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SPECIAL PUBLICATION

A Review of the Physical Properties of Textured Polyester Yarns and Fabrics and Their Relationship

by

M.P. Cawood

SOUTH AFRICAN
WOOL AND TEXTILE RESEARCH
INSTITUTE OF THE CSIR

P.O. BOX 1124
PORT ELIZABETH
REPUBLIC OF SOUTH AFRICA

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A REVIEW OF THE PHYSICAL PROPERTIES OF TEXTURED POLYESTER YARNS AND FABRICS AND THEIR RELATIONSHIP

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INTRODUCTION

Textured yarns, especially polyester, play an important role in the synthetic and natural yarn market and in the apparel sector the false twist textured yarns have maintained the dominant position.

The textured yarns used in knitting today differ in many ways, e.g. in linear density, in the number of filaments in the yarn cross-section, in the yarn bulk properties, in the type of texturing process, etc., and each produces a fabric with its own specific aesthetic appeal and physical properties. These yarns are open to choice in practice and, therefore, a knowledge of the influence of these properties on the fabrics knitted from them should be useful in making the correct choice of yarn according to the required fabric properties.

This review briefly covers some of the work which has been reported concerning the physical properties of textured yarns and fabrics (especially polyester) and their relationship.

THE INFLUENCE OF YARN AND PROCESSING VARIABLES ON YARN AND FABRIC PROPERTIES

Texturing

The appearance of textured polyester fabrics in the dyed and finished state is highly dependent upon the type of textured polyester used. The most common false twist textured yarns fall into one of the following categories:

(a) Single heater, autoclave steam set stabilised yarn.
(b) Double heater stabilised yarn.

(c) Single heater unstabilised yarn.

During the texturing process there are many variables which can be altered and which can in some way affect the yarn properties and consequently the fabric properties. These include throwster (texturing) variables such as first overfeed, heater temperature, false twist spindle speed, package wind-up and processing time, as well as autoclave variables such as time, temperature, condensation, steam penetration, etc.

Yarns set in the autoclave are usually well set, have little residual torque and produce little fabric spirality[1] Yarns processed on the double heater machines apparently have less dye shade variations although other work has shown the opposite[1].

The yarn-to-fabric relationship is especially significant in textured yarn fabric design[2] Table I shows the effect of increasing false twist texturing settings on fabric characteristics[2].

TABLE I

GENERAL EFFECT ON FABRIC CHARACTERISTICS WHEN INDIVIDUAL FALSE-TWIST MACHINE SETTINGS ARE INCREASED[2]

Fabric Characteristic	**Effect on Fabric Characteristic**			
	Overfeed (Heat Zone) increasing	**Temperature increasing**	**False Twist (turns/m) increasing**	**Spindle Speed (r/min) increasing**
Stretch and recovery	Increases	Increases to a point, then decreases	Increases to a point, then decreases	Decreases
Appearance	More prominant	More prominant	More clarity	Less prominant
Coverage	Increases	Increases to a point, then decreases	Increases	Decreases
Handle	Harsher	Harsher	Harsher	Less stiff
Drape	Stiffer	Stiffer	Stiffer	Softer
Yield	Less	Less	Less	No effect
Moisture absorption	Increases	Increases to a point, then decreases	Increases	Decreases
Warmth to Weight	Increases	Increases to a point, then decreases	Increases	Decreases

Hunter[3] reviewed the causes and measurement of barré, and the causes of barré due to texturing are dealt with in detail in his paper. The main causes of barré at the texturing stage appear to be variations in texturing temperatures, twist level, tensions and spindle speed. Control limits for these variables are suggested for the prevention of barré[3]

Knitting

In recent years the trend in double jersey knitting has been towards fine gauge double jersey machines (as well as single jersey) one reason being to produce medium to lightweight men's outerwear from relatively fine textured yarns with tighter constructions to provide improved fabric properties, e.g. air permeability and snagging. Perhaps, one of the most important of these fabrics has been a double blister with a 2/2 twill effect (also termed gaberdine)[4]. However, 18 gauge double jersey machines, knitting 167 dtex textured yarns into fabrics of 200 — 280 g/m², remain the most popular[5].

According to Knapton[6], in 1973 the most popular knitted structures were interlock for underwear and Punto-di-Roma, Swiss double pique and rib for outerwear. However, with the development of finer gauge machines and finer textured yarns, interlock print and piece-dyed fabrics have become extremely popular. Swimwear and sportswear from polyamide yarns are also mainly knitted into interlock. Punto-di-Roma is used extensively in the wool industry as a plain and plain piece-dyed fabric and in cotton, rib and interlock are popular for underwear.

Many of the problems which are encountered during further processing and in the end product originate during the knitting process. The most troublesome of them is *knitting barré*. Hunter[3] has discussed all the aspects relating to this type of barré in some detail in a review. To summarise, some of the most important causes of knitting barré are variations in course length, faulty machine settings, yarn bulk variations and uneven yarn tensions. These can be overcome to a certain extent by using positive feed together with the control of yarn tension and yarn speed, good machine maintenance and settings, adequate and uniform yarn lubrication, the use of delayed timing wherever possible and choosing structures with random needle selection[3]

Munden *et al* [7] investigated the effect of *yarn tension* in knitting on the dimensional properties of plain fabrics knitted from stretch yarns. They found that, without positive feed, a change in yarn tension from about 2 — 15 cN may affect the stitch length by up to 15%. With positive feed, the stitch length is not affected by a change in tension between the positive feed unit and the knitting elements, but a change in tension between the package and the positive feed unit from about 2 — 25 cN may cause the stitch length to change by up to 6%. This variation may be reduced to approximately 1% if the input tension to the positive feed is kept between about 10 — 20cN. There was also some evidence that loss of yarn bulking potential and fabric collapse resulted when the yarn entered the knitting elements at a high tension. The average k_1 (k_S) values also increased slightly with a decrease in the input tension at the positive feed. The fabrics with the increased k_1 (k_S) values had the greatest thickness. The ideal combination of input tensions suggested to give maximum bulk appears to be a tension of 10 — 20 cN between the yarn package and the positive feed unit and 2 — 5 cN as the yarn enters the knitting zone[7].

From a practical viewpoint, the input tension of synthetic yarns during knitting, as a rule should be of the order of 1 to 2 cN/tex[8]. Safe tensions are those extending the fibre within the central Hookean region for each yarn. Those tensions extending the fibre to the yield region cause irreversible deformation of the fibre[8].

Pratt[9] attempted to correlate knitting variables and fabric physical properties of *Swiss pique* textured polyester fabrics (dyed but not heat set). Of the variables investigated, only the sum of the rates of feed of yarns to the jersey and rib needles correlated with the physical properties. An increase in the sum of the feed rates increased the fabric width, the fabric shrinkage during dyeing in the length direction, the fabric thickness, the fabric bulk, the air permeability, the course and wale direction stretch, the course direction recovery from stretch and the course direction fold recovery. Increasing the feed rates also resulted in a decrease in the stitch density, the width shrinkage during dyeing, the wale direction recovery from stretch, the wale and course direction work of fold compression (related to the ease of creasing), wale direction fold recovery and the fabric mass per unit area[9]

It has been suggested[10] that fabrics knitted from textured yarns should not be knitted too tight since the knitter cannot then take full advantage of the bulk potential built into these yarns. However, the slacker fabrics are knitted, the less satisfactory the wear properties (e.g. snagging, abrasion, bagging, etc.) are likely to be[10].

Dyeing and Finishing

The dyeing and finishing of textured polyester fabrics can to a large extent determine the end product properties since it is at this stage that the fabric is allowed to shrink (during scouring and dyeing), is dimensionally rearranged to meet fabric yield requirements (during heat setting) and is treated with lubricants, antistatic agents, anti-snag agents, softening agents, etc.

The finishing process of textured polyester fabrics basically requires three processes. These are *scouring* or *dry cleaning, dyeing* and *heat setting*, not necessarily in this order. Most of the problems occurring in these processes are reported[11] to be:

(a) barré

(b) rope marks, creases and wrinkles
(c) variations in fabric properties, e.g. handle and dimensional properties.

Scouring

Scouring is carried out primarily to remove the knitting oils so that they are not heat-set into the fabric. It also shortens the dyeing cycle and saves on auxiliary chemicals, as well as improves the fabric handle, the blister effect and the finished yield.

Knitting and texturing oils have been found to be one of the major problems in dyeing and it was suggested that scouring with a low foam non-ionic detergent with soda-ash (1% o.m.f) at 71°C for 15 — 20 mins would give good scouring results[12].

The residual yarn shrinkage and bulk development (% crimp rigidity) gives rise to fabric shrinkage during the scouring process. It was found[13] that area shrinkage of knitted polyester fabrics, when treated in a virtually tensionless free-floating state, was dependent on scouring time and temperature (approximately proportional to temperature). Furthermore, shrinkage reached its maximum after 3 min with a gentle milling of the sample. It was further suggested that tensions on the fabric during scouring must be kept below 9,8 N/m during wet treatment at high temperatures to achieve good shrinkage[13]. A crepe structure was found[11] to relax more during scouring than a ripple or pique structure.

Both the rates of heating and cooling are reported[11, 14, 15] to be very important for obtaining crease free fabrics. Pratt[11] and Gilliam[15] suggest that the rate of heating or cooling should not exceed 1,7°C/min. Others[14] also found that the danger of running creases was minimised when a cooling rate of 1 — 2°C/min was used. Anti-crease lubricants are also claimed[11, 14] to help prevent creases, rope marks and wrinkles. Another precaution to avoid the abovementioned faults[15] is not to load fabrics in cold water or unload hot fabrics. High reel speeds in a beck with a fairly low liquor to goods ratio have also been recommended[11, 15]. Pratt[16] has published a list of twenty-eight points which he suggests will reduce production problems, especially creases and cracks, in piece dyed textured polyester fabric.

Heat Setting

The heat setting process is essential to develop maximum performance in fabrics made from polyester (and other synthetic fibres) and to produce easy care properties. It gives dimensional stability to the fabric and builds in the desired fabric hand, recovery from stretching and crease and wrinkle recovery[17, 18].

Heat setting temperatures from 150°C to 180°C generally seem to be the range of temperatures used commercially. Lower temperatures are claimed[17] to give poor fabric recovery whereas higher temperature may give problems with dye sublimation.

Pratt[11, 19] investigated the effect of heat setting temperature on some fabric physical properties and found that an increase in heat setting temperature decreased fabric thickness and fabric mass (only up to 170° C after which there was an increase in fabric mass), increased the air porosity (slightly) and the bulk (bulk reached a maximum at 150° C and then dropped off rapidly above 160° C). He suggested that [11, 17, 19] a heat setting temperature of 160° C would give the best overall properties. Gilliam[15] also felt that this temperature would produce excellent overall fabric properties.

Gregory[20] stated that the most sure method of controlling snagging in knit fabrics is to draw the surface loops back into the body of the fabric whilst setting at 165°C — 170° C. This was achieved by extending the fabrics by up to 10% in the width, based on the relaxed scoured width, but not exceeding the greige width[20].

Parish[20] was reported as finding optimum width and length washing and hot head press shrinkage at a stenter temperature of 170° C. Gregory[20] stated that work carried out at ICI, on optimum heat setting temperatures, revealed that yarn type made very little difference to the achievement of stability by heat setting at a given temperature. Yarn dyed fabrics as well as fabrics dyed at the boil in the presence of carrier achieved stability at heat setting temperatures of 150° C — 160° C as long as the finished dimensions were near the relaxed scoured dimensions. However, if the fabrics were to be stretched to meet lower yields at the expense of leaner handle, loss of crimp and development of shine, high temperatures were required for stability. ICI further felt that high temperature dyed fabrics required setting temperatures of 165°C — 170° C in order to overcome the hydro-setting of dyeing[20]. It has also been proposed[21] that for menswear, higher heat setting temperatures (190° C) and semi-decating be used to stabilise the fabrics. Furthermore, heat setting should be done with underfeed to reduce stretch properties[21].

Knits of spun polyester (100% or blends) are reported by workers at Du Pont[18] to be heat-set according to the way they are dyed. Piece dyed fabrics are heat-set at 163° — 177° C after dyeing whereas package dyed fabrics are set in an open width frame at 163° C for 45 seconds with the fabric supported and relaxed. Continuous filament polyester when carrier dyed must be set at 160° C — 163° C for 30s, whereas when dyed under pressure, temperatures of 171° — 177° C for 30s are recommended[18].

The amount of overfeed used in heat setting greatly affects finished fabric appearance especially fabrics with raised surfaces (ottomans and blisters)[17]. Pratt[19] reported that a reduction of overfeed from 10 to 0% decreased fabric mass by about 8 g/m^2, and decreased the fabric length which varied according to the finished width. He also found[11] that an increased width stretch decreased the fabric mass per unit area linearly as expected and increased the air porosity. He further reported[22] that fabric shrinkage (hot head pressing at 177° C) decreased as overfeed and heat setting temperatures increased.

Although heat setting is mostly carried out after dyeing, Pratt found[19] that heat setting before dyeing (pressure dyeing at 110° C and 121° C) reduced shrinkage during dyeing (from 15% in the length to 2,5%). Furthermore, fabrics that were not set before dyeing weighed more since they shrank more in length during dyeing and relaxed more in width after heat setting. Fabrics that were set before dyeing were bulkier. Goods which were not heat set before dyeing but set after dyeing at 149° C shrank as much as 5,8% after 5 drycleanings[22]. Fabrics set at 182° C were acceptable but this temperature was likely to cause dye sublimation[22]. Heat setting before dyeing could, however, cause uneven dyeing if exposure conditions varied[18].

Pratt therefore suggested[22] that the best approach would be to heat set the fabric before dyeing and again after dyeing at about 171° C to 177° C. Gregory similarly suggested[20] a finishing sequence of presetting at 165° C — 170° C after scouring, a 125° — 130° C dyeing followed by a final stenter at 120° C, especially for tighter knitted men's wear. He claims that this routine gave no cockling, improved dye fastness and reduced barré to a minimum.

Dyeing

Much research has been carried out on the dyeing of polyester[28] and most workers have concentrated on attempting to eliminate or covering barré by trying to find the optimum dyestuffs, dyeing temperature and carrier concentrations. This aspect is covered in a review article[3]. It appears that high pressure or high temperature (116° C — 129° C) dyeing with a carrier (1 — 5%) and levelling agent is the best way of covering barré. For atmospheric dyeings very high concentrations of carrier as well as longer dyeing times are required to cover barré. However, the choice of dyestuffs is critical since there are various dyestuffs on the market with different sublimation fastness[3].

Pratt investigated[11, 19] the influence of heat setting temperature and carrier level on some fabric physical properties. He found that as the carrier level increased, the fabric thickness decreased, the fabric became less bulky, the bagging properties (described as work recovery) improved, the air permeability decreased and the wrinkling improved.

Wilson[23] stated that the fabric load size in any pressure dyeing machine can affect the wet width after dyeing, as well as the finished yield, blister and hand. For each type of structure and mass per unit area, therefore, a standard load size per dye machine should be established if standard finishes are expected. Yarn dyed fabric in comparison to piece dyed fabric is claimed[17] to produce a firm and crisp fabric.

men's wear the finer linear densities are suitable for sport and dress shirts as well as double knit slacks[33].

It has been reported[34] that, in practice, the low linear density yarns produce better coverage together with superior handle and drape. The lower the yarn linear density, for the same filament decitex, (i.e. the fewer number of filaments in the yarn cross-section), the greater is the tendency of the filament to migrate, showing more frequency of reversal and therefore greater stretch potential is acquired by the filaments. As a result they are also more affected by heat[34]. The advantages of knitting jacquard effects in extra fine gauge (28 gauge) are better drape, decreased air permeability and increased resistance to pilling[25].

For a given stitch length, Munden *et al*[7] found that the yarn collapse in the fabric was greater for fabrics knitted from yarns of lower linear density, i.e. the collapse depended on the MTF.

Filament Linear Density

It has been found[34] that the fewer the number of filaments in the cross-section of a textured yarn of a given linear density, the greater its stretch and resistance to extension, and the quicker it recovers. This is due to the easier filament migration referred to earlier.

Furthermore, it is stated[2,34] that, for a given yarn decitex, an increase in the number of filaments in the cross-section creates a softer handle, better drape and increased coverage. Elsewhere it is reported that the lower the decitex per filament, the softer the fabric hand, although the danger of barré or even snagging is increased[36]. The most common filament linear densities appear[37] to be around 4,0 to 5,5 dtex. As the decitex per filament decreases, problems in processing are encountered and broken filaments, bulk differences, dyeability differences and therefore barré are the result. However, the advantages of using finer decitex per filament yarns are a softer handle, silkier drape, less snagging and the higher finer crimp results in a non-glitter effect. Some further disadvantages of finer filament linear density include easy wrinkling (but more readily removable), permanent creases do not stay in very well, more dyestuff is required to obtain a certain depth of shade and good lustre, and high bulk cannot be readily obtained[37].

Yarn Structure

Plied yarns, in comparison to single yarns, are claimed[34] to have better stretch and more vigorous recovery in the resultant fabric for an equivalent total yarn linear density. This is again explained in terms of the migratory behaviour of the filaments.

Munden *et al*[7] found that for a given stitch length, fabric knitted from one end collapsed to a greater degree than the fabric knitted from two ends. It was also found that 2 ends of 33 dtex/2 yarn gave similar results to those obtained with a 67dtex/2 yarn, and figures obtained with 4 ends of 33 dtex/2 were roughly comparable with those obtained from 111 dtex/2 yarn, i.e. yarns with the same resultant linear density performed similarly.

Filament Cross-section

Several filament cross-sectional shapes are used in textured yarns, ranging from circular to multilobal. Round, trilobal, pentalobal and octalobal are the most common cross-sections encountered[37]. It is the shape of the cross-section which is claimed to determine the lustre of the fabric. When a high degree of lustre is desirable a clear polymer (or a polymer without a dulling agent) is used and a filament having a straight sided cross-section is extruded for increased light reflection. For a low lustre, semi-dull polymer is used and concave shaped lobes rather than straight lobes are extruded. Between five and eight lobes would give a low lustre yarn whereas three or four lobes would have excessive surface area for light reflection. Too many lobes, however, become similar to a circular cross-section and have excessive light reflection. Furthermore, the cross-section is claimed to have an effect on the fabric handle and drape. A modified cross-section is also claimed to assist in soil release and also produces a soil hiding effect in fabric form[37]. It has also been found[34] in practice that multilobal cross-section textured yarns have sparkle, glitter, increased covering power and a silk-like hand and appearance.

Szlosberg[38] has also stated that the shape of the cross-section materially affects such fabric properties as lustre, sparkle, hand, cover and possibly soiling. Cross-sections such as trilobal, tetralobal and pentalobal are engineered primarily to heighten sparkle and lustre but they also have an effect on cover and handle. The drawback of these cross-sectional shapes is that a certain amount of cross-section distortion occurs during texturing and some of the effect (sparkle and lustre) is lost. He suggests that, in such a case, a bright polymer without a delustrant be used. He feels, however, that the round cross-section filaments will stay popular since they are easier to texture and produce products with good uniformity, handle and all round characteristics. The only disadvantage is their glitter effect in direct sunlight and producers have overcome this with multilobal (e.g. octolobal) cross-section filaments[38].

Yarn Lubrication

The lubrication of textured yarns is normally undertaken at two stages during the production process. The first stage is after the fibre has been extruded and before drawing. This is known as a *spin (or producer) finish.*

The spin finish is applied in emulsion form so as to obtain a uniform application of finish in amounts of 0,5 — 1% at a precise moisture level[39, 40]. The functions of this finish are to impart to the yarn low frictional properties, to assist in the drawing and winding process, to confer anti-static protection, to prevent filament ballooning and to impart cohesion between the filaments[40].

The spin finish[34] will also affect the amount of tension which is required during texturing, the degree and mode of heat transfer, the amount of twist required as well as the yarn speed. This finish is, however, subsequently evaporated off during texturing and much of the lubricating effect is lost. It is, therefore, necessary to apply a second lubricant.

The second application is during the rewinding process where the yarn is wound onto a package in preparation for knitting. The lubricant applied at this stage is known as the *coning oil.* This is to assist in the performance of the yarn during knitting. Application of between 2 and 6% coning oil is normally sufficient to provide a good knitting performance[17, 19, 39, 41].

Variations in the amount of lubricant and whether it has been satisfactorily removed during scouring can influence the dye uniformity of a fabric critically[17]. Where the fabric was heat treated before scouring (i.e. before removal of coning oils) it was found that fastness to rubbing, water and washing deteriorated. This was presumably the result of dye migration to the yarn surface caused by the presence of the coning oil. No deterioration in fastness resulted from storing dyed yarn containing recommended amounts of coning oil.

Fabrics that have not been stripped entirely of coning oil are less subject to sewing damage than fabrics that have been scoured free of oils[42].

Other Properties

Stretch and elongation can also be tested[18] as a quality control measure for checking the quality of yarns with respect to mechanical defects and subsequent knittability. The determination of tensile strength is only an advantage if either the initial strength of a flat yarn is low or if the stress during the texturing process is so high that damage to the yarn is to be expected[43]. Michelena has stated[26] that, generally, a textured polyester yarn with a strength of about 27 cN/tex (3 gf/denier) or lower will be very difficult to knit and that a reduction in strength of 20% due to texturing is acceptable.

Another important area[26] in testing yarn is its dyeability. Differences in dyeability will show up yarn faults which could have occurred during extrusion, drawing or texturing. It has been found that by knitting twenty packages on a single feed machine and subsequently dyeing the sleeve in a small open bulk unit, the behaviour of the yarn lot can be predicted with a great degree of accuracy.

The knittability[26] has also been predicted by using a continuous tension analyser in conjunction with a single end knitting machine. A continuous recording of tension fluctuations from a cone as it delivers yarn is charted and compared with yarn which had good knitting performance.

TEXTURED YARN FABRIC PROPERTIES

Double jersey structures suited to mens' wear and ladies' wear have succeeded in their field because of the high production rates and the advantage of the product having built-in elasticity and the power to recover after deformation[6]. These recovery properties lead to comfort in wear but strict control must be maintained over these properties. The fabrics that have been successful in women's wear are not necessarily ideally suited to the men's wear requirements for the following reasons :

1. High permeability due to the open structure
2. Fabrics have a tendency towards bagging at high strain zones such as the knees and elbows.

When setting standards for fabric properties or developing testing methods for fabrics, it is vitally important to take into consideration the requirements of the market. An evaluation must be made of the consumer need in any particular time and geographical location, for it is the person who is to wear the garment who must be satisfied.

Strasser has classified[44] standards into two categories, namely, those which must be constantly modified with time and those that remain permanent for the forseeable future. He then further categorised these standards under the following headings:

1. *Aesthetics* which include crease/shape retention and wrinkle recovery.
2. *Comfort*, which comprises handle, stiffness or liveliness, stretch/extension recovery, air permeability and moisture absorption.
3. *Wearability* referring to pilling, snagging and abrasion.
4. *Easy care* defined by machine washability and dimensional stability.

Properties that were regarded as especially important in apparel were found in a survey in the USA[45] (in order of preference) to be *easy care* (less ironing, crease resistance and washability), *appearance* (aesthetic attraction, stability, fit, etc.), *comfort* and *economy* (price).

Similarly, apparel attributes that are the consumer's major ooncern, although not in this order of importance, are reported by Jay[46] to be *maintenance of durability* (i.e. how much wear will a fabric endure before losing is aesthetic attractions), *easy care* and *permanent press* properties together with shrinkage performance, fabrics must not be chemically or mechanically tendered during finishing, acceptable *pilling* rate, acceptable *snag* performance, acceptable *colour fastness* and *crocking,* acceptable *hand* and *drape,* and *stretchability.*

Chapman categorized[47] the characteristics of bulked continuous filament polyester fabrics according to their merits (i.e. comfort resulting from multi-direction stretch, dry crease resistance, ease of washing and non-iron character), potential weaknesses (i.e. snagging, wash stability and stitch damage) and adverse characteristics (i.e. air permeability, lustre and lack of crease sharpness). Furthermore, he felt that fabric branding standards should include standards of fabric mass, structure, dimensional stability to garment making up processes, as well as machine washing, snagging, sewability and colour fastness.

In the following table, typical causes of double jersey apparel returns (male and female) are shown for 1974, as published by Monsanto[48].

TYPICAL CAUSE ANALYSIS OF DOUBLE JERSEY APPAREL RETURNS (%)

Abrasion	**Dimensional**	**Colour**	**Appearance**	**Accessories**	**Hand**	**Steam**	**General**
Male Apparel 94,4	—	—	—	1,0	—	—	1,0
Female Apparel 14,2	63,7	2,2	4,8	1,0	1,0	9,6	4,5

Snagging

A snag has been defined[49,50] as "that defect characterized by the collapse of more than one yarn loop along the course direction as a result of one yarn loop being caught and pulled by an asperity or the rough spot of an object". A further fabric fault of a similar nature, namely fuzzing, has also been defined by Leung and Hershkowitz[49, 50] as "the fabric defect characterized by the presence of broken filaments that emerge from the fabric surface as a result of abrasion by an external rough surface".

Fuzzing or snagging of yarns in a fabric occurs frequently and filament yarns are naturally more susceptible to this type of mechanical damage. Although not such a serious problem in the women's wear field, it is probably the most serious problem in the men's wear area, the reasons being that men are much harder and rougher on their clothes and lighter fabrics used in men's wear are more prone to snagging[51,52].

The ease with which yarn or filament is disfigured in the fabric is reported[53] to depend on, amongst other things, the type of yarn and its linear density, the structure of the fabric, the tightness of the fabric, the mass of the fabric and the finish the fabric has received. The tendency for a fabric to snag is also accentuated if the fabric is[51, 54]:

1. Lightweight
2. Constructed with loose stitches
3. Knitted from low twist yarn
4. Constructed with tuck stitches
5. Not heat set after dyeing
6. Knitted to produce a raised (ripple or bourrelet) effect.

Leung and Hershkowitz[49, 50, 55] have developed what they term the construction density factor (CDF) which is a relationship between the yarn run-in, the loops per wale per feed, the yarn linear density and the density of the yarn. If the finished fabric width and yarn shrinkage could be predetermined, and if the yarn linear density, machine gauge and stucture were known, the yarn run-in could be specified to produce a fabric of acceptable performance. From their experimental results, it was shown that the snagging and fuzzing performance of four double jersey structures (interlock, Swiss pique, Punto-di-Roma and modified interlock) was a function of stitch tightness. Also, fabrics with equivalent CDF values as well as yarn type were found to have similar performance irrespective of yarn linear density, machine gauge and stitch structure. Minimum CDF requirements for acceptable snagging and fuzzing performance for double jersey structures knitted from various yarns were defined, with an acceptable wear performance being obtained with a CDF $\geq$ 57. In their experiments, they used the Mace tester (with modified rating standards) as a snagging test and a modified Brush test for fuzzing[49, 50, 55].

Hunter and Smuts[5] determined the snagging (on a Mace tester) of a range of commercial textured polyester fabrics and found no dependence of the snag rating on fabric mass per unit area but found blister fabrics to snag more than the other structures. A rating of 3 to 4 for women's wear and 4 for men's wear on the Mace tester is reported[51] to be an acceptable performance although many feel that these values are too severe.

Much of the snagging problem can, therefore, be eliminated by choosing optimum tightnesses, yarn linear densities, fabric structure, etc. On the other hand, chemical treatment can also do much to improve snag performance by minimising the physical disturbance caused when filaments are accidentally caught.

Helfgott has described[51] a system, known as the Macegard system, for the improvement of snag performance as well as making the fabric dimensionally stable to washing and drycleaning. Furthermore, it will not affect the aesthetic properties and is easy to use and only requires a pad with a tenterframe. The Macegard contains self crosslinking acrylic copolymers as well as other components not mentioned.

Verona laboratories[52], after laboratory tests on different finishes, decided a crosslinking acrylic dispersion was the best snag resistant finish. The treated fabric also showed no tendency to bag, fuzz or pill. A process[56], combining chemicals and heat setting, has recently been developed, and is claimed to impart improved snag resistance to double knits with increased fabric recoverability from stretch. Treated fabrics are also claimed to withstand as many as 10 machine washings using cold water detergent at 43°C.

Other anti-snag finishes have also been discussed[54] and guides to these type of finishes have been published[57,58].

Sewing Performance

Sewing damage occurs right at the end of the production line and can, therefore, be a costly problem. This fault occurs more readily in knitted fabrics and is even a greater headache in men's wear knitted fabrics since they are usually more tightly knitted than women's wear.

Stitch damage, according to most workers[53,59-64] can be classified as follows:

(a) *Yarn breakage* caused by a needle point striking a yarn loop and damaging it, or a needle penetrating a loop too small to accept the thickness of the needle and consequently the loop is forced to "rob" yarn from surrounding loops leading to the bursting of the yarns.

(b) *Needle heat damage* as a result of the softening of the synthetic fibres caused by a heated needle at high sewing machine speeds.

Munden and Leeming[59,64] pointed out that both these types of damage are caused by high yarn friction in the fabric (yarn-to-yarn friction) arising when the yarn has to be "robbed" from adjacent loops in order to increase the loop size temporarily to allow for needle penetration. Alternatively, high yarn-to-needle friction can result during needle penetration if the fabric is not lubricated sufficiently and this results in needle heating and softening of the yarn. However, in practice possibly less than 5% of sewing failures are due to needle heating effects.

The sewing performance of a fabric will, therefore, depend on certain fabric variables (fabric structure, yarn bulk/strength, fabric finishing and fabric lubricants) as well as sewing machine variables (needle type and size, machine speed, needle coolants, sewing thread, thread tensions and thread lubricants)[53].

Some fabric structures will make loop expansion easier than others. For example, it is said[53] that jacquard structures are more susceptible to stitch damage than bourrelet or blister structures because of the greater freedom of yarn movement in the latter structures.

The problem seems to be more acute in fine gauge fabrics[65] especially of tight constructions[62]. Furthermore, 24 gauge fabrics have been found to have a greater propensity for sewing damage than 18 gauge fabrics and 100% textured set polyester filament double knit fabrics are the most resistant to sewing damage, whereas 100% spun polyester or spun polyester/wool are the most prone[65].

It has been proposed[53] that the finishing route of fabrics for men's wear (8 — 10% width extension or to greige width demensions, whichever is the least) has a detrimental effect on sewability. ICI, however, has shown that finishing with width extension, within a range giving satisfactory dimensional stability is not a major cause of sewability problems[53].

The dyeing and finishing of a fabric influence the frictional properties of the fabric and is, therefore, critical, especially as far as the amount, as well as the type of lubricant or softener, on the fabric or applied to the fabric, are concerned. HATRA[61], in experiments on a worsted Punto-di-Roma fabric, found a dramatic decrease in stitch damage with an increase in the lubricant content of the fabric. The choice of the lubricant, however, depended on its effect on other fabric properties. Braun *et al* [66] found the amount of wax applied to polyester/wool yarns to have a significant influence on the forces generated during needle penetration, reducing them considerably. Munden and Leeming also reported[59,64] on the dramatic effect that the application of a lubricant has on the sew ability. They[64] found that a small amount of a certain lubricant improved the sewing performance as well as the handle of the fabric. Spraying on a lubricant ahead of the sewing line would also help, although the lubricant was not effective when still wet[64]. Tests carried out[53] to determine the most effective fabric lubricant showed a polyethylene type softener to have the best results, but only at high concentrations. It also appears to have anti-static properties and does not affect fabric handle[53]. Du Pont[62] have also found a lubricant which improves sewing performance and if applied at a 1,5% level it will not influence the handle or the finishing properties. It has also been found elsewhere[67] that needle penetration forces could be reduced considerably by enough lubricant and, therefore, man-made fibre goods which have been scoured and heat set may require additional lubricant to improve sewing performance.

Air permeability

Another property, inherent in knitted fabrics, which has presented problems, especially in men's outerwear, is the high air permeability of these fabrics which results in them being draughty and uncomfortable. High air permeability could, of course, be an advantage in sportswear for warm weather.

Oxtoby[68] found that, in general, conventional knitted fabrics allow 10 —

18 times more air to pass through than woven fabrics. Furthermore, he reported a general trend for the air permeability to decrease as the fabric mass per unit area increased, although some exceptions existed. This meant that 18 gauge fabrics produced fabrics with a lower air permeability than 22 gauge fabrics[68]. Strasser suggested[44] that finer machine gauges with finer yarns will produce higher stitch densities and improved porosity properties (decreased air permeability) of the fabrics.

Lo[69] found, as expected, a good inverse relationship between the air permeability and the tightness factor, but the rate of decrease depended entirely on the structure. The effect of tightness factor on the air permeability for the Swiss piqué structure was very small. The single piqué structure was the most permeable due to the tuck stitches in the structure. The interlock and Punto-di-Roma structures were the next most permeable because of the interlock base. All the rib based fabrics had similar values. The pin-tuck and texi-piqué as well as the six feeder repeat Punto-di-Roma and piquétte structures were found to have the lowest air permeability. No explanation could be given for the results obtained in the four latter structures[69].

Other reports[44, 70] also state that the air permeability of a fabric is dependent entirely on the structure of the fabric and is practically independent of the fibre used.

Postle[71] found that in general, Punto-di-Roma fabrics have a lower resistance to air flow than Swiss double piqué structures in wool. However, a Punto-di-Roma fabric with a run-in-ratio of 1,2 : 1 had similar or lower air flow values than the Swiss piqué fabrics but this structure presented fabric dimensional problems. He, therefore, suggested a modified 8-feeder repeat Punto-di-Roma structure (first four feeders identical to conventional Punto-di-Roma but in the second group of four feeders, feeders 1 and 2 are reversed to become feeders 6 and 5, respectively) which produced a more regular and wider fabric for low values of run-in-ratio. He also found that an increase in the tightness factor (at a constant run-in-ratio) decreased the air permeability[71].

Work on the physical properties of some double jersey tuck structures in wool revealed[72] that air permeability increased as the fabric mass per unit area decreased. At the same run-in values, the pin-tuck generally had the lowest air permeability followed by the single piqué and the royal interlock was the most permeable.

Hunter and Smuts[5] have suggested that it is possible to reduce air permeability significantly, even at the same fabric mass per unit area, by knitting finer yarns into tighter constructions and by decreasing the filament linear density in the yarn. In another report, the same authors[73] reported that mass per unit area, fabric density and mean fibre diameter influenced the air permeability significantly for a range of commercial wool and wool blend double jersey fabrics. Yarn linear density and machine tightness factor, however, had no influence within the ranges covered[73].

Average values given by Hunter and Smuts[5] for some commercial polyester fabrics are:

One layer : 143 mℓ/s/cm² at 98 Pa water pressure (11% CV)
Two layers : 92 mℓ/s/cm² at 98 Pa water pressure (16% CV)

Typical permeability values for some weft knitted textured polyester fabrics are also given in an article by Amemori[74]:

137 dtex : 155 mℓ/s/cm²
167 dtex : 148 mℓ/s/cm²

Resistance to Bagging

The tendency for knitted fabrics to "bag" at those positions where they are subjected to the greatest stresses, for example, at the knees and elbows, has presented yet another problem to fabric manufacturers, especially in men's wear and ladies slacks.

Hunter and Smuts[5,73] found that the bagging (IR %) was not influenced by any of the yarn or fabric variables they considered for textured as well as wool and wool blend double jersey fabrics. The average bagging value found for the textured polyester fabrics was 61% IR (4% CV). Immediate recovery results of greater than 59% are considered satisfactory, 53-59% are borderline and less than 53% are unsatisfactory[75].

Tuck structures in wool were found to have a high bagging propensity as a result of the incorporation of a tuck loop into the structure[72]. At the same mass per unit area the pin-tuck fabrics had a slightly lower propensity to bag than the other fabrics[72].

Drape

Fabric drape can be defined as the extent to which a fabric will deform when allowed to hang under its own weight. It is one of the fabric properties which affects the aesthetic appeal of a garment in use.

Hunter and Smuts[5] found the drape coefficient of a range of textured polyester fabrics to depend to some extent on their fabric mass per unit area, increasing with an increase in the mass per unit area. The average value was found to be 51% (20% CV)[5]. The drape coefficient of some double jersey tuck structures in wool was found[72] to increase as the course length at either the tuck feeder or interlock feeder or both decreased. At the same mass per unit area, the pin-tuck fabrics were the most flexible and the royal interlock the stiffest[72].

Bursting Strength

It has been found[76] that, in the case of knitted fabrics, bursting strength is the most suitable way for determining the tensile properties. Hunter and Smuts[5] found the bursting strength to increase with an increase in the fabric mass per unit area (average value for textured polyester fabrics = 1 820 kN/m^2 with a CV of 15%). The minimum fabric bursting strength allowed by Dan River Inc.[77] is 415 kN/m^2 (ASTM-231 Mullen).

Bursting strength values of some tuck structurers in wool had the tendency to increase as the run-in at either the tuck or interlock feeders decreased[72]. At the same mass per unit area values, the royal interlock fabrics tended to have the highest bursting strength and pin-tuck the lowest value[72].

Fabric Shrinkage

Three types of shrinkage occur in fabrics knitted from synthetic fibres[22,78].

(a) *Relaxation* shrinkage occurring when tensions caused by the physical distortion of the fabric are relaxed.
(b) *Fusion* shrinkage which is the result of hot treatments, such as pressing, which relieve internal stresses in the yarn.
(c) *Residual shrinkage* which is the shrinkage that remains in the fabrics and is experienced by the consumer during cleaning and use.

Fabric shrinkage is apparently a greater problem in men's wear than in women's wear due to more severe tests conditions as well as stringent requirements[22,78]. It has been found[79] that, for synthetic fabrics, dry tumbling at elevated temperatures causes higher levels of relaxation shrinkage and larger changes in shape than static wet-relaxation treatments.

A shrinkage of 3% (or about one garment size) in each direction after five commercial dry cleanings or five home launderings and tumble drying for dress goods has been regarded as acceptable[22,78]. In men's wear 2% in each direction is permissible[21, 22, 78]. Dan River[77] has a minimum standard of 4% washing shrinkage in each direction for 100% polyester knit fabrics. A shrinkage of 3% either way after three machine washes at 60° C followed by tumble drying has also been reported[47] as a standard for Crimplene in women's wear.

Lilly[80] suggests that restored shrinkage should not exceed 2% (2,5% at the most) after three washes (AATCC 96-1972) and maximum pressing and curing shrinkage should not exceed 1,5% and 2%, respectively. Total acceptable limit is therefore 3,5% for a satisfactory standard, with 4,5% marginally acceptable. Knits in the dress and blouse category have been specified[81] to have no more than

3,5% shrinkage for heat set fabrics and 5% for other women's garments.

Data presented by Wentz *et al* [82] showed that about 50% of damage claims for shrinkage were attributable to the manufacturer of the garment or fabric, 25% were caused by consumer abuse and the balance by improper handling during dry cleaning. It is felt[70] that the major cause of problems with shrinkage is due to heat setting.

Studies at the International Fabricare Institute[82] have shown that heat setting at 163° C provides satisfactory dimensional stability but 196° C gives even better results. Pratt[22, 78] suggests reducing shrinkage by heat setting before dyeing, knitting a tight fabric, reducing fabric mass, reducing yarn linear density rather than stretching, using two stages to dry and heat set after dyeing, and using a temperature of 171-177° C to heat set after dyeing.

Knapton[83] recently reported that area washing shrinkage for textured polyester knitted fabrics increased with run-in-ratio and less shrinkage occurred at higher heat setting temperatures (125° C-150° C). He advocated that k-values should be used to engineer fabrics for dimensional stability and then the fabrics should be heat set at a minimum stretch[83]. Elsewhere, it has been suggested[84] that an improvement in dimensional stability can be achieved by knitting finer (lower decitex) yarns and tighter stitch constructions in fine gauge (22 and 24 gauge).

Other Fabric Properties

Pilling, wrinkling, abrasion resistance, crease recovery, breaking strength and elongation are not considered critical properties when dealing with textured polyester fabrics and these have, therefore, not been discussed. They can of course be measured to complete a quality control exercise but textured polyester fabrics generally perform well as far as these properties are concerned.

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Published by
The South African Wool and Textile Research Institute
P.O. Box 1124, Port Elizabeth, South Africa,
and printed in the Republic of South Africa
by P.U.D. Repro (Pty) Ltd., P.O. Box 44, Despatch