Japan Text. News, No. 226*, 78 (Sept., 1973).
53. Ishikawa, N., *Japan Text. News, No. 253*, 78 (Dec., 1975).
54. Links, H., *Textil Praxis Int.*, **31** 1162 (Oct., 1976).
55. Gopalan, N.S., *Wool & Woollens of India*, 17 (Nov., 1973).
56. Anon., *Mellor Bromley*, (Leicester) Publication.

57. Seghezzi, H., *Mell. Textilber.*, **57**, No. 11, 912 (1976).
58. Robinson, T., *Textilverdelung,* **12** No. 6, 264 (1977).
59. Preston, J.M. and Nimka, M.V., *J. Text. Inst.*, **40**, P676 (1949).
60. Petkar, B.M. and Oka, P.G., *Colourage,* **24**, 21 (28 April, 1977).
61. Morton, W.E. and Hearle, J.W.S., Physical Properties of Textile Fibres, Heinemann Ltd., London, 1975.
62. Roberts, N.F., *Text. Res. J.*, **26**, 687 (1956).
63. Beal, R.P. Dullaghan, M.E., Goodell, M.W. and Lulay, A., *Text. Chem & Col.*, **6**, 630 (January, 1974).
64. Okabayashi, M., Yamazaki, C., Terada, K. and Negishi, T., *Text. Res. J.*, **46**, 429 (1976).
65. Hallada, D.P., *Can Text. J.*, **92**, 70 (Aug., 1975).
66. Onions, W.J., *Text. Inst. Ind.*, **12**, 204 (July, 1974).
67. Anon., *L'Industrie-Textile, No. 1067,* 289 (May, 1977).
68. Jain, P.C., *Colourage,* **21**, 27 (27 June, 1974).
69. Entwhistle, R., *Text. J. Austr.*, **49**, 26 (April, 1974).
70. Mansfield, R.G., *Text. Ind.*, **140**, 160 (Sept., 1976).
71. Rutherford, H.A., *Text. Chem. Col.*, **6**, No. 11, 237/33 (Nov., 1974).
72. Clarke, G., *Britt. Knitt. Ind.*, **47**, 58 (Oct., 1974).
73. Anon.; *Japan Text. News,* No. 269, 52 (April, 1977).
74. Schmidt, W. and Prengel, H-G., *Textiltechnik,* **26**, 483 (1976).
75. Albrecht, W., *Textilveredlung,* **11**, No. 3, 90 (1976).
76. Jung, H., *Mell. Textilber.*, **57**, No. 10, 787 (1976).
77. Szilva, E.G., *Sources and Resources,* 1977/7, 22 (1977).
78. Müller,. S. and Obterloh, F., *Chemiefasern/Textil-Industrie,* **27/79**, E78, (May, 1977).
79. Shiraki, H., *Japan Text. News,* No. 237, 73 (Aug., 1974).
80. Bhatty, F.A., *Pakistan Text. J.*, 40 (Sept., 1964).
81. Malabon, R.W., *Text. Inst. Ind.*, **11**, 240 (1973).
82. Dykes, J.B. and Muller, T.E., *Indian Text. J.*, **86**, 147 (April, 1976).
83. Varghese, J., Pasad, D.M. and Patel, P.B., *Colourage,* **24**, 23 (13 October, 1977).
84. Parikh, R.S., Mair, P.K., Singh, B., Rawat, J.S. and Ranganathan, S.R., *Colourage,* **23**, 43 (9 Dec., 1976).
85. Anon., *OE Report,* **1**, No. 3, 13 (1977).
86. Anon., *Text. J.* of *Austr.*, **51**, 21 (Dec., 1976).
87. Lennox-Kerr, P., *Text. Asia,* **8**, 107 (June, 1977).
88. Wakil, A.A. and Khan, F., *Pakistan J. Sci. Ind. Res.*, **18**, 162 (1975).
89. Sengupta, S.R., *Colourage,* **22**, 35 (4 Sept., 1975).
90. Sinha, M.K., *J. Text. Inst.*, **65**, 612 (1974).
91. Mukherji, S.N., *Ind. Text. J.*, **85**, 92 (Jan., 1975).
92. Dasgupta, P.C., Sen, S.K., Sen, K., Mazumdar, M.C. and Chakravarty, A.C., *J. Text. Ass.*, **36**, No. 3, 132 (July/Sept., 1975).

93. Ghosh, S.K. and Sinha, M.K., *Ind. Text. J.*, **87**, 111 (Nov., 1977).
94. Anon., *Japan Text. News*, No. 234, 37 (May, 1974).
95. Anon., *Text. Month*, 52 (May, 1974).
96. Anon., Japan Text. News, No. 265, 55 (Dec., 1976).
97. Gupta, N.P. and Arora, R.K., *Indian Text. J.*, **87**, 101 (Feb., 1977).
98. Chadwick, A., *Textiles*, **6**, No. 3, 58 (1977).
99. Hall, D.M., Mora, E.C. and Broughton, R.M., *Text. World*, **127**, 44, (August, 1977).
100. Mackenzie, J.P., *Text. Inst. Ind.*, **14**, 15 (Jan., 1976).
101. Anon., *Knitt. Times*, **43**, 70, (15 July, 1974).
102. Mackenzie, J.P., *Text. Inst. Ind.*, **14**, 15 (Jan., 1976).
103. Anon., Shell Chemicals Publication in Polypropylene Fibres and Yarns from Film (Holland, 1971).
104. Anon., *Colourage*, **23**, 43 (16 Sept., 1976).
105. Anon., *Text. Ind.*, 13 (Oct., 1976).
106. Zogu, I., *Teintex*, No. 1, 6 (1977).
107. Anon., *Japan Text. News*, No. 277, 73 (Dec., 1977).
108. Dunham, A.A., *Knitt. Times*, **43**, 35 (17 June, 1974).
109. Cegarra, J. Puente, P. and Valldeperas, J., *Text. Chem. Col.*, **6**, 170/23 (August, 1974).
110. Zimmerman, J., *Text. Manuf.*, **101**, 19 (Jan., 1974).
111. Holfeld, W.T. and Shepard, M.S., *Can. Text. J.*, **94**, 80 (April, 1977).
112. Morris, W.J., *Textiles*, **6**, No. 2, 30 (June, 1977).
113. Morris, W.J., *Textiles*, **6**, No. 2, 30 (June, 1977).
114. Anon., *Am. Dyest. Rep.*, **66**, 20 (March, 1977).
115. Hallada, D.P., *Can. Text. J.*, **92**, 70 (August, 1975).
116. Holfeld, W.T. and Hallada, D.P., *Knit. Barré, Causes and Cures*, AATCC Symposium 39 (1972).
117. Albrecht, W., *Mell. Textilber.*, **58**, No. 7, 528 (1977).
118. Beste, L.F. and Hoffman, R.M., *Text. Res. J.*, **20**, 441 (1950).
119. Anon., *Colourage*, (Man-Made Textiles), 23 (24 June, 1976).
120. Agnihotri, V.G., *Colourage*, **22**, 25 (25 Dec., 1975).
121. Kothari, J.D., *Man-Made Textiles India*, 433 (Aug., 1975).
122. Uzumaki, M., *Japan Text. News*, No. 257, 43 (April, 1976).
123. Mount, W.J., *Text. Inst. Ind.*, **13**, 73 (March, 1975).
124. Vellins, C.E., *Britt. Knitt. Ind.*, **47**, 61 (Nov., 1974).
125. Anon., *Chemiefasern/Textil-Industrie*, **27/79**, E33 (March, 1977).
126. Doshi, S.M., *Colourage*, **22**, 25 (20 March, 1975).
127. Barks, D.E., *Text. Month*, 96 (Nov., 1974).
128. Consterdine, K., *Rev. Prog. Coloration*, **7**, 39 (1976).
129. Suchecki, S.M., *Text. Ind.*, **140**, 25 (Aug., 1976).
130. Adcock, A., *Text. J. Austr.*, **49**, 34 (Sept., 1974.

131. Shetty, S.M. and Parikh, V.R., *Colourage*, **22**, 59 (7 Aug., 1975).
132. Heimann, S. and Tobias, W., *Int. Dyer Text. Printer*, **153**, 463 (2 May, 1975).
133. Rosborough, E.I., *J. Text. Inst.*, **65**, 133 (1974).
134. Sengupta, A.K., *Ind. J. Text. Res.*, **1**, 53 (June, 1976).
135. Anon., *NONWOVENS REPORT*, 3 (November 1977).

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