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Textiles: Some Technical Information and Data: I

by

L. Hunter

SOUTH AFRICAN
WOOL AND TEXTILE RESEARCH
INSTITUTE OF THE CSIR

P.O. BOX 1124
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In textiles, as in other disciplines, technical and scientific information is increasing at a tremendous pace and the number of scientific and technical articles published is also growing at an ever increasing rate. Such publications are invaluable sources of factual data and information to the textile technologist and scientist but because of the growing volume, information retrieval is becoming increasingly difficult. Although computerised information storage may solve the problem one day there appears to be no complete solution available at the present time. Nevertheless, review articles published from time to time, as well as publications such as The Wira Textile Data Book[1] contribute much towards making such information available, thus alleviating the situation.

In the past few years, while scrutinising the technical and scientific journals dealing with textiles, the author has often noted little bits of information and data of particular interest. Since much of the information is not available in a compact and readily accessible form, it was considered to be of some value to compile and publish certain of the information collected over the years. In many cases the references were noted together with the information, but in others the reference (source of information) was never recorded. Such information has nevertheless also been included, notably that considered to be of particular interest and the author therefore apologises to the sources of such information for omitting them. The author presents the information as originally given and lays neither claim to nor accepts responsibility for the accuracy thereof. Much of the information and values quoted refer to overseas countries but in most cases these could also be used locally as a guide.

COTTON FIBRE PROPERTIES

The following classification of cotton, according to staple length, has been encountered[2]:

Short	under $^{13}/_{16}$"	(< 20,6 mm)
Medium	$^{13}/_{16}$" – 1"	(20,6 mm – 25,4 mm)
Medium Long	1 $^{1}/_{32}$" – 1$^{3}/_{32}$"	(26,2 mm – 27,8 mm)
Long	1$^{1}/_{8}$" – 1$^{5}/_{16}$"	(28,6 mm – 33,3 mm)
Extra long	longer than 1$^{3}/_{8}$"	(> 35 mm)

Cottons with average physical properties are stated[3] to be the most popular and functionally useful in most end products. For example, cottons ranging from 25 mm to 27 mm (1" to 1$^{1}/_{16}$") in staple length, 4,0 to 4,5 in micronaire reading, 75 000 to 90 000 lbs/sq inch in strength, 7 to 8 *per cent* in elongation and Low Middling to Middling in grade have been processed efficiently into fabrics suitable for the majority of end uses.

BUNDLE TENACITY OF WOOL (STELOMETER)

Normally a decrease in tenacity of between 10 and 20 *per cent* occurs as a result of dyeing[13] and a tenacity value of below about 10 gf/tex is regarded as critical for further processing. A high correlation between bundle tenacity and yellowness, urea-bisulphite solubility and lanthionine content was found[13].

THE YELLOWNESS OF WOOL TOPS

The following yellowness standards for wool tops have been set up by the Deutsches Wollforschungsinstitut[13]:

Class	Colour	Yellowness Index* (%)
1	White	below 45
2	Very light yellow	46 – 50
3	Light yellow	51 – 55
4	Yellow	56 – 65
5	Very yellow	over 65

*Yellowness Index = $\sqrt{(100 - R_y)^2 + [2{,}35\,(R_x - R_z)]^2}$ where R_x, R_y and R_z are the reflectance values determined by using the red, green and blue Elrepho tristimulus filters.

A high correlation between yellowness index and lanthionine content, urea-bisulphite solubility and bundle tenacity[13] was found. The yellowness was measured with an Elrepho (Zeiss).

CHEMICAL CHARACTERISTICS OF WOOL

Zahn[176] suggested the following tolerances for certain chemical characteristics of wool:

Foreign Matter	Dichloromethane extractable matter pH of acqueous extract Soda Content (maximum) Pyridinextractable sulphuric acid (maximum) Chrome content (maximum)	0,5 to 1,0% 9,5 (9,8) 0,5% 0,5% 0,6%
Amino acids	Cystine content Cystein content (maximum) Lanthionine content (maximum) Cysteic acid content (maximum)	11% to 12,5% 0,3% 0,4% 0,4%
Chemical Solubility	Alkali Solubility (of Finest Merino) Increase in Alkali Solubility due to chlorination (maximum) Increase in Alkali Solubility due to carbonising (maximum) Alkali Solubility of Carbonised Wool Tops (maximum) Increase in Alkali solubility due to acid dyeing (maximum) Urea Bisulphite solubility of wool dyed with chrome dyes – at least β-Keratose in tops (maximum) β-Keratose in chrome dyed wool (maximum)	10% to 15% 17% 6% 2% to 3% 20% 3% 10% 20% 30%

ABSORBTION OF WATER BY WOOL

Dry wool absorbs 35 *per cent* of its mass in water (33 *per cent* is more precise) and, in doing so, swells about 16 *per cent* in diameter for a one *per cent* increase in length. The elastic modulus and fibre surface friction are decreased thereby[14].

DUST IN COTTON CARD ROOMS

One milligram of dust per cubic metre of air is the American federal standards for card rooms[15]. It is expected[16] that this could be reduced to 0,5 or 0,25 mg/m^3.

SLIVERS FOR OPEN-END (OE) SPINNING FRAMES

It has been stated[17] that these should satisfy the following:

(i) They should not contain particles of trash weighing over 0,15 mg .
(ii) The average mass of particles extracted by hand should not exceed 0,1 mg .
(iii) The average mass of particles of trash extracted by the Shirley Analyser should not exceed 0,025 mg .
(iv) The total mass of trash present should not exceed 0,4 *per cent* (i.e. 4 mg/g of sliver).

To maximise yarn quality it is recommended[17] that:

(i) Second passage draw frame sliver be used;
(ii) Nep content be less than 150 neps per gram of sliver;
(iii) The sliver be "regular" according to Uster standards, i.e. not more than 3,8 *per cent* CV (3,0 *per cent* U) for a 3 ktex sliver. It is most important to avoid "hard" impurities heavier than 0,15 mg .

NEPS IN WORSTED TOP SLIVER

These approximate a Poisson distribution which gives a mean and variance of n and a standard deviation of $\sqrt{n}$. Therefore, if the average number of neps per gram is two, a total of 200 tests is required to achieve an accuracy of 10 *per cent* at the 95 *per cent* level of significance[18].

SPINNING

Recommended conditions for spinning polyester and blended yarns on the cotton system:

Card room	:	50–54 *per cent* RH; 22–24°C
Spinning	:	38–42 *per cent* RH; 24–26,7°C

The latter conditions are commonly encountered in cotton spinning departments[19] and give the minimum end breakage rate[20] while high temperature and humidity conditions give maximum lea strength when the latter is measured under standard atmospheric conditions[20].

Rovings for Repco spinning should be produced at 21°C and 65 *per cent* to 70 *per cent* RH[21] while spinning at 55 to 65 *per cent* RH is preferred[22].

For Open-end (OE) spinning 25 to 30°C and 50 to 70 *per cent* RH are regarded as acceptable[23]. OE spinning is apparently less sensitive to atmospheric conditions than ring spinning[23].

In the case of worsted yarns atmospheric conditions of 26,7°C (80°F) and 69 *per cent* RH can be used in the spinning room[24] while for the preparation and spinning of polyester and polyester/wool on the worsted system 65 *per cent* RH and 21°C have also been suggested.

In single end strength testing, an increase in the ambient conditions from 65 *per cent* to 75 *per cent* RH will result in a 4 *per cent* to 5 *per cent* increase in the strength of cotton yarns and a decrease of about 6 *per cent* in that of wool yarns[25].

FUSION OF SYNTHETICS DURING SPINNING

The problem of fusion of synthetics during ring spinning can be solved by correct traveller selection and ring contours and by making sure that the yarn is not pinched between the traveller and the ring[26]. When spinning cotton, polyester or other short or medium staple length fibres on Saco-Lowell's Model SCB Spinomatic, rings having an electro-polished finish are recommended since they provide a mat surface to minimize friction-generated heat. For worsted fibres (long staple) a lubricated vertical or conical ring can be used[26].

FAULTS IN YARNS

In a recent study[27] on the faults which occur in yarns it was concluded that, with reference to all the spinning systems and material types investigated, the majority of all yarn faults which can be considered disturbing are the result of fly. This fly can attach itself to the material in the processes prior to spinning and, as, fly primarily consists of short fibre, results in slub-like disturbances in the yarn. The majority of fly-type faults is produced, however, on the spinning machine itself. The best would be to suck off all fly immediately it is produced, and in this way, it could be expected that 50 *per cent* to 75 *per cent* of all faults in spun yarn would disappear.

ENDS DOWN

In the case of 20 tex cotton yarns about 30—35 ends down per 1 000 spindle hours can be considered about average while 50 are poor and 10 are good[26]. The average speed for cotton ring spinning was said to be approximately 10 500 r/min[26] in 1972. Ends down can be reduced by automatic wind-up and start up of frames, automatic doffing, variable speed drives with built in devices for automatically varying the spindle speed as the bobbin builds in size, meticulous care of the spinning frame, proper ring and traveller selection and proper maintenance of drafting elements[26]. A value of 40 ends down per 1 000 spindle hours is often taken as a standard for ring-spun cotton yarns[28], while 35 ends down per 1 000 spindle hours have been quoted[29] as being average for a 20 tex ($^1/_{30}$'s c.c.) cotton yarn. For combed cotton, 8 to 25 ends down per 1 000 spindle hours are considered to be low. One mill averages about 14 ends down per 1 000 spindle hours and aim at a maximum of 20 at spindle speeds (ring spinning of cotton) ranging from 10 500–12 500 r/min[19].

In the case of OE yarns 60 endsbreaks per 1 000 rotor hours at 45 000 r/min are considered acceptable[30]. Douglas[31] mentions 50 to 70 ends down per 1 000 turbine hours for a 36 tex yarn at a delivery speed of 40 to 60 m/min while Lennox-Kerr quotes an end breakage rate of 40 to 60 per 1 000 rotor hours on OE frames[32].

For 25 to 28 tex wool/polyester worsted yarns 30–35 end breaks per 1 000 spindle hours are typical. A value of 40 end breaks per 1 000 spindle hours for a 28 tex worsted yarn has also been mentioned[24].

TAPERS OF COMMON WINDING CONES

The following are the tapers (½ angle) of various cones in common use[33]:

Dye Packages : 4° 20′
Hosiery Cones : 9° 15′
For Filaments (cone and pineapple package) : 3° 30′

One end break per 100 kg of yarn is considered normal during twisting (plying or folding)[34].

VARIATION IN YARN LINEAR DENSITY (COUNT)

It has been stated that linear density (i.e. count) deviations of between 7 and 10 *per cent* from the mean can result in a disturbing appearance in both woven and knitted fabric[35, 36, 37].

The following broad classification for the CV values (based upon 100 metres lengths) of various yarns has been suggested[38]:

MAXIMUM VALUES (*PER CENT*) OF THE COEFFICIENT OF VARIATION OF YARN LINEAR DENSITY (COUNT) IN THE DISCUSSED INTERNATIONAL STANDARDS FOR SOME TEXTILE YARNS

Quality Class	Cotton (combed & carded)	Worsted System yarns	Bast fibres (except jute)	Jute	Woollen System yarns	Filament yarns
Very regular	below 2,0	below 2,0	below 2,5	below 3,5	below 2,5	below 0,5
Regular	2,0 – 2,5	2,0 – 2,5	2,5 – 3,5	3,5 – 5,0	2,5 – 4,0	0,5 – 1,0
Medium regular	2,5 – 3,5	2,5 – 3,0	3,5 – 4,5	5,0 – 6,5	4,0 – 5,5	1,0 – 1,5
Irregular	3,5 – 4,5	3,0 – 3,5	4,5 – 5,5	6,5 – 8,0	5,5 – 7,0	1,5 – 2,0
Very irregular	above 4,5	above 3,5	above 5,5	above 8,0	above 7,0	above 2,0

WOOL WORSTED YARNS

Freeman[43] stated that a package dyed 28 tex wool yarn having the following physical properties knitted satisfactorily (a defect rate of 2 per 22 metres of fabric) on an 18 gauge double jersey machine:

Moisture content	:	12–15%
Oil and/or wax content	:	1,0–1,5%
Elongation at break	:	10–20%
Tensile strength	:	200–300 gf

Formaldehyde in the dye bath preserves wool's tensile properties when dyeing at high temperature, for instance, when package dyeing blends of polyester and wool[43].

PHYSICAL PROPERTIES OF SEWING THREADS

The table on the next page has been reproduced from a recent article[44].

OE YARNS

Rotor cleanliness is critical[45], trash inside the rotor causes ends down, cleaning frequency depends on cleanliness of sliver but once per 32 hours[46] and also about every 16 hours[45] have been suggested. Bowen[47] also states that trash and spinfinish build-up rank high on the list of problems encountered in OE spinning.

The number of faults in an OE yarn tend to increase towards the end of the package[31], (probably due to the time elapsed since the rotor was last cleaned).

The mouthpiece of the rotor cover plays an important part in dictating not only whether or not a particular fibre or blend can be spun but it also has an important effect on the characteristics of the finished product. A smooth mouthpiece produces a smooth "hard" yarn while a serrated mouthpiece produces a hairy "soft" yarn[48].

OE yarn loftiness is different when using smooth and fluted rotor tube outlets and similar differences can be obtained by twist changes[49, 50].

A $2\frac{3}{16}$" (56 mm) diameter rotor can spin fibres up to $1\frac{9}{16}$" (40 mm) in length[48]. A rotor 90 mm in diameter can spin fibres up to 2,5 inches (63,5 mm) long[48]. Smaller rotors generally spin lower quality yarns[51].

Fibre finish and crimp are said to affect spinning performance[30].

High crimp fibres do not spin well on OE frames, because of fibres sticking to each other due to friction[49].

A lubricant applied to fibre causes fibre slippage and uneven spinning[49].

THE COMPARISON OF THE PHYSICAL FEATURES OF VARIOUS SEWING THREADS

Fiber	Tetoron		Nylon	Tetoron/ Cotton	Cotton	Silk
Yarn Type	Filament	100% Spun	Filament	Spun Yarn	Spun Yarn	Filament
Count	50	60	50	60	50	50
Construction	70de 1 x 3	64's 1 x 3	70de 1 x 3	60's 1 x 3	50's 1 x 3	21 medium 4 x 3
Denier (de)	230	265	230	267	319	207
Tenacity (gf/de)	5,6	4,1	4,7	3,5	2,9	4,2
Elongation (%)	25	24	27	15	8	16,2
Shrinkage in Boiling Water (%)	0	0	1,5	0,5–2	3–7	2–4
Dye Fastness in Washing	5–4	5–4	5–4	4–3	4–2	3

Polyester fibres are often difficult to spin on an OE frame because of spin finish in the rotor[52] and at least 110 fibres per yarn cross-section are required (1,7 and 2,8 dtex, 38 mm fibres used).

About 10 *per cent* to 15 *per cent* of the OE fibres are hooked in the rotor, depending upon staple length and the diameter of the rotor[49].

Flax is said to be too brittle for OE spinning[30].

Within limits, OE spinning equipment is apparently not very sensitive to staple length or micronaire value nor does relative humidity have all that much effect. London and Jordan[53] state that as staple length was changed from 32 mm to 38 mm and 51 mm very little change in OE yarn strength was observed although fibre denier had a critical effect on yarn strength. The critical effect of cotton fineness on OE yarn strength has also been pointed out by Kroulik[54].

In the case of OE spinning 25–30°C and 50–70 *per cent* RH are regarded as acceptable, it apparently being less sensitive to atmospheric conditions than ring spinning[23].

Twist factors of 48 to 53 [t.p.cm $\sqrt{tex}$ (5,0 to 5,5 cotton system)] apparently give maximum strength for OE yarns although ones as low as 43 to 45 (4,5 to 4,75) and even down to 38 (4,0) are being used[55]. Dyson[56] states that Vincel (Rayon) OE yarns show a maximum tenacity at twist factors below 25 and that they are spun to the same twist factors as those used in ring spinning.

Staple length apparently has an effect on yarn strength and twist factor but it is not as critical to OE spinning as it is to ring spun yarns[55]. Fibre crimp, rigidity, elasticity and fibre to metal friction are all important[55] in determining spinning performance.

Optimum balloon height above OE package when unwinding yarn is 15 to 25 cm.

Apparently 20 to 22 tex OE yarns (100 *per cent* acrylic 50 *per cent* acrylic/ 50 *per cent* polyester and 50 *per cent* rayon/50 *per cent* polyester) have been knitted on 40 gauge (i.e. 20 n.p.i.) Raschel warp knitting machines together with textured and untextured continuous filament yarns to produce fabrics ranging in mass from 170 to 270 g/m^2. The single OE yarns replaced two-ply ring spun yarns[57].

OE yarns are not considered suitable for interlock type (underwear) fabrics[58, 59], although one manufacturer[60] apparently produced a superior underwear fabric by redesigning the structure and a special softening operation during finishing.

Compound needle machines are preferable to bearded or latch needle machines for OE yarns[30, 32].

OE YARNS vs RING SPUN YARNS

(i) Physical Properties

Conflicting opinions[49] have been expressed about the effect of staple length on the strength of OE yarns.

It has been stated[61] that generally, the relationship between the tensile and evenness properties of OE and ring spun yarn is a function of fibre length with an increase in fibre length favouring ring-spun yarns. OE yarns have a higher extension and breaking strength than ring-spun yarns for fibre lengths around 18 mm but the reverse is true for longer fibres[61]. The coefficient of variation of breaking strength of OE yarns is apparently much lower than that of ring-spun yarns[32, 61, 62, 63].

OE yarns generally have 1,5 to 2 *per cent* higher extension at break[46] (lower elongation has been reported in one case)[64] than ring-spun yarns but are said to be up to 15 *per cent* weaker[46] and 10–20 *per cent*[32], 10–25 *per cent*[65], 20–30 *per cent*[45] and 10–40 *per cent*[49] have also been mentioned. The difference apparently becomes more marked as the fibre length increases and as the yarn becomes finer[65]. Klaeui[63] states that, on average, yarn toughness is higher for OE yarns than for ring-spun yarns.

OE yarns are generally more even[46] and contain fewer faults (slubs)[45, 66], knots[65, 66] and neps[49, 58] (possibly more neps depending upon the cleanliness of the input sliver and the technical arrangement of the OE machine[31]), than ring-spun yarn. Yarn appearance is also better and fluff is less than one-third of that in the ring-spun yarns[65].

Short term uniformity of OE yarn is better than that of ring-spun yarns[31, 49, 58, 67]. The difference becomes more in favour of OE yarns as twist is increased[49].

Chisholm[68] states that economics do not favour OE yarns of below about 27 tex and technological reasons prevent the spinning of yarns having less than 100–120 fibres depending upon the spinning machines used. It has also been stated that 80–100 fibres per yarn cross-section were required for OE spinning compared with 50 to 60 for a ring frame with roller drafting[69].

Ring-spun yarns are said to become more economical than OE yarns around 20–22 tex[30, 32] (above 25 to 37 tex, depending upon local conditions has also been mentioned[23]) but very much depends upon other factors such as re-winding and labour cost. A cross-over point at 37 has been mentioned[31] if rewinding and clearing are necessary while another author stated[70] that they were economically most attractive around 25–50 tex using short staple fibres.

OE yarns are generally harsher and have poorer fibre parallelization than ring-spun yarns[49].

OE core fibres have more twist than fibres at the yarn surface[49].

Yarn to metal friction of unfinished OE yarn is said to be greater than that of ring-spun yarns[53] although waxing can reduce it to an acceptable level[65].

Abrasion resistance of OE yarns is said to be better than that of ring-spun yarns[31, 65] (in another article[53] it is stated to be worse). A wax disc followed by wax emulsion lubrication enhance knitting quality of dyed yarns[62].

OE yarns have a specific volume (cm^3/g) about 10 *per cent* higher than ring-spun yarns[58].

OE yarns are said to be some 15 *per cent* bulkier than ring-spun yarn[30, 32] although they do not apparently offer any greater cover in the fabric[32]. (Warlick[45] states that they do). An OE yarn which is to replace a ring-spun yarn should be about one to two tex units coarser than the latter[30, 32].

OE yarns give better cover in loose fabrics but poorer cover in tight fabrics[50], because they flatten out less than ring-spun yarns[49].

OE frames equipped with drafting rollers make yarn more like ring-spun yarn than OE frames equipped with combing rollers, but at some sacrifice of production rate[49], combing rollers, it is claimed, produce loftier yarns than ring spinning[71].

Breakages during warping are said to be 40 *per cent* lower for OE yarns, end breakages during weaving is about 50 *per cent* less and broken picks about 35 *per cent* lower compared with ring-spun yarns (30 tex cotton OE yarn)[65].

As far as knitting is concerned the high friction and high bending stiffness of OE yarns are disadvantages. Nevertheless, the knitting performance and also weaving performance of OE yarns are often quoted as being better than those of the corresponding ring-spun yarns[45, 58, 59, 60, 62, 64, 66, 72].

OE yarns apparently give greater stitch clarity, reduced shedding during knitting[52, 57] and have a more even fabric appearance than ring-spun yarns[57].

According to Lord[73] OE yarns result in lower spirality and shrinkage than ring-spun yarns in knitted fabrics although snarling of the yarn could present problems[59].

Catling[66] states that woven fabrics from OE yarns have a better handle and knitted fabrics a harsher handle than their ring-spun yarn counterparts. Sheldon[58] stated that OE yarns generally give a firmer and crisper handle than ring-spun yarns.

Conflicting results have been reported about the abrasion resistance of fabrics produced from OE yarns compared with that of fabrics produced from ring-spun yarns[49, 50, 53].

OE yarns give poor tear strength but better fabric tensile strength than do ring-spun yarns[49, 50].

(ii) **Dyeing**

OE yarns require roughly 25 *per cent* less dyestuff than do ring-spun yarns to produce the same shade effect[46].

It has also been stated[49] that dye shades of OE yarn fabrics are generally deeper (at about equal dye take-up), but dye take-up is not significantly different.

In printing, fabrics produced from OE yarns take up colour more quickly than those produced from ring-spun yarns(30, 32) although it is stated that they wick dyestuff much more slowly than fabrics produced from ring-spun yarns. The latter results in prints which are much more distinct and clear for fabrics produced from OE yarns than their ring-spun counterparts(53).

(iii) Sizing

In sizing warps of OE yarn, if the same add-on is required as for ring-spun yarn, it has been proved necessary to reduce the size viscosity by 10–15 *per cent*(30, 32). A reduction in size concentration of 10–20 *per cent* has also been suggested(65) when sizing OE yarns due to their good absorbency.

(iv) Raising

Normally more passages will be required than with ring-spun yarns for raising (napping)(30, 32). Kroulik(54), on the other hand, states that fabrics produced from OE yarns are easier to raise due to the lower twist of the fibres on the yarn surface and that a similar (or smaller) number of passages will be required for fabrics produced from OE yarns.

(v) Setting

Steam setting at 90°C is recommended for OE yarns(65). Twist setting is done by 45 minutes of autoclaving, using 2 cycles of steam and 2 of vacuum(45).

(vi) Finishing

It has been stated(65) that the same effect can be obtained for woven fabrics from OE yarns with a resin concentration 10–20 *per cent* less than that which is required for woven fabrics produced from ring-spun yarns.

Excessive tension during finishing must be avoided or else the fabric extensibility will suffer(32).

(vii) Shrinkage

There is little difference between the washing shrinkage of fabrics produced from OE and that from ring-spun yarns(65).

(viii) Pilling

Pills apparently form more easily but are also detached more easily in the case of fabrics knitted from synthetic OE yarns(65). In the case of acrylic knitted fabrics, resin finishing is usually applied to improve anti-pilling properties. In another article(53) it was stated that wear tests have shown fabrics produced from OE yarns (particularly synthetics and blends) to have a higher pilling propensity than those from ring-spun yarns although conventional pill tests failed to distinguish between them.

(ix) **Warp Knitting**

With OE yarns, 225 metres of warp knitted fabric were produced with only two stoppages while knitting with ring-spun yarns resulted in roughly one stoppage per two metres of fabric. Resultant OE yarn fabric had a hard handle because of high twist but softeners could reduce this[46]. Compound needle machines are preferable to bearded or latch needle machines for OE yarns[30, 32].

(x) **Hairiness**

OE yarns apparently have more short hairs and fewer long hairs than ring-spun yarns. Furthermore, the average length of the protruding fibre ends and the number of such ends are less than in conventional yarns[74]. It was concluded[74] than OE yarns are less hairy than conventional yarns but that the hairiness is more irregularly distributed. Sheldon[58] and Lord[73] also stated that OE yarns were less hairy than ring-spun yarns. Warlick[45] stated that OE yarns are 20–25 *per cent* less fuzzy than ring-spun yarns and cause less shedding during knitting. London and Jordan[53], on the other hand, state that OE yarns have more fibre loops on their surface than ring-spun yarns and this could cause them to be more hairy.

SELF-TWIST (REPCO) YARNS

In Repco (self-twist) spinning, fibre length is of greater importance than fibre diameter with short fibre content very important and it should be less than 20 *per cent* for fibres shorter than 20 mm[22]. A 20,5 μm top (60 mm hauteur) could be spun into R37 tex/2 yarns on the Repco, roving uniformity and cleanliness being important for good results[75].

It has been stated[76] that a Repco (self-twist) spinner requires a mean fibre length (Almeter hauteur) of 60 mm or greater and, for pure wool, no less than 37 fibres in the yarn cross-section (34 for synthetics). Oil content of blends should be as for conventional dry spinning (1 to 1,5 *per cent*)[77] with the total extractable matter content in the case of wool not exceeding 1,5 *per cent* (1 *per cent* has also been mentioned for blends)[22]. Strength of all wool self-twist (Repco) yarns vary from 2 gf/tex to 4 gf/tex[75].

Normally 2,2 gf/tex is the tenacity required for Repco yarns to facilitate subsequent processing[21] on a two-for-one twister although if the yarns are to be knitted, at least 5 gf/tex is required. This can be achieved with at least 50 *per cent* of synthetic fibre in the blend[21]. In the case of 55 *per cent* polyester/45 *per cent* wool tenacities of 6 to 7 gf/tex can easily be obtained while in the case of 100 *per cent* polyester or 100 *per cent* acrylic, yarn tenacities of the order of 10 gf/tex can be achieved[21].

The irregularity of self-twist and self-twist-twist yarns is apparently higher than that of conventional yarns[78]. The following values have been suggested[77] for the maximum self-twist for self-twist yarns of different linear densities (counts):

Resultant (tex)	Max. Twist (turns per half cycle)
R88,6 tex/2	20
R60 tex/2	24
R44 tex/2	28
R35 tex/2	32
R30 tex/2	34
R25 tex/2	37

Over-twisting should be avoided. Winding tension should be 0,33 g/tex. Excessive tension will affect the self-twist level.

The lower the folding (plying-STT) twist the lower the general streakiness with 472 t.p.m (12 t.p.i.) for R50 tex/2 ($^2/_{36}$'s) apparently being satisfactory[75]. The following formulae have been given for the plying (folding) twist levels for self-twist yarns when producing self-twist-twist yarns[79].

$$\text{Minimum turns per metre} = 14{,}1\ (\text{Turns per half-cycle}) + \frac{878{,}5}{\sqrt{\text{tex}}}$$

$$\text{Maximum turns per metre} = 14{,}1\ (\text{Turns per half-cycle}) + \frac{1757}{\sqrt{\text{tex}}}$$

Clearing, waxing and winding on to a cone type package is preferred for self-twist yarns[21].

Two end breaks per kg of self-twist yarn were obtained during clearing compared with eight per kg for ring spun yarns[80]. Drafts used during spinning are in the mid-twenties.

Three end breaks per machine per hour are considered satisfactory for pure wool although it often can go up to 6 or 8 per hour without any apparent reason. At two end breaks per machine per hour, Repco spinning apparently becomes more economical than conventional spinning at linear densities above R44 tex/2 ($^2/_{40}$'s) but higher end breakages raise this linear density[75].

Experimentally, 54's and 56's quality fibres could be spun but generally, spinning is limited to 58's quality and finer[76].

Trials[81] have shown that N.Z. halfbred wools, having mean fibre diameters of 25,8; 27,9 and 30,2 μm could be spun and that tenacities significantly lower than 2 gf/tex were acceptable for heavier yarns. New Zealand crossbred wool, 39 μm in diameter, could also be spun but only from paired rovings under extreme conditions of roller weighting as the twisting efficiency of the oscillating roller system appears to be inversely related to the coarseness of the fibres. No evidence was found of fibre "bridging" between adjacent strands having caused ends down at commercial yarn counts.

High bulk acrylic yarns produced on a Repco machine have also been knitted successfully and the fabrics produced, apparently compare favourably with those produced from more conventional yarns[82]. In double jersey they normally tend to have a firmer handle and better stitch clarity and abrasion resistance[82].

Although similar in mechanical properties and irregularity self-twist acrylic yarns are more hairy, less bulky (lower apparent diameter) and more resistant to abrasion and cyclic extension than conventional acrylic yarns[83].

Fabrics made from self-twist yarns appear to crease less and shed creases more easily than those made from other (conventional) yarns[76].

In knitting, Repco yarns give rise to less fly shedding, improved stitch clarity and fewer fabric holes (mainly owing to fewer knots). Knitted fabric performance is apparently similar in pilling and wear characteristics to that of fabrics produced from conventional ring-spun yarns[21]. It was reported that self-twist yarns gave spirality in fully-fashioned garments but this was overcome when the yarn was steamed[75].

TWISTLESS YARNS

Most fabrics woven from twistless yarns are said to be stronger, more durable, more stable and to have better lustre and appearance than comparable fabrics produced from conventionally spun yarns[70]. In knitted fabrics interlocking of yarns is not as good as in wovens but there is still adequate binding of the fibres for most end uses[70].

TEXTURED YARNS

A tension of 0,5 to 0,9 gf/tex is sufficient to remove all crimp from a textured yarn and if the length of the yarn under the above tension is compared with that under a tension of 0,01 to 0,02 gf/tex an idea can be obtained of the crimp or stretch of the yarn.

Excessive abrasive wear of needles by textured polyester yarns could be due to insufficient lubricant, excessive delusterant, excessive yarn to metal friction or the presence of zirconium in the titanium dioxide used to give the yarn a dull finish.

With most coning lubricants (oils) three to four *per cent* will be sufficient to provide the right level of lubrication[84, 85]. Oil content on the yarn can be measured by several methods. One of the most accurate is Soxhlet extraction with ethyl ether for 3–4 hours. A quicker method uses 1.1.1 trichloroethane while a method utilizing a spectrophotometer is also receiving interest[86].

Allowable yarn defects (knots) in textured yarn is about one per million yards of yarn[87] while a value of two knots per cone of textured polyester yarn has also been mentioned[88].

Michelena[84] states that, generally, a textured polyester yarn with a strength of about 27 gf/tex (or 3 gf/denier) or lower will be very difficult to knit and that a reduction in strength, due to texturing, of 20 *per cent* is considered acceptable. Shah and Paranjape[89] state that, for 44 dtex (10–12 filaments) semi-dull polyamide (nylon) textured yarn a tenacity of 45 gf/tex, as measured on a Scott IP2 tester at a gauge length of 20 cm, is good. An increase in linear density of, on the average, 3,9 *per cent* occurred due to texturing while losses of 13,3 *per cent* in strength and 12,1 *per cent* in elongation, due to texturing, were noted.

A variation of ± 3 *per cent* in crimp rigidity is often regarded as acceptable although it would be noticeable if the yarn in two adjacent courses differ in crimp rigidity by 6 *per cent*. Wignall[90] mentioned a case where a yarn, having a crimp rigidity of 9,9 *per cent* compared with that of 8,3 *per cent* for the other yarns, showed up as a horizontal bar.

Morris and Roberts[91] found that variations in crimp rigidity can occur due to short term variations in temperature during false-twist texturing. They found[92] that the crimp rigidity increased with increasing heater temperature. Beck[93] found that increasing texturing temperature increased fibre density, the latter is a measure of the crystallinity (an increase in density being associated with an increase in crystallinity)[94].

Schmidlin[95] demonstrated the relationship between dye uptake and setting temperature, the curve showed a minimum near 180°C. Truslow[96] found that, for polyester, the density increased and the dye uptake decreased with an increase in temperature.

Vaughn and Maynard[97] investigated the effects of heater temperature and yarn input tension, during false twist texturing of polyester, on the yarn structure. They concluded that 10°C differences in heater temperature caused detectable differences in fibre structure (measured in terms of density, crimp rigidity and tensile properties) but 2°C differences did not. Within the levels investigated, the tension of the yarn entering the first feed roller had no apparent effect on the fibre structure.

The correlation between dye shade before and after crimping can be very low for nylon. The same holds for variation in dye shade[98].

The following tolerances have been mentioned for false twist texturing machines[99, 100] to minimise barré due to this source:

Heater Temperature	:	± 2°C
Spindle Speed	:	± 3%

Tension above the spindle should be approximately three times that below the spindle and atmospheric conditions should be controlled (e.g. 21 to 27°C and 55 to 65% RH)[100]. Calder[101] states that the yarn tension in the heater should be controlled to within ± 0,5 gf.

Yarn aged as much as one week and knitted with freshly textured yarn will cause slight barré, yarn aged two weeks will cause medium barré and more than two weeks will cause severe barré[100].

The following variations are said to produce similar shade differences[101]:

(i) 15°C in heater temperature;
(ii) 200 t.p.m in twist level;
(iii) 1 gf in the tension of the twisted yarn in the heater.

DRAW-TEXTURING

Normally the linear density of yarn supplied to a draw-texturing machine lies between 247 and 286 dtex (225 and 260 denier) to give a 167 dtex (150 denier) textured yarn. Yarns coarser than 286 dtex exhibit a substantially reduced zero tenacity point (temperature)[102]. It therefore appears that a draw ratio below two is advisable.

Draw-textured yarn gives reduced barré (i.e. better dye uniformity) and the following differences have been reported between Dacron (Du Pont) draw textured and fully drawn textured polyester yarns[103]:
Draw-textured yarn has a higher crimp frequency, higher crimp contraction, lower torque (i.e. reduced liveliness), faster dyeing rate, lower air permeability and greater bulk (in fabric form) than the fully drawn textured yarn.

Increased stretch, higher bulk, reduced liveliness and increased dye uniformity have also been claimed for draw-textured yarn. It was stated that fully drawn textured yarns exhibit higher dye variance under pressure than do draw-textured yarn at atmospheric pressures[104]. It has been stated that draw-textured yarns have tenacities slightly lower and elongations slightly higher than those of conventional textured yarns[105].

Increased bulk[106], dye uniformity[106], knitting efficiency[107] and evenness[108] have also been claimed for draw-textured yarns in other articles while in some instances it has been stated that fabrics produced from draw-textured yarn have lower bulk than those produced from conventional textured yarns[109].

Ageing of draw-textured feed yarn (i.e. storage period prior to draw-texturing) could be reflected in the dye depth of the textured yarn[110].

Texturing of undrawn material has not proved as practical a proposition as partially orientated yarn (POY) because of the brief life-span of the former. Undrawn material has a storage life of only three to four days whereas partially orientated material (residual draw ratio 2, approximately) has a storage life measured in months rather than weeks[106], storage life being improved by greater molecular pre-orientation and a higher molecular mass of the polymer. Reichman[108] states that POY should be converted into textured yarn within the space of roughly three to eight weeks and that there is no clear-cut evidence that draw-textured yarns are less prone to barré.

WARPING

A tension of 0,1 to 0,15 gf/denier is recommended when warping continuous filament yarns for Tricot knitting and the performance during warping is considered good if the fault rate is lower than 0,5 per end per million yards.

WARP KNITTING

The front guide bar on a 28 gauge Copcentra machine imposes less strain on the yarns than the back guide bar and it is therefore recommended that the weaker yarn be used in this bar[111]. The most common gauge of tricot machines is 28 and the main yarns knitted on this are 44–60 dtex continuous filament, although 83–167 dtex textured polyester yarns have been knitted on this gauge machine for outerwear. The maximum yarn linear density which can be knitted successfully is considered to be 167 dtex textured polyester. Raschel machines with a gauge of 40 (20 n.p.i.) are generally used for ladies' and men's outerwear fabric in textured polyester (167 dtex).

The optimum balanced runner ratio for locknit fabric is said to be 3:4 or 1:1,33 (i.e. the back beam supplying three length units of yarn for every four supplied by the front beam). Other possible ratios are 1:1,2 and 1:1,1 but excessive loop distortion results[112].

For 44 dtex nylon fabrics knitted on 28 gauge two guide bar tricot machines at 25,6 to 26,4 courses per cm (65–67 c.p.i.) the following runner lengths are used for any combinations of the specified lapping movements[112]:

Lapping Movement	Run-in per Rack (cm per 480 courses)
1–0/0–1	112 (44″)
1–0/1–2	122 (48″)
1–0/2–3	163 (64″)
1–0/3–4	203 (80″)
1–0/4–5	244 (96″)

Thus for locknit the front guide bar knits 1-0/2-3 with a run-in per rack of 163 cm (64″) and the back guide bar knits 1-0/1-2 with a run-in of 122 cm (48″)[112].

A 15 tex cotton yarn is close to being optimum on a 28 gauge (n.p.i.) tricot machine.

A 25 tex OE yarn performed better (4 ends down per 55 metres of fabric) on a 21 gauge Copcentra machine than a 23 tex yarn (6 ends down per 55 metres of fabric)[113].

A 25 tex staple fibre yarn performs better on a 21 gauge Tricot machine than one of 30 tex while on a 28 gauge machine a 15 tex yarn performs better than a 10 tex yarn. In the case of Tricot machines 20–24 gauge (i.e. n.p.i.) is suitable for spun yarns while 40 gauge (i.e. 20 n.p.i.) and coarser Raschels are suitable[114]. Guides with an oblong hole or a grooved side are recommended for spun yarn since they render easy passage of the yarn with minimum fibre fly.

Compound needles are preferred to bearded and latch needles for knitting staple fibre yarns[113, 114, 115, 116]. Plastic sheets between warps and needles reduce fly on the latter and faults when processing staple fibre yarns[114].

A R20 tex/2 (2/60's) Prograde yarn knitted satisfactorily at one fault per 91 metres (100 yds) on a 21 gauge Copcentra machine at 1 000 courses per minute[117, 118] and a ten tex (1/60's) caustic soda mercerised yarn knitted satisfactorily (at 1 000 c.p. minute) on 28 gauge Copcentra and Kokett machines[117, 118].

On a 28 gauge Copcentra machine there is an upper limit for 100 *per cent* spun fibre fabrics of 12 tex (1/50's c.c.) on two full set bars. At 12 courses/cm the resulting fabric (102 g/m^2 –152 g/m^2) would be suitable for shirts[113].

A chemical treatment which improves the strength, extension, friction and knitting performance of cotton yarns has apparently been developed under sponsorship of Cotton Incorporated[119].

Combined cotton/Vincel blends have been spun to 14,5 tex at a twist factor of 38 t.p.cm $\sqrt{\text{tex}}$ (4 Cotton) and knitted on the front guide bar (with textured polyester in the other bar) of a 28 gauge machine in a reverse locknit structure with a fault rate of one per 15 metres of fabric[120]. Vincel/Courtelle OE yarn (21 tex) has also been knitted on a 28 gauge Tricot machine with a 55 dtex polyester flat filament yarn.

The performance of warp-knitted fabrics in formal suits and blazers is stated[121] to be superior to that of weft knits in terms of snagging, sharpness of crease and freedom from bagging. The better snagging resistance of warp knitted fabrics has also been pointed out by Weser[122]. Weft knitted fabrics are generally more extensible and elastic than warp knits but the latter generally have lower air permeability, snagging and bagging[123].

Fifteen tex cotton/polyester blend yarns and 44 dtex Terylene were used on a 28 gauge Tricot machine for casual shirts but the fabric (108–118 g/m^2) showed a tendency to pill in the collar area. This was overcome by using R15 tex/2

($^2/_{80}$'s c.c.) yarns instead of the single yarn. The 15 tex yarn performed better than a 10 tex yarn (both tried on the front guide bar).

In weaving, yarn to fabric take-up varies from about 1:1 to 3:1 while in warp knitting it varies from about 3:1 to 8:1.

It has been stated that, for the knitting of staple fibre yarn, atmospheric conditions should be controlled at 60 to 62 *per cent* RH[124].

SINGLE JERSEY

Single jersey machines have up to 120 feeders on a 30″ diameter and can produce up to 91 metres (100 yds) of fabric per hour.

Shirting fabrics have been knitted from R20 tex/2 ($^2/_{60}$'s c.c.) and 20 tex ($^1/_{30}$'s c.c.), cotton yarns on 26 and 28 gauge single jersey machines. The fabrics were subsequently mercerised[118].

Machine washable (Superwash) single jersey fabrics from 100 *per cent* wool can be produced from 44 tex yarn on an 18 gauge machine. A yarn twist factor of 26 t.p.cm $\sqrt{tex}$ (2,2 W_O) and fabric cover factor of 18 (1,5 W_O) were suggested[125]. Properly constructed, dyed and finished single jersey fabrics will exhibit approximately 3 *per cent* length and 0,1 *per cent* width relaxation shrinkage and zero felting shrinkage after five domestic washings and drying cycles at 49°C (120°F) using normal laundry powder and tumble drying at moderate settings[125].

In hosiery and pantyhose manufacturing the knitting department should be kept at the following conditions:
21°C to 27°C and 50 to 60 *per cent* RH[126] while McCain[127] suggested 21°C to 27°C and 55 to 65 *per cent* RH.

DOUBLE JERSEY FABRICS

Most women's wear fabrics range from 370 g/m^2 to 510 g/m^2 while men's wear range from 240 g/m^2 to 310 g/m^2 and for sports coats from 340 to 440 g/m^2. For men's tailored clothing knitted on 18 to 24 gauge machines 210 g/m^2 to 235 g/m^2 is considered the lighter end of the scale and 270 to 290 g/m^2 the heavier end of the scale.

The range of fabrics knitted on 22–24 gauge double jersey machines from 111 dtex textured polyester is 200 g/m^2 to 220 g/m^2 for summer dresses.

For knitted men's wear in textured polyester 15 *per cent* elongation in both directions with total recovery is normally expected.

A 60 *per cent* cotton/40 *per cent* polyester double knit fabric where two feeds of 25 tex ($^1/_{24}$ c.c.), 70 *per cent* cotton/30 *per cent* polyester and one feed of 167 dtex textured polyester are used provides a good balance of fabric properties suitable for men's sports slacks and ladies' dress goods[128].

VARIATION IN COURSE LENGTH

In the case of double jersey fabric knitted from worsted yarn a course to course variation in stitch length of about 1 *per cent* is considered normal(129).

Course length variation should be below 2 *per cent*, if it is greater than 8 *per cent* it is noticeable (range expressed as a percentage)(40, 130).

Variation in course length greater than 5 *per cent*(131) (and sometimes greater than 3 *per cent*) when using continuous filament yarn will produce barré. Rush(100) and Gill(132) also stated that a 5 *per cent* variation in course length will show in the finished cloth. In another article it was stated that a course length variation greater than 10 *per cent* would probably cause barré in weft knit fabric(133).

BARRÉ

Barré is often caused by differences in dye shade or dye uptake of yarns from different packages (due mainly to differences in either extrusion or texturing conditions such as variation in temperature or spindle speed during texturing) and differences in linear density (count) and degree of texturing (crimp) of yarns from different packages. Causes of barré common to both staple fibre and continuous filament yarns are: incorrect yarn feed rates at different feeders (this could be due to variations in the yarn input tension, cam setting or positive feed setting) dial and cylinder not properly aligned, etc.

In plain double jersey fabrics knitted from textured nylon a difference of 5 *per cent* in course length between feeds will normally produce a visible bar(132).

Variation in course length greater than 5 *per cent*(100) (and sometimes greater than 3 *per cent*) when using continuous filament yarn will produce barré. In one instance a yarn with a crimp rigidity of 9,9 *per cent* compared with that of 8,3 *per cent* at the other feeds showed up as a horizontal bar(90).

To minimise shadow barré (due to cylinder and dial not being aligned) the cylinder and dial gap should be checked at eight places around the circumference. Shadow barré may also be caused by uneven roller take-down pressure(100). To reduce barré dial and cylinder "run-out" should be less than 0,076 mm ($\frac{3}{1\,000}$") and parallelism should be better than 0,076 mm ($\frac{3}{1\,000}$")(103).

A good method of covering barré in textured polyester fabrics is to dye at high temperatures (250–265°F) with a carrier of the butyl benzoate-type (1 to 3 *per cent*)(131).

To mask barré in textured polyester fabric, butyl benzoate-type carriers proved most effective followed by methyl-napthalene types. Dyeing was carried out at 121°C (250°F) for one hour with 4 *per cent* carrier. Increase in carrier decreased barré up to a certain point after which it increased again(134).

The type and concentration of carrier also have a significant effect. Biphenyl

(2–5 *per cent*) was found to be a good carrier for covering barré (2 to 5 *per cent* at 240°F)[135].

Gill[132] states that, in the case of crimped nylon yarn, a yarn processing difference of ± 2°C will produce a visible shade difference if the yarn is dyed with very sensitive dyestuffs.

Very high concentrations of carriers (e.g. 20 *per cent* of biphenyl) have to be used at atmospheric pressure to obtain good barré coverage although longer dyeing times and fabric preparation also facilitate barré coverage[135].

Nerosol Green and Siberlan Blue dyes are used to test for barriness and according to the results a critical or less critical shade is used. Willingham[136] found that for both low- and high-energy dyes there is an optimum dyeing temperature and carrier concentration, for example when dyeing with a low-energy dye at 250°F between 0,5 and 2 g/*l* of carrier was required while for the same dye, no carrier was necessary at 265°F. Various fugitive dyes suitable for the prediction of barré have appeared on the market[137].

FAULT LEVELS IN KNITTED FABRICS

Allowances in double jersey fabrics for holes are ⅛ yd (11,4 cm) for a small hole and ¼ yard (22,9 cm) for a bad needle or a large hole. A width tolerance of ± 1 inch (±2,54 cm) is allowed.

Up to five completely unmendable faults per 64 metres (70 yds) of warp knitted (e.g. Co-we-nit) cloth are allowed, above which allowance has to be made to the customer[138].

Tricot specifications may call for four or less knitting faults per 100 yds (91 metres) of fabric[112] after which the purchaser has to be compensated.

It has also been stated that an acceptable limit for mendable faults in a 40 yd (36 metres) roll of textured polyester double jersey fabric is about 12 while for wool it may be 112 or more[139].

Raschel thermal fabric is considered to be first quality if there are no more than 8 faults per 18 kg of fabric[140]. It was claimed that the circular machine described was capable of turning out a roll with an average of no more than three bad places[140].

A value of 15 faults per 100 kg of fabric has also been quoted for warp knitted fabrics.

Apparently it is generally accepted that wool yarns with regains of less than 9 *per cent* give a high fault rate during knitting and a poor stitch clarity.

In filament warp knitting it is not unusual to run as much as 100 metres of fabric before there is a single defect due to the yarn. Most producers of continuous flat filament yarn for warp knitting admit to one fault in 2,5 to 4,5 by million metres of yarn. Typical locknit fabric from continuous filament yarn should not contain more than one fault, (either knitting or dyeing and finishing faults), per 9 metres (10 yds) of fabric.

Spun yarn fault rate of a tricot warp knitting machine is about one fault per 15 metres of fabric produced.

Open-end yarn (21 tex 50 *per cent* Polyester/50 *per cent* Vincel) was knitted on two bars of a 40 gauge Raschel machine to a fault rate of five faults per 150 metres[120].

A defect rate of two faults per 25 metres of double jersey fabric knitted from 28 tex wool on an 18 gauge double jersey machine is regarded as being low.

In the case of spun yarns used in combination with textured polyester on a 24 gauge Racop warp knitting machine about 5 stops per million yards of yarn were considered to be reasonably good while 22 to 71 stops were considered as very poor[141].

The Dallas Apparel Manufacturers Association[142] allows one defect per 10 yds of fabric, where a defect is any condition which, if present in a finished garment, would cause that garment to be classified as a second.

The following table of values has also been encountered:

EXPECTED FAULT RATES IN KNITTED FABRIC
(Faults per hundred lbs – 45,5 kg of fabric knitted)*

Fabric Type	Ends out	Drop stitch	Cuts	Holes	Needles
Plain Wool (Milano etc.)	3	3	15	1	0,5
Flat Jacquard Wool	3	5	30	1	1
Blister Jacquard Wool	4	15	85	1	1
Flat Jacquard Polyester	1	1	4	0,3	0,3
Blister Jacquard Polyester	1,5	1,5	8,5	0,5	0,6

*Ends out covers a yarn breakage at the feeder.
Drop stitch refers to a single dropped stitch that is not accompanied by a yarn break.
Cut refers to a drop stitch accompanied by a yarn break within the fabric.

TOLERANCES FOR KNITS

In their specification for Textile Tolerances the SABS gives tolerances for, amongst other things, warp knitted piece goods, cotton interlock piece goods, cotton hosiery yarn and hand knitting yarn.

The following are the sales contract tolerances of the "Knitted Textile Association (American)"[143] for knitted apparel fabrics:

Mass per running metre : ± 5 *per cent* of specifications
Width : ± 3,5 *per cent*

Wales or Courses or both	:	± 5 *per cent* if specified
Quantity	:	± 10 *per cent*

The Dallas Apparel Manufacturers Association has the following quality standards for knitted fabrics[142, 144].

No more than one defect per 10 linear yards is allowed, a defect being any condition which, if present in a finished garment, would cause that garment to be classified as a second. Selvedge defects scored are defects which would affect the cutting width or hamper the spreading or cutting operation and may be scored as one defect per yard. Any hole other than tenter frame pinholes will be classified as a defect. Only face side of fabric is normally examined. Measured length will be equal to or greater than the stated length in each case. Each piece will be at least 25 yds in length. The cutting width (i.e. the width between pinholes) must be equal to or more than the minimum specified. Claims will be based on the narrowest cutting width. Fabric mass per yard must fall within the range specified on the purchase instrument. The sample average will be the basis for claims. Conditions such as barré and bowing must be judged by the extent and degree to which they would affect a finished garment and may be scored as one defect per yard.

FOUR POINT SYSTEM FOR RATING KNITTED FABRICS[145]

Fabric 163 cm–168 cm (64″–66″) in width is taken as standard. A fabric is rated as second quality if it is allocated more than 50 points per 100 linear yds (91 metres). All holes except pin holes incur the maximum penalty of four points which is also the maximum number of points which may be scored per yd of fabric. All defects within 2,54 cm (1″) of either selvedge as well as any fault which is beyond the control of the manufacturer are to be ignored.

Size of Defect (length, l, in inches)	**No. of Points**
$l \leqslant 3$	1
$6 \geqslant l > 3$	2
$9 \geqslant l > 6$	3
$l > 9$	4

Fabrics exceeding 163 cm–168 cm are allowed a proportionally higher number of points. Only the face side of the fabric is to be examined.

Recently Dan River Inc. has released specifications[146] for apparel fabrics. These are given in the following tables.

MINIMUM FABRIC STANDARDS FOR KNITS

Property	Test Method	100% Polyester	Shirtings and Blends	Tubular Single knits	Cotton Velour
Appearance	AATCC-124-1969, II-B (3 washes)	4,0	4,0	–	–
Crease Retention	AATCC-88C-1971, II-C (3 washes)	3,0	3,0	–	–
Bursting Strength	ASTM-231 (Mullen)	60	40	40	60
Shrinkage					
Pressing & Curing	Appropriate Cycles	2% x 2%	3% x 3%	–	–
Washing	AATCC-135-1970, II-B (3 washes)	3% x 3%	3% x 3%	8% x 8%	12%x12%
Total		4% x 4%	5% x 5%		
Restorable to	AATCC-96-1972, II-E-2 (Restoration Procedure)			5% x 5%	6% x 6%
Growth, % after 1 hour recovery	Celanese MTD-EL-II-9A	4%	4%	4%	4%
Crockfastness	AATCC-8-1972				
Dry		4	3–4	–	3–4
Wet		3	2–3	–	2–3
Colourfastness to Abrasion	AATCC-119-1970	4	3–4	–	–
Colourfastness to Sublimation 30 seconds, Dry Contact Heat at 350°F		4	3–4	–	–
Colourfastness to Laundering	AATCC-61-1972, II-A				
Shade Change		4	3–4	–	3–4
Staining		4	3–4	–	3–4

GENERAL WOVEN FABRIC STANDARDS

DEFECT LEVELS: Using the "4-Point" grading system and Dan River's threshold for defects --

28 points/100 square yards, average.
40 points/100 square yards, maximum for any one piece.

FABRIC DISTORTION:

½ inch bow – on goods up to 45″ wide.
1 inch bias -- on goods up to 45″ wide.
1 inch bow – on goods over 45″ wide.
2 inches bias – on goods over 45″ wide.

PUT UP: Fabrics are put-up in standard cut lengths (40 yds, and up) with up to a single 20–40 yard cut per case. Pieces are spliced only when splice occurs within one loom cut.

CARE INSTRUCTIONS:

Care instructions are furnished by individual style on Dan River contracts.

WIDTH: Minimum width is specified by individual style on an overall basis on Dan River contracts.

MINIMUM FABRIC STANDARDS FOR MEN'S AND BOY'S WOVEN SPORTSWEAR

PROPERTY	TEST METHOD	END USE	
		Jeans	Casuals
Washed Appearance[1]	AATCC 124-1969, II-B (3 washes)	3,5	3,5
Crease Retention	AATCC 88C-1971, II-C (3 washes)	4	4
Seam slippage	ASTM D-434	35 lbs	25 lbs
% Shrinkage Precured, warp x fill	AATCC 135-1970, II-B (3 washes)	2% x 2%	2% x 2%
Post-cured, warp x fill Pressing and curing	Appropriate cycles	2% x 2%	2% x 2%
Washing	AATCC 135-1970, II-B (3 washes)	2% x 2%	2% x 2%
Total, press, cure, and wash		3,5% x 3,5%	3,5% x 3,5%
Non-permanent press[2]	AATCC 96-1972, II-E-3 (3 washes)	3% x 3%	3% x 3%
Tear Strength (Elmendorf)	ASTM D-1424	3,5 lbs	3,0 lbs
Tensile Strength (Grab)	ASTM D-1682	60 lbs	50 lbs
Crock Fastness[3]	AATCC 8-1972		
Dry		3 – 4	3 – 4
Wet		2 – 3	2 – 3
Colourfastness to Abrasion	AATCC 119-1970	3 – 4	3 – 4
Colourfastness to sublimation 30 seconds, dry contact heat at 360°F		3	3
Colourfastness to Laundering	AATCC 61-1972, III-A		
Shade Change		3 – 4	3 – 4
Staining		3 – 4	3 – 4

(1) Puckering of fancy weaves or colourations may occur on specific styles. This puckering is not measured by AATCC 124, and is not considered.

(2) Non-permanent press fabrics tested for shrinkage in a home washing machine and tumble dryer must be hand steam ironed sufficiently to restore fabric to a wearable level of smoothness before measuring shrinkage.

(3) Crocking of dark colours and reds cannot be guaranteed because of limitations in the current state of technology.

GENERAL KNIT FABRIC STANDARDS

DEFECT LEVELS,	using the "4-Point" grading system and Dan River's threshold for defects – 40 points/100 linear yards maximum.
FABRIC DISTORTION	1½ inches bow. 2 inches bias.
PUT UP	Fabrics are put up on roll in 20 yard and up lengths with no splices on a roll.
CONSTRUCTION	Wales and courses – 5% variation from standard.
YIELD	Per Piece – 5% variation from standard. Per Shipment – within specified tolerance by individual style.
CARE INSTRUCTIONS	Care instructions are furnished by individual style on Dan River contracts.
WIDTH	Minimum width is specified by individual style on Dan River contracts.

ACCEPTABLE SHRINKAGE LEVELS

Width or length shrinkage in dresses and jackets of more than four *per cent* (linear) apparently give rise to complaints in the case of double jersey wool fabrics.

About 3 *per cent* shrinkage of cotton knitwear is regarded as satisfactory. This can be achieved by a durable press finish involving padding the fabric with a cross-linking agent, drying and subjecting it to compressive shrinkage and then curing to cross-link the fabric(147). Agitation of cross-linked knitted fabrics in a slack state also reduced residual laundering shrinkage to about 3 *per cent*(147).

In knitted products, such as dress shirts, sports slacks, dresses and blouses, shrinkage values of 3 *per cent* or less are often expected(128).

A shrinkage of 3 *per cent* in knitted women's wear (constituting about one size change) is generally regarded as acceptable(148) whereas the tolerances in men's wear are much narrower and a 2 *per cent* change in length and width would be permissible. This refers, in particular, to polyester double jersey fabrics(131, 135). Increasing carrier concentration and temperature during the dyeing of textured polyester fabrics increases fabric shrinkage. Final heat setting at 340 to 350°F on a stenter imparts dimensional stability to textured polyester double jersey fabrics, 15 to 20 seconds increasing to 45 seconds for heavier fabrics normally being adequate.

EFFECT OF WEAVE ON FABRIC PROPERTIES

Less tightly packed fabrics tend to crease less and in woven fabrics the best weaves are those which comprise the minimum number of intersections. A $^2/1$ twill is always preferable to a plain weave while a $^3/1$ twill is even better. A poplin weave is notoriously bad from a creasing point of view(149).

The edge wear and tearing strength of cotton fabrics for durable press work trousers appeared to be influenced primarily by yarn mobility within the fabric structure. A $^3/2$ twill performed better than a $^3/1$ twill, with fewer picks of a coarser filling yarn providing further improvement in edge wear and tearing strength(150).

Kyame and Ruppenicker(151) drew the following conclusions based on a laboratory study of the properties of hundreds of woven cotton fabrics differing in mass, weave, type of cotton, warp yarn linear density (count) and durable press treatment: weave type influences fabric wear to a considerable degree with fabrics made from coarse yarns outwearing those of comparable mass (weight) made from fine yarns. Fabrics made from single yarns withstand laundering better than those made from equivalent two-ply yarns. The findings indicate strongly that the wear performance of a fabric is closely associated with –

(a) the freedom of the yarns to move about within the confines of the fabric's structure; and

(b) the degree of exposure of these yarns to the forces causing wear.

Examined in greater detail their conclusions were:

1. **Weave Type:**

A $^3/2$ regular twill required more than twice the number of launderings to show wear than did a plain weave of the same mass made from the same yarns. The better performance of the twill is attributed to the yarn floats formed by its fewer interlacings. These allow the yarns to roll with or yield to the abrading forces, distributing the wear more evenly. In the plain weave, the more numerous interlacings restrict movement, causing faster wear.

Although the steep twill has the same number of interlacings as the regular twill the distribution is such that no filling yarn floats appear at the fabric surface exposed to wear. This causes the exposed warp yarns to wear faster. A similar situation exists in the satin weave; here the filling yarns receive only half as much exposure, and the warp yarn floats are slightly longer. The nett result is that the wear characteristics of the steep twill and the sateens are about the same and fall between those of the regular twill and plain weave.

2. **Yarn Count:**

In fabrics of the same mass, those made from coarse yarns have a looser construction than those made from fine yarns because fewer threads per cm are needed to make up the mass. Two factors contribute to the better wearing qualities of coarse yarn fabrics – the looser construction allows more freedom for the yarns to move about within the fabric's structure, and more wear is needed to damage the thicker coarse yarns.

3. **Singles versus Plied Yarns:**

Singles yarns are made by twisting a ribbon of fibres to form a substantially round strand; plied yarns are made by twisting together two or more singles yarns to form a single, somewhat round strand. In the test, the plied yarn used was made by twisting together two singles yarns, each one-half the mass of the singles yarn with which the plied yarn was to be compared. The explanation for the poorer performance of the plied yarn fabrics is that the thinner singles yarns in the plied yarn wore through individually long before the heavier singles yarn in the singles yarn fabric did.

The results demonstrate that long wearing apparel with the cool, carefree comfort of cotton can be produced from the more loosely constructed, coarser-textured weaves made from heavier yarns, or, with some sacrifice of durability, from finer textured, tighter weaves.

A group of 20 weave variants has been woven at the Southern Laboratory. Among them are granite, gaberdine, broken twill, offset twill, pointed twill, dimity check, basket, and oxford weaves. Some are quite attractive and should find favour in meeting today's rapidly changing styles and tastes. Most of these experimental weaves perform as good as or better than the $^3/2$ twill which did so well in the earlier evaluations, thus providing the consumer with easy-care cotton that are both stylish and durable.

It was found[152] that, in the case of worsted fabrics woven from a 22 μm wool, for a constant cover factor, plain-weave fabrics had much lower air permeabilities than twill and hopsack fabrics with the air permeability increasing slightly with increasing yarn linear density. The breaking loads of the plain-weave fabrics were intrinsically greater than those of twills, which in turn were stronger than hopsack fabrics in the same sett. There was little effect of yarn linear density on cloth assistance factor (the ratio of fabric breaking strength per yarn to yarn breaking strength). The tearing strength was greatest for hopsack which was followed by twill and then plain weave for similar setts. Flat abrasion showed the plain weave to have the greatest abrasion resistance in a given sett.

WEAVING AND SPINNING OF FLAX YARNS[153]

Breaking extension of flax yarns was found to be the most important yarn property determining the breakage rate in spinning and weaving. It was followed, in importance, by breaking strength, abrasion resistance and regularity of the yarn. The breaking extension of the flax yarns was approximately 1,5 *per cent* and the breaking strength of the bleached yarn about 21 gf/tex and that of the unbleached yarn about 17 gf/tex in the case of a 56 tex yarn.

DURABLE PRESS

Good correlations have been found[154] between tumble dry durable press ratings and dry wrinkle recovery angles, and between line dry durable press ratings and wet wrinkle recovery angles. Furthermore, a good correlation was found between the sum of dry and wet wrinkle recovery angles and tumble dry ratings.

Durable press cotton materials must apparently give crease recovery angles of 280–300° (warp plus weft)[155] and this is the level normally aimed at[59].

Suggested specifications[156] for Durable Press finished fabric are given below:

Property	Prior to Washing	After 30 Launderings
Smooth appearance (DP rating)	4	3,5
Puckering rating	4,5	4
Crease retention rating	4	3,5
Dry Wrinkle Recovery (Warp & Weft)	280	276
Wet Wrinkle Recovery (Warp & Weft)	260	250
Dimensional stability (% Shrinkage)	1,0	0

A rating of 5 is excellent while 1 is poor.

It has been found[157] that if resin treated cotton fabrics (in the form of dummy-sleeves) were to survive 40 wash cycles in a commercial wash at 92°C, they must withstand around 1 000 to 2 000 flex abrasion cycles. If DP-level treated fabrics could withstand 25 wash cycles and 500 or more flex abrasion cycles, they can be considered to have satisfactory wear life. Samples prepared in the laboratory by using combinations of the best additive and the most promising curing method withstood 800–1 000 Stoll flex abrasion cycles and more than 40–50 wash cycles without any damage apparent in the fabric. Dry crease recovery angles of the treated samples ranged from 250 to 280° and wet crease recovery angles ranged from 240 to 260°. Wear trials on cotton DP shirts showed that out of the 105 shirts, 21 rejections were due to poor tear strength and only five rejections were due to poor abrasion resistance[157].

PERMANENT PRESS

This is a term given to garments which have the ability to hold their shape during wearing and washing, including creases or pleats intentionally put in during manufacture and at the same time, the ability to shed wrinkles and creases resulting from wear[158]. Maximum shrinkage allowed is normally 2 *per cent*[158].

PILLING IN SINGLE JERSEY

The following are the requirements for producing good pilling resistant single jersey fabrics for men's shirting in polyester blends[121]:

(a) low-pill polyester;
(b) minimum of 24 gauge;
(c) two-ply yarn;
(d) fabric or yarn singeing (this is apparently the most effective).

A caustic soda treatment also facilitates pilling resistance in that it weakens the polyester and so facilitates pills which form, to drop off. The application of resins which act as surface binders also improves pilling resistance. Mercerised cotton is said to perform well although it is rather expensive[121].

"SHINE" IN WOOL WORSTED FABRICS

Examination of shiny areas in worn garments by means of a scanning electron microscope show wool fibres from which cuticular cells have been removed and which are beginning to wear to form the flattened surfaces which are responsible for shine[159]. Laboratory work on worsted fabrics suggests that a test fabric mounted on a felt base and abraded by PVC on a Martindale abrasion tester produced shine similar to that obtained on fabrics during normal wear and that the propensity of the fabric to develop shine can be changed by finishing. High temperature steam setting increases shine whereas the type of resin treatments used to impart permanent-press properties to wool fabrics lowers the propensity of the cloth to develop shine[159].

CLOTH BOW AND SKEW

The AEIH Technical Committee has proposed the following tolerances[160]: angular deviation in the weft with a visible weft is 2 *per cent* for worsteds and 2,5 *per cent* for woollens. This apparently means that on a 150 cm cloth the tolerance is 3 cm for worsteds and 3,75 cm for woollens. The tolerance for cloth with invisible weft is 4 *per cent.*

DRAPE

Sudnik[161] gives the following broad classification for the drape of various fabrics as determined on a Cusick drape tester:

End Use	Drape Coefficient (%)		
	24 cm template	30 cm template	36 cm template
Lingerie	< 80	< 40	< 20
Underwear	65–90	30–60	15–30
Dresswear	80–95	40–75	20–50
Suitings	90–95	65–80	35–60
Workwear, rainwear	> 95	75–95	50–85
Industrial	> 95	> 95	> 85

Hunter and Smuts[162] found an average drape of 67 *per cent* for all wool Punto-di-Roma double jersey fabrics with an average mass per unit area of 338 g/m^2.

ABRASION RESISTANCE

The abrasion resistance of double jersey (Punto-di-Roma) wool fabrics increases as the fabric becomes heavier and tighter and as the yarn becomes coarser while the abrasion resistance of feeder blend fabrics is similar to that of pure wool fabrics[159, 163]. Blister fabrics have a much lower abrasion resistance than Punto-di-Roma and Jacquard fabrics[159]. As fibre diameter increases so does the abrasion resistance[162]. A mass loss greater than 5,5 *per cent* after 10 000 cycles on a Martindale tester (795 g headweight) is regarded as being excessive for all wool double jersey fabrics[162].

In the case of the Ma.tindale Abrasion test employing a headweight of 596 g (21 ozs), for instance, on wool-synthetic feeder blend double jersey fabrics, between 22 000 and 25 000 cycles to hole are normally regarded as an acceptable level of durability for men's wear[148] while a value of 25 000 cycles has also been suggested[163].

The error of the mean of four test results as obtained on a Martindale is roughly ± 3 000 cycles.

It has also been suggested[163] that, for men's double jersey outerwear (wool and wool blends), a mass of at least 350 g/m^2 is required to ensure good allround performance including low air permeability and bagging propensity and good crease retention while lighter weights should be satisfactory for other end uses, such as dresses. The abrasion resistance of synthetic yarn fabrics is said to increase with the linear density (denier) per filament[164].

SNAGGING

A 3–4 rating for women's wear and 4 for men's wear on the Mace snag tester may be set as requirements for acceptable performance[165]. Many people, however, feel that these values are too severe.

Estimates of 600 cycles (i.e. 10 minutes) on the Mace were stated to be equivalent to 30 wearings in men's wear (300 hours) or 20 wearings in women's wear (200 hours)[166] while Schubert[167] found that a 5 hour test on the ICI Snagging Box produces the same degree of snagging as one minute on the Mace tester. The chain length critically affects the results obtained on the Mace tester and the sharpness of the Mace points also plays a role (a difference is noticeable within 6 months of fairly constant use)[166].

The tendency for a knitted fabric to snag is accentuated if it is:

1. light weight;
2. loosely knitted;
3. knitted from low twist yarn;
4. not heat-set after dyeing;
5. knitted to produce a raised (ripple or bourrelet) effect or if it incorporates tuck stitches.

Washing or drycleaning often increases the snagging potential of a fabric while a lubricant can reduce the tendency for a fabric to snag. Certain products (e.g. Mace-Gard and Rezista) which are said to reduce fabric snagging are commercially available.

TYPICAL VALUES FOR WOVEN AND WARP AND WEFT KNITTED FABRICS

The following table has been reproduced with minor modifications from an article by Amemori[116]:

TYPICAL VALUES FOR WOVENS AND WARP AND DOUBLE KNITS

	Elongation (%)		Distortion (%)		Breathability (Permeability) $cm^3/cm^2/sec$	Snagging
	Warp	Weft	Warp	Weft		
Woven (Textured Polyester) 167 dtex	5,5	7,8	0,1	0,2	35	4-5 grade
Weft Knit (Textured Polyester) 138 dtex (20 gauge)	26,3	30,8	0,7	1,8	155	2-3 grade
Weft Knit (Textured Polyester) 167 dtex Wool 25 tex (20 gauge)	28,3	55,5	1,2	3,0	148	3-4 grade
Warp-Knit (Textured Polyester) 167 dtex Wool R29,5 tex/$_2$	17,0	19,5	0,2	1,0	90	5 grade

Hunter and Smuts[162] obtained the following average values on a range of commercial Punto-di-Roma double jersey fabrics knitted from wool and wool blends:

Average Values for Certain Properties of Punto-di-Roma Fabrics		
	Mean	**CV (%)**
Fibre diameter (μm)	22,3	4,6
Run-in-ratio	1,68	7,7
Machine Tightness Factor	15,6	3,8
Yarn linear density (tex)	27,7	5,6
Fabric mass per unit area (g/m²)	338	5,9
Fabric thickness (mm)	1,41	9,0
Fabric density (g/cm³)	0,254	7,8
Drape coefficient (%) – all wool only	67	7,0
Bursting strength (kgf/cm²) – all wool only	7,6	4,6
Resistance to bagging (IR%)*	63,8	8,4
Martindale abrasion (percentage mass loss after 10 000 cycles)	3,62	27,8
Martindale abrasion (number of cycles to rupture 795 g headweight)	32 700	25,0

*The resistance to bagging (percentage immediate recovery – IR%) was determined on an Instron tensile tester according to the Celanese bagging test[168].

On the basis of wearer trials carried out on synthetic knitted fabrics, Thomas[168] concluded that an IR value greater than 59 *per cent* should be acceptable as far as their resistance to bagging during wear is concerned.

STATIC

It is suggested that 3×10^{-7} Coulombs (2 000 volts) is the threshold for an unpleasant shock while a discharge of 4×10^{-7} coulombs gives a severe shock[169]. Values of 2 500 volts[170] and 3 000 volts[171, 172] have also been suggested. These normally refer to static charges collected when, for instance, walking on a carpet.

A value of 10^9 ohms/square (resistance in ohms x width of specimen ÷ distance between electrodes) is aimed at by ICI for antistatic clothing[173].

CONDUCTIVITY

In the case of cotton, a moisture content variation of between 3,5 and 13 *per cent* involves a decrease in resistance from 10^{11} to 10^{4} ohms. Limitations of using conductivity to assess moisture content is when water bridges the gaps between the electrodes. This occurs for cotton around a moisture content of 20 *per cent* and for wool and acetate around 40 *per cent*(174).

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