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The Causes and Measurement of Knitted Fabric Barré

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The causes of Barré in fabrics knitted from continuous filament yarns, and their identification, are discussed. Ways of eliminating, or at least minimising, Barré as well as various techniques of measuring and quantifying Barré are reviewed.

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PREAMBLE

Barré has been defined[1] "as a continuous visual barred pattern or stripiness parallel to the yarn direction in a knit or woven fabric that is caused by physical, optical, or dye differences in the yarns or geometric differences in the fabric structure acting either singly or in combination to produce the barred pattern". These "bars", which appear either lighter or darker than the rest of the fabric, often extend the full width of the material (or, in warp knitting, the full length of the fabric) and more often than not repeat at regular intervals (i.e. are periodic) along the length, or part of the length, of the fabric. It may be noted that Klaeui[2] states that what weft knitters call barré warp knitters refer to as streaks.

It has been maintained[3] that all circular knit fabrics from textured yarns tend to have barré to some extent but that some dyestuffs will cover barré better than others[4, 5]. In practice, fabrics vary from barré free to severely barré with the level at which it becomes unacceptable depending on factors such as fabric structure, dye shade, end-use, economy etc.[6] For example, barré standards of men's wear cutters are apparently higher than those of women's wear cutters[4]. Acceptance standards, therefore, should be a matter for agreement between buyer and seller.

It has been stated[7] that barré claims can be related to one of five basic sources, with the following distribution: raw yarn – 10 *per cent*, texturing – 34 *per cent*, knitting – 36 *per cent*, dyeing – 14 *per cent* and mixed yarns – 6 *per cent*. Another source[4] estimated that only 10 *per cent* of barré problems originate in the knitting room. Holfeld and Nash[8] stated that knitters experience between 20 and 30 *per cent* rejects on account of barré when knitting critical fabrics such as piqués from textured polyester yarns.

In the case of nylon, the trend towards bright colours, which often require the use of critical, rate sensitive dyes, is claimed to be at least partly responsible for growing barré problems[9]. Martin[10] stated that all nylon yarns have a certain level of stripiness.

This paper proposes to review the fundamental aspects and causes of barré and how these are identified in practice, ways of eliminating or reducing barré and, finally, the objective measurement of barré i.e. how can the severity of barré be quantified since this is the first step towards establishing meaningful standards on which agreement may be reached between buyer and seller.

CLASSIFICATION OF BARRÉ

Often mentioned causes of barré are chemical differences in the fibre polymer, differences due to drawing, uneven deposition of spinning oils and mechanical deformation in knitting[11]. The major cause of barré, however, is physical differences in the individual fibres due to variation in fibre structure[11]. Polyester dyeability is said to be primarily dependent upon the degree of crystallinity while dyeing rate is determined primarily by the density (molecular orientation) of the amorphous regions[11]. Barré in nylon fabrics, dyed with acid dyes, can result from differences in depth of shade caused by[12] differences in dye capacity (i.e. differences in the number of sites) or differences in dyeing rate (i.e. orientation differences).

Blore[4] classifies barré into three categories viz. –

1. Yarn barré – caused by either chemical or physical differences in the yarn or both, this includes dye variation.
2. Shadow barré – which appears as a graduating stitch density and is generally caused by cylinder out of true circumference, dial out of true centre or dial not truly horizontal.
3. Stitch or machine barré – where one or more course lengths in the repeat differ from the others. This could be due to differences in yarn input tension, positive feed setting or cam adjustment.

To this list could perhaps be added bulk differences in textured yarn while yarn processing tensions during knitting could also lead to configurational non-uniformities[12].

Mixed yarns are one of the most obvious causes of barré in which case one or more yarns differ from the others in[12]:

(i) Lustre – higher delustrant content masks dye and makes yarn appear light.
(ii) Filament cross-section – non-circular filament cross-section normally causes the yarn to appear lighter.
(iii) Filament linear density (dtex or denier) – reduction in filament linear density, at a constant yarn linear density, makes the yarn appear lighter.
(iv) Twist.
(v) Total yarn linear density.

FUNDAMENTAL ASPECTS

The original polyester fibre structure contains regions of stress, but spontaneous relaxation of these stresses and shrinkage are inhibited by the internal frictional forces between the structural elements, and the crystallites which tend to lock the structure together. When a polyester fibre is heated above its glass transition temperature, but below its melting temperature, local melting and recrystallisation processes become possible and the fibre structure tends to increase in average orientation, and considerable shrinkage may occur[13]. These effects are significantly affected by fibre tension. It is normally expected that the sorption and diffusion of dye take place only in the less-ordered (amorphous)[14] regions of the polyester fibre so that both the diffusion coefficient and the equilibrium sorption of the dye in the fibre will depend on both the extent of these disordered regions, and on their local configurations and properties[13]. It is this which makes the dyeing behaviour so sensitive to variables encountered in texturing[13].

Crystalline regions within a drawn polyester fibre increase in amount, in size and in perfection on relaxed annealing[13]. The difference between the average properties of crystalline and disordered material in the fibres also increases i.e. the fibre begins to develop a more pronounced two-phase type of structure. The glass transition temperature is decreased by annealing without tension. When a highly-drawn fibre is annealed under sufficient tension, a much more homogeneous type of structure is obtained which is still oriented and, on average, more perfect in structure than the original drawn fibre[13].

Although a polyester fibre is reasonably stable after texturing residual stresses may still exist and slow relaxation or creep may lead to gradual changes in the fibre structure (or ageing) during storage[13].

During the crimping process, crystallinity increases while the orientation of both ordered and unordered regions decreases for both polyester and nylon[15]. Yasuda[16] found that, for nylon 6 fibres, the amount of crystallinity was unaffected by tension during heat setting although the amorphous regions were affected.

Rate of dyeing is a function of fibre orientation[12], and although it is initially established during yarn manufacture, it is much more susceptible to change by "normal" processing of yarn into fabric. As a rule of thumb, tensions on nylon 66 filament yarns at room temperature should be kept below about 1,8 cN/tex to avoid such re-orientation of the structure which will influence the dyeability. At higher temperatures the tensions must be even lower. Increased orientation results in a reduced dye rate. Exposures to dry heat generally also reduce the dyeability of nylon, while exposures to steam could increase the rate of dyeing.

DETERMINING THE CAUSE(S) OF BARRÉ

In practice, one of the main objectives is to establish whether the barré originated on the knitting machine or in the yarn. It is often impossible to determine whether a dye difference was introduced during texturing or was present in the feed yarn[17]. Barré due to variation in the dye affinity of different yarns could be due to a variety of reasons. At worst it may be present in the flat yarn, aggravated by the throwster, exaggerated by the knitter and amplified by the finisher[3].

One approach to determine what is responsible for barré is to make an educated guess based on a careful examination of the fabric, by means of both transmitted and reflected light, and then to test this hypothesis. If the first is negative, move onto the next most logical hypothesis, and so on. A process of elimination is therefore applied until a solution is found. Each fabric must be treated as an entity, i.e. yarns, stitch lengths etc. should be compared with each other over various repeats and never with an external reference[18,19].

Preliminary Tests:

Some steps in identifying the cause(s) of barré: Observe the fabric by means of both reflected and transmitted light. Mark a few "bars" by carefully inserting pins into the roque courses to facilitate identification. A metallic spray-paint may be applied lightly to the fabric and if the barré disappears it suggests the cause is a difference in the heat history of the yarn[18, 19].

It can be determined if[12] differences in depth of shade is the cause of barré by means of plastic replicas. At Du Pont[20] barré due to physical effects was separated from that due to dye by placing a styrene plastic sheet over the fabric and subjecting it to pressure and heat for several minutes until the plastic softens and forms an impression of the fabric.

Yarn can also be unravelled from the fabric and wound around a small cardboard strip or knitted on a small diameter machine. If colour differences persist it clearly indicates difference in depth of shade[19]. Course lengths of barré and non-barré fabric areas can be compared to establish whether the barré originated on the knitting machine (at least two feeder repeats should be covered).

Yarn bulk may be measured by winding the yarn under a suitable and controlled tension onto a disc, to a constant volume, weighing the disc and then calculating the specific volume[21].

Diagnostic Dyeing:

As a first approximation, barré in a polyester fabric which has been dyed with disperse dyes *to equilibrium* must be physical or configurational in origin[9]. It is preferable, when knitting tubes from different yarn packages, to knit a reference yarn between each package to which shades after dyeing are always referred[9]. Disperse dyeings on polyester are critical or structure (rate) sensitive[9].

If barré is still evident when dyeing nylon with a disperse dye such as Disperse Blue 3 it indicates a configurational (i.e. non-dye) cause[12]. Diagnostic dyeing of nylon with equilibrated level dyeing acid dyes and with highly rate sensitive dyes, respectively, can establish whether sites or orientation is the problem (i.e. after a dye difference has been shown to be the cause of the barré). Examples of diagnostic dyeings have been given[12].

If only dyed fabrics are available, analysis is much more difficult. In some cases more than one cause of barré may be present in a particular fabric. Stripping the dye and then redyeing with good levelling dyes (e.g. Alizarin Blue FG + Lyogen P for nylon 66 and Palanil R and Dilatin OD for polyester) can also be used as a tool for identifying the cause(s) of barré[22] and so can viewing in UV light.

Comparison of Chemical and Physical Properties:

Any one, or more, of the tests about to be described can be used to confirm the initial tests described above or even to positively identify whether fibre structural differences are responsible for the barré.

Degree of molecular orientation can be determined by using polarised infra-red (IR) radiation or by observing X-ray scattering diagrams[23]. The degree of crystallisation may be calculated from the relation of the intensity of the crystalline portion to the overall intensity of radiation.

Degree of crystallinity can be related to density[23]. Changes which affect molecular mass of a polymer can be detected by measuring the viscosity of a dilute solution of the fibre, the latter being sensitive to degradation and polymerisation[14]. Dimethylformamide for acrylic, formic acid for nylon, chloroform for triacetate and orthchlorophenol for polyester have been used.

Gupta and Sudarshana[24] found that an increase in the crystallinity resulted in a decrease in the dye-uptake and *creep* of polyester fibres while the reverse was true for nylon 6 fibres. A decrease in the amorphous orientation decreased the *creep* and dye-uptake of polyester fibres while the reverse applied to nylon 6 fibres.

Stress-strain curves may be used to identify causes of barré[7] the initial modulus being greatly influenced by temperature prehistory. The dynamic modulus is said to be an excellent method for measuring the orientation in a fibre, the dynamic modulus increasing with increasing orientation[15]. Melting point also increases with increasing crystallinity[15]. Increasing texturing temperature increases polyester fibre density, the latter increasing with an increase in crystallinity[15, 25]. Density was found to be an excellent measure of thermal history of polyester and could be used to determine whether a dye problem is related to texturing temperature[25]. It has been stated[25] that, for each texturing speed there was a temperature control point around which texturing temperature variations have a minimum effect on dye-uptake. Truslow[14] measured the density and dye-uptake of polyester fibres and found that the density increased and the dye absorption decreased with increasing heat setting temperature.

Iodine adsorption as well as dissolution of polyester fibre in sulphuric acid have also been used to investigate the effect of setting[26] while Narsian and Venkitaraman[26] described a method for determining the rate dyeing factor and stated that iodine adsorption was a useful indication of changes in the supermolecular structure of polyester fibres. A high correlation was found between iodine adsorption and rate of dyeing. Gacen *et al*[27] observed that the sorption of iodine by polyester increased with increasing temperature until it reached a maximum and the increasing (rising) section of the sorption curve could supply information on differences in the distribution of ordering (orientation) in the non-crystalline regions of the fibre. It was claimed that the iodine sorption curve permitted a clear distinction to be made between polyesters of different dye affinities. It has been stated that the iodine sorption test is very sensitive to the fine structure of polyester fibres, although when the test is carried out at a single temperature, the sensitivity of the test depends upon the temperature selected[27]. Lade[28] stated that only the amorphous regions absorb iodine and it can therefore be used as a measure of the degree of setting.

Heatsetting of synthetic fibres also makes them less soluble in mineral acids because of the increase in crystallinity[28], and the time taken for a fibre to dissolve

(CDT or CST) in a mineral acid can be used as an indication of the heat history of the fibre.

Studies relating the critical dissolution time of polyester fibres in selected solvents and the changes in crystallinity of fibre after thermal treatment have been carried out[26, 29, 30]. A study[31] has also been made of the relationship between critical dissolving time (CDT) of polyester and the temperature and phenol concentration in solvent mixtures with tetrachloroethane. It was found that CDT allowed a clear distinction to be made between a polyester of normal dyeing affinity and a sample with modified affinity[31, 32].

Galil[30] found a linear correlation between the dyeing parameter K/S and the logarithm of CDT and between the density of polyester fibres and log CDT. An increase in CDT implies an increase in inter-molecular cohesion[32]. Carrier dyeing of polyester increases the CDT values[32]. The critical dissolution time (CDT) is claimed[32] to be a simple but very sensitive and precise parameter for detecting changes in the structure of polyester fibres produced by heat or hydro-thermic treatment (with or without tension constraints). The measurement of polyester fibre shrinkage in methylene chloride has also been suggested[33] as a means of detecting variations in fibre structure.

TEXTURING ASPECTS

In some cases about one-third of the shade variance in a dyed textured polyester yarn apparently comes from the feed yarn with the remaining two-thirds introduced during the texturing process[17]. Of all the texturing variables not positively fixed on the texturing machine, temperature apparently has the greatest effect[7].

Vaughn and Maynard[15] investigated the effects of tension and heater temperature during texturing on various properties (melting temperature, density, dye-uptake etc.) of polyester and found that 10°C differences in heater temperature caused differences in fibre structure but no such differences were detectable for 2°C differences. The tension of the yarn entering the first feed roll had no apparent effect on fibre structure within the levels tested. Melting point was insensitive to the changes in tension and heater temperature. In another case a difference in texturing temperature of 5,6°C was also required to give objectionable barré for textured polyester[17]. It has also been found that a yarn processing temperature difference of 2°C will produce a visible shade difference if crimped nylon yarn is dyed with very sensitive dyestuffs[3]. The following variations are said to produce similar shade differences[34]:

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

Baldwin[35] recommended that the texturing conditions selected for a specific yarn should be such that the dye-uptake is relatively insensitive to variations in heat. Tolerances for temperature during texturing is ±2°C and for spindle speed

±3 *per cent*[7,35]. Tension above the spindle should be approximately three times that below the spindle[7]. Calder[34] stated that the yarn tension in the heater should be controlled to within about ±0,5 cN. The following control limits during the texturing of polyester yarns have also been suggested[17] –

Spindle speed : ± 3 000 r/min
Thread tension above spindle : ± 1 cN
Temperature : ± 1°C

In one article[36], where draw-textured (POY) and conventional feed polyester yarns were compared, it was stated that the two fibres had the same dye capacity and that the draw-textured yarn is less sensitive to temperature differences during texturing (these normally changing the crystallinity) but more sensitive to texturing process variables which lead to orientation differences and, therefore, to dye rate differences. Since rate differences can be levelled in dyeing procedure approaching equilibrium conditions, the draw-textured product will normally be more uniform than those of the regular set textured yarns. Routes which direct polyester dyeing toward equilibrium conditions include shorter bath ratio, longer dyeing cycles, low energy dyes, high bath temperatures and increased carrier concentrations, of which only the latter two are practical[36].

POY yarns give reduced barré in multifeed knitting[37] although the ageing of draw-textured feed yarn (i.e. introducing a storage period prior to draw-texturing) could be reflected in the dye depth of the textured yarn[38]. Reichman[39] stated that POY should be converted into textured yarn within the space of approximately three to eight weeks and that there is no clear-cut evidence that draw-textured yarns are less prone to barré, although in other articles[40–43] it was stated that draw-texturing results in more uniform dye pick-up. Barré coverage and levelness of simultaneous draw-textured polyester yarn are apparently superior to those of conventional textured yarn[44]. Dye uptake of POY yarns increases slightly over a prolonged storage period. In another study[41] it was found that dyeability was the characteristic most sensitive to ageing, and, for the particular brand of polyester yarn studied, it was concluded that the feed yarns easily could be stored for up to three months in a well-ventilated warehouse prior to draw-texturing.

Atmospheric conditions suggested for texturing a certain brand of POY polyester yarn were 22 ± 1°C and 68 ± 2% RH[44]. In another article[7] it was stated that temperature (21°C to 27°C) and humidity (55 to 65% RH) should be controlled during texturing.

CONE-WINDING AND LUBRICATION

Tension variation during cone winding or during warping, the latter for weaving or warp knitting, can also lead to barré[5,45].

Apparently careful selection and proper utilisation of fibre lubricants can influence the degree of barré[46], uniform application being essential. Wacht[47] found that, for nylon, re-coning immediately after texturing and then knitting this yarn with other yarns which had not been re-coned resulted in barré but if the yarn was allowed to age for two months between texturing and re-coning, no barré occurred. He also found that hardness variation in soft cones did not cause barré whereas the same variation in hard cones was likely to cause barré. There was a general tendency for barré severity to increase with increased mass differences of cones creeled simultaneously. Differences in oil levels did not result in barré. Mixing textured nylon yarns of different ages was found to be a likely cause of barré. Introducing nylon yarns plied from all S or all Z singles yarns into a fabric knitted from balanced plied yarns (S and Z) resulted in severe barré. Variations in twist levels also caused barré although normal twisting operations are not likely to produce variations in twist levels severe enough for barré. Tension variations during plying could also lead to barré[47].

Excessive tensions on the yarn during coning or backwinding can also decrease bulk permanently[7]. Rush[7] maintains that a variation in package hardness can cause barré, so can re-winding. Mixing aged yarn (two weeks or more) with freshly textured yarn on the knitting machine can also lead to barré[7]. Therefore, never mix rewound yarn with regular production[7].

In terms of barré plied yarns, high bulk yarns and double heater yarns are said to be superior to their alternatives[4].

It has been stated[48] that the non-volatile part of a semi-fuming fibre finish applied to polyester yarns must resist oxidation, to prevent excessive deposits from forming on the heater plates or draw rolls, since the build-up of a tacky film or varnish residue can cause many problems during drawing and texturing, and result in yarn variations leading to barré during dyeing.

Differences in oil content between individual yarns can cause barré[49]. Residual oil levels of about 0,25 *per cent,* after scouring, are recommended. It has also been suggested that, during storage, fatty esters are adsorbed or absorbed preferentially by polyester from an oil mixture and these are not necessarily removed by scouring or dry-cleaning[49].

KNITTING ASPECTS

Holfeld and Nash[8] were of the opinion that as many as 30 *per cent* of the knitting machines in routine usage were either not in adequate mechanical condition or adjustment, or both, to produce critical, plain fabrics from low bulk yarns without barré problems. They suggested that such machines be identified and not used for critical type fabrics in textured polyester. They maintained that course length variations as low as one *per cent* from the mean, when reinforced in three or more consecutive courses, could lead to barré.

Most plain fabrics made from textured filament yarns will show some degree of barré if there is more than 3 *per cent* (5 *per cent* claimed by some) variation in course lengths while other fabrics, such as crêpes and blister stitch designs will show some barré with more than 5 *per cent* variation in course length[3, 4, 7, 19, 50, 51]. Elsewhere it was claimed that course length variation should be below two *per cent,* if it is greater than eight *per cent,* barré is noticeable[52,53].

The use of yarn tension and speed meters on the knitting machine is absolutely essential if barré due to course length variation or yarn tension variation is to be avoided[4]. A tension of 3 cN or lower after the positive feed has been suggested[7].

The fabric structure can have a decided effect on the severity of barré. For instance, crêpe and random blister stitches are superior to plain type structures for barré coverage[4]. To minimize barré, those structures in which a yarn forms loops which run in a perfect horizontal line must be avoided, i.e. try to break up consecutive (adjacent) loops of a particular yarn. Random needle selection, as in a crêpe pattern is therefore ideal. Swiss Piqué is apparently one of the most difficult barré-free fabrics to knit[54]. Using combinations of tuck stitches and miss stitches on both cylinder and dial help to break-up barré[54]. Lutz[5] mentioned Swiss and French Piqué, Punto-di-Roma, all diagonals both 2 x 1 and 2 x 2 and single and double blisters as being barré prone.

Barré is accentuated with an increase in the number of knitting feeders[4,55] and with a decrease in the linear density of the individual filaments[55,56].

Hall and Rawlings[36] state that the following precautions help to reduce knitting or machine barré: adequate and uniform yarn lubrication, machines set level and stable, machines that have dial and cylinder run-out of less than 0,0076 mm, machines with dial-to-cylinder parallelism better than 0,0076 mm, and an intermediate fabric take-down tension. The cylinder/dial gap should be checked at eight places around the circumference[7] and too low a dial height should be avoided[10]. Shadow barré is usually[7] associated with faulty machine settings (dial and/or cylinder misalignment) but can also be caused by uneven take-down roller pressure[7,54]. Slippage between rollers should be avoided and also too low take-down tensions.

Holfeld and Nash[8] investigated the problem of knitting machine barré, where differences in yarn bulk/crimp are caused during knitting by variations in yarn tension. They stated that low bulk (tight) yarns appear darker than normal while high bulk yarns (loose ends) appear lighter than normal. Knitting machine barré is rarely a problem with high bulk yarns, such as stretch textured nylon yarns, having bulk values (skein test) between 50 and 60 *per cent* or higher.

To minimize barré[54] positive feed wheels must run freely, crimp should be removed evenly over all feeders prior to positive feed device, rough edges, cracks and grooves in yarn guides must be avoided[4,54], tension prior and subsequent to positive feed must be the same at all feeders and the yarn package should be positioned directly beneath first guide. The bottom of the yarn package should not press heavily against the cone support, excessive oil on tapes could lead to slippage between tape and wheel, yarn threading and path must be the same for different feeders producing the same type of stitch. Delayed timing (two to eight needles)[54] should be used where possible[7,10,54], with dial needles retracting just far enough to cast off their loops, while knock-over gauges should be used if delayed timing is not feasible (e.g. Jacquard-type machines)[54].

From a practical viewpoint the tension of synthetics in knitting are, as a rule, of the order of 1 to 2 cN/tex (1 to 2 gf/tex)[57]. Safe tensions are those extending the fibre within the central hookean region for each yarn. Excessive tensions, (i.e. those extending the fibre to the yield region) cause irreversible deformation of the fibre (slippage of micelles, changed cross-linkages and rheology etc.) and consequently change the gloss, dye absorption and light reflection[57]. An over-stretched yarn will dye lighter.

Differences in yarn bulk can sometimes be caused by differences in tension during knitting[58]. Variations in the amount of lubricant on the yarn can also lead to barré[58] and so could variation in delustering agent and fibre surface[58]. Variation in fibre-to-metal friction during knitting can result in a poor quality fabric or show up as barré in dyed goods[48]. A coning oil with limited shelf life can show viscosity changes with time which will affect the amount of oil picked up on the yarn and consequently the delivery tensions to the knitting machine[48].

DYEING ASPECTS

Pratt[59] stated that, although variation in polyester yarn dyeability are induced either in yarn manufacture or in texturing, the dyer also has some responsibility since choice of dyestuff, too short dyeing times and insufficient carrier can result in barré. Martin[10] was also of the opinion that, although finishing cannot cause barré, it can make the greatest contribution towards producing barré-free fabrics. Pressure dyeing is generally recognised as the best means of covering barré in polyester[59]. Temperatures of 116–121°C have been recommended[60]. It has been stated that pressure dyeing polyester with carrier will eliminate most of the defects caused by differences in yarn history and knitting machine barré[20].

In atmospheric dyeings apparently no set of conditions gives adequate uniformity for critical double knit textured polyester fabrics[36], pressure dyeing is required, and, for a particular polyester, 129°C with 3 g/ℓ of carrier has been recommended. In another article[60] it was stated, however, that very high concentrations of carrier (e.g. 20 *per cent* of biphenyl) have to be used at atmospheric pressures to obtain good barré coverage although longer dyeing times and fabric preparation also facilitate barré coverage[60].

It has been suggested[61] that the critical stage in the dyeing of polyester occurs during the period in which the dye liquor is heated to about 70°C. A mild retarding agent acting at the start of the dyeing and up to about 85°C apparently improves matters[61]. Recently a process for reducing barré has been patented[62]. Prior to dyeing the fabrics are subjected to dry heat for between 30 seconds and 15 minutes at a temperature roughly equal to the highest texturing temperature.

When dealing with barré caused by differences in crystalline structure in textured polyester yarns, Kirjanov[58] suggested the following rule of thumb: At a given temperature (around 121°C or higher) and dyeing time, the barré will be covered better if the amount of carrier used does not decrease the dye take-up of the fabric when compared to a dyeing under the same conditions but without the carrier.

Any factors which move the dyeing system closer to equilibrium in dyeing should reduce barré[13]. Such factors as an increase in temperature, an increase in dyeing time and the promotion of migration and levelling should reduce barré. High temperature dyeing is less sensitive to differences in heat setting, false twisting and autoclaving temperatures but is somewhat more sensitive to orientation differences than carrier dyeing. Carriers accelerate dyeing and should facilitate the approach to equilibrium. However, they also increase initial barré and may have an adverse effect on the final barré unless they are used in sufficient excess to promote migration and levelling. It has been recommended that high temperature dyeing be used whenever possible to minimize barré in textured polyester and if carriers must be used, for example to minimize orientation differences, then it is often better to add the carrier after the initial exhaustion of the dye is almost complete. Alternatively the fabric may be pretreated in the carrier or hydroset before dyeing[13].

In dyeing textured polyester, differences in dyeability may be due to either dye rate difference or dye capacity difference or both[36].

Rush[7] states that, in most cases, differences in dyeing rate rather than in equilibrium exhaustion are observed for textured polyester, these being due to differences in fibre structure caused by variation in temperature or stress during the various treatments the yarn received. Techniques that promote transfer, such as higher temperatures, higher temperatures plus a carrier, or longer dyeing times will aid in minimizing this effect. Nevertheless, such procedures could degrade the hand, bulk and elasticity of textured polyester. Before dyeing, the barré potential of the fabrics should be determined by laboratory dyeing. Fabrics which are prone to barré should be used for dyeings where the shades involved tend to cover up dyeability differences. Clements[17] described a critical laboratory test procedure for determining the dye variability of textured polyester yarns.

Differences in orientation of the amorphous regions of polyester can be overcome by increasing dyeing time and temperature[11], but not differences in crystallinity. Phillips and Keuhni[11] found a good correlation between severity of barré in polyester and $s/_D$, where s is the equilibrium exhaustion and D is the diffusion coefficient (low energy dyes have a low $s/_D$ values). Dyeing at the highest possible temperature will always be advantageous[11] and setting or pretreatment in water at 121°C for 30 minutes has been found useful in some cases. Often, actions which can reduce barré are in conflict with the trend towards rapid dyeing. A carrier is generally more effective than a levelling agent for covering barré in polyester[11].

High energy dyestuffs, which do not sublime readily, do not cover barré as well as low-energy dyestuffs[4, 60]. Dyes of higher molecular mass (weight) and higher sublimation fastness tend to be most sensitive to structural differences in polyester fibres[13].

High pressure (i.e. high temperature) is regarded by Kirjanov[58] as the most practical way of dealing with barré in textured polyester. Although increasing the carrier concentration and dyeing time normally results in a more efficient coverage of barré, it sometimes has the opposite effect. It is not necessarily true that low energy dyes guarantee freedom from barré or that barré-free goods cannot be obtained with high energy dyestuffs. The necessity to dye barré goods at temperatures above the boil at about 121°C is probably unavoidable. Dyeing at 135°C, however, does not necessarily improve barré, in fact under certain conditions it can even intensify barré. The addition of certain levelling agents also sometimes enhance the barré effect[58].

Willingham[63, 64] also found that, when carrying out dyeing trials with two low-energy and two high-energy dyes, as either the carrier concentration or the dyeing temperature or both, were increased, the degree of difference in dye rate between the yarns decreased until there was a reverse in the dye rate. This illustrated that for both low- and high-energy dyes there was an optimum carrier concentration and temperature at which these dyes should be used. For example, when dyeing with a low energy dye at 121°C between 0,5 and 2 g/ℓ carrier was required while for the same dye, no carrier was necessary at 129°C. When dyeing polyester at 121°C for one hour with four *per cent* carrier, butyl benzoate carriers were the most effective with methylnaphthalene types and methyl-2-hydroxy-3-methyl benzoates the next most effective. Emulsified perchloroethylene/aromatic mixtures used when dyeing at 121°C and emulsified perchloroethylene used at 129°C are also very effective in minimizing barré in textured polyester knits[64]. A good method of covering barré in textured polyester fabrics is to dye at high temperatures (121–129°C) with a carrier of the butyl benzoate-type (one to three *per cent*)[51]. Biphenyl was found to be a good carrier for covering barré (two to five *per cent* at 116°C)[60].

It has been suggested[13] that *o*-phenyl phenol carrier modifies the fibre structure in a way which reduces the effects of the orientation differences between fibres.

It has also been stated[13] that equilibrium selectivity in carrier (i.e. low temperature) dyeing is rather insensitive to heat setting *tension* but is very sensitive to heat setting *temperature* while the reverse holds for high temperature dyeing.

Equilibrium dyeing of nylon exposes differences due to the number of sites but reduces differences due to dye rate. It has been stated that, for nylon, disperse dyes cover most rate differences (fibre orientation) and amine end (site) differences, level dyeing acid dyes cover many rate differences but are sensitive to amine ends while critical acid, premetallised and direct dyes are very rate sensitve and also slightly amine end sensitive. Dye capacity (site) differences can be minimized[12] by the use of an anionic blocking agent with level dyeing acid dyes.

Exposure to ultra-violet light can change the dyeability of nylon[12]. In package dyeing, non-uniformly wound packages can result in shade differences within the package[7]. Apparently fabrics that are overstretched on the stenter or are heat-set at too high a temperature show barré more clearly[4].

Freytag *et al*[65] found that when heat setting polyester fabrics the temperature must be controlled to ± 2°C or shade differences will occur.

QUALITY CONTROL

In this section some of the routine tests and precautions which can form part of a quality control program for textured yarn and fabric are discussed. Quality control tests recommended[35] for textured yarns are: knit sleeve and dye; measure breaking strength and elongation at break, skein shrinkage (crimp rigidity), oil content, cone hardness and number of knots. Other factors to monitor for textured yarns are: linear density (dtex), number of filaments, evenness, dyeability, broken filaments and shrinkage[7]. Phillips and Keuhni[11] suggest a laboratory dyeing procedure to establish the proneness of polyester to barré.

Susceptibility of fabric to barré may be assessed on the knitting machine by spraying fugitive tints onto the fabric and the fabrics can then be dyed in such a way as to minimize the barré[66, 67].

The throwster can reduce the incidence of barré by carrying out sensitive dyeing tests on each cheese of yarn produced. The same should be done by the knitter on the undyed fabric[3].

Skein shrinkage is considered[68] the best possible tool to characterize a textured yarn even though there is no correlation between skein shrinkage and fabric yield, fabric hand or fabric shrinkage. It is rather a means of ensuring consistency in the yarns. Denton[69] states that the Shirley tube test and the crimp rigidity test (e.g. Hatra) are similar in their response to changes in heater temperature in the production of false-twist yarn, but that the tube test is much more sensitive to changes in twist over the practical range. Denton goes on to say, however, that, as with any of the other commonly used tests for textured yarns, the tube test will not detect variations in yarn properties causing variations in dyed shade unless these arise from *gross* differences in texturing conditions. Gill and Moore[3], testing one thousand cheeses, found that the crimp rigidity of a crimped nylon yarn varied from 41 to 49 *per cent* compared to a nominal value of 45 *per cent*. They used Cibalan Blue BRL, which they maintained is very sensitive to physical variation in nylon, for some trial dyeings.

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 six *per cent*. Wignall[70] 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.

MEASUREMENT OF BARRÉ

Up to this point, the various causes of barré and means of identifying these as well as eliminating or minimizing barré have been discussed and attention will now be turned towards the measurement (i.e. quantifying) of barré.

The objective measurement or quantifying of barré is important in so far as it can form the basis of an agreement between buyer and seller as to what degree of barré will be acceptable. It would also facilitate the quantitative evaluation of the effect of various factors on barré severity.

Martin[10] has described an instrument (Appearance Meter) for measuring dye shade differences on a dyed yarn. By using this instrument on nylon yarns it was found that the correlation between dye shade before and after crimping could be very low while the standard deviation of depth of shade was sometimes better after crimping than before. Amine end group differences in the flat yarn do, however, show up as differences after crimping. Brown[6] also mentions that there is a very tenuous relationship between barré in finished and unfinished goods.

Hatra has attempted to quantify the degree of barré with their Barriness Scales, involving five grades based on the principle of Grey Scales but more narrowly spaced[6]. The precision and use of the Hatra Barriness Scale have been investigated in various articles[71, 72]. Wright and Hager[72] found it an excellent technique of rating barré severity. It has been suggested[73] that, under current market conditions, a Hatra Barriness Scale grade of greater than 3,5 indicates a commercially acceptable fabric while 3,0 to 3,5 suggests borderline cases.

Various instruments have been developed and used for the measurement of fabric streakiness[6, 74—80], although few of these have got beyond the laboratory stage. Most of these instruments function on an optical principle, with the fabric being scanned by either reflected or transmitted light or both. The variation in the intensity of the light (either reflected or transmitted) is then recorded and analysed and used as a measure of the streakiness of the fabric.

Perhaps one of the most interesting instruments relevant to the present subject is the one developed by the CSIR[80] where a fabric is scanned by means of both reflected and transmitted light. The reflected light is collected by an integrating sphere and detected by two photomultipliers, one sensitive to green and the other to infra-red. If it is assumed that a dye does not absorb in the infra-red region of the spectrum, then the difference between the infra-red and green signals can be attributed to dye differences. If the difference trace therefore matches the barré pattern it can be concluded, with reasonable certainty, that the barré is due to differences in the dye uptake of the different yarns which in turn could be due to any one or more of a variety of factors present in the yarn. This would, therefore, eliminate the possibility of the barré originating on the knitting machine. If the pattern of the difference signals does not coincide with that of the barré, a structural difference is indicated. This could be due either to variations on the knitting machine or physical differences in the yarn (e.g. texture or bulk, linear density, filament cross-section or surface, etc.).

The CSIR instrument is also so designed that it can give a numerical value to variations in the reflected light which could enable the severity of barré or fabric streakiness to be quantified. The machine is not yet in commercial production although SAWTRI is at present evaluating it.

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