5

False-twist textured yarns

5.1 Introduction

In Chapter 4, the various elements of the machine were considered along with how they influence the final properties of the textured yarn. Here the types of yarn and how their form can be modified on the machine will be explored. Again the work described below will be based upon the production of polyester by the false-twist route but the same general principles can be equally applied to polyamide (nylon) and polyolefin (polypropylene) yarns. Where specific exceptions occur, these will be highlighted. The questions that must be asked are:

1 how is a yarn defined?
2 how are the process conditions on the texturing machine adjusted to make the yarn conform to this definition?

5.2 Definition of yarn type

Some, or all, of the following classifications can define a yarn produced by the false-twist route.

1 **Chemical nature of the yarn** – polyester, sometimes abbreviated to PES or PET, polypropylene abbreviated to PP and nylon (polyamide) abbreviated to PA6 or PA6.6. These are the two most common nylon yarns in textile applications.
2 **Nominal denier and filament number** – i.e. 167/32 or 167 dtex (150 denier) f32. Alternative nomenclatures are used, e.g. putting the number of filaments first and then the nominal textured denier, or quoting the POY decitex, then the filament number and then the nominal textured denier are both common, i.e. 290/32/167.
3 **Number of yarns plied together** – (see Section 5.3.2), i.e. 1/167/32 or 2/167/32 or 3/167/32, etc. The first digit represents the total number of plied ends.

4. **Lustre of the product** – i.e. bright, semi-matt, matt (or dull). Thus 1/167/32 semi-matt.
5. **Cross-section of the filament** – i.e. round, trilobal, pentalobal, hexalobal and so forth. Thus 1/167/32 semi-matt, round cross-section.
6. **Degree of stretch in the textured yarn** – i.e. high-elastic (single-heater) or set (double-heater) yarn. Thus 1/167/32 semi-matt, round cross-section set.
7. **Direction in which the twist is inserted in the yarn** – i.e. S or Z and for multi-ply yarns SS, SZ, ZZ, etc. Thus 1/167/32 semi-matt round cross-section, set Z twist.

This final description qualifies the yarn as belonging to a specific type. For most products, but especially polyester, one further classification is possible.

8. Has the polymer itself been modified such that the yarn is now, for example, dyeable with cationic dyestuffs or has flame-retardant properties, etc?

Within these classifications some cannot be altered by the processing conditions on the texturing machine. These are the yarn parameters, which are fixed during either the polymerisation or extrusion phases of the process; these are the filament number, the filament cross-section, the lustre and the dye affinity of the yarn. To some extent the texturing process can enhance or reduce the lustre characteristics of the yarn (see Section 5.3).

Leaving behind the yarn parameters that cannot be altered by the texturing process, those that can be determined by the conditions on the texturing machine are examined below and in Section 5.3 in greater detail. These are:

1. yarn denier by use of draw ratio and effect on tensile properties;
2. production of combined or plied yarns by use of air-jets during texturing;
3. intermingling jets;
4. use of an air-jet to produce torque-free yarn;
5. yarn skein shrinkage;
6. changes in bulk;
7. lustre modification.

Within each of the broad categories there are many variations which can be employed to fit the properties of the yarn exactly to those required for it to perform satisfactorily in terms of process efficiency and in fabric.

5.3 Modification of yarn properties

5.3.1 Yarn denier by use of draw ratio and effect on tensile properties

The denier of the finished yarn can be directly related to the spun denier of the POY and the draw ratio employed on the texturing machine. It should also be noted that the tension at which the yarn is wound on the textured yarn package also has a discernible effect on the apparent denier of the yarn, as does the degree of interlace present in the yarn (due to yarn compaction). An approximation of the finished denier can be found by:

$$\text{approx. finished denier} = \frac{\text{POY denier}}{\text{draw ratio}} \times \%\ \text{take-up overfeed (increase)} \qquad [5.1]$$

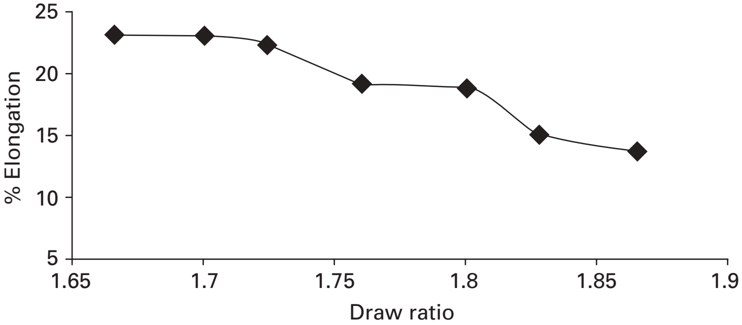
where take-up overfeed is the percentage difference in speed between the centre shaft of the machine and the speed of the shaft driving the wound package.

Obviously the denier of finished yarn can be increased simply by combining two or more running ends of textured yarn together and by joining the separate ends using some form of intermingling. This is discussed separately in Section 5.3.2. Intermingling alone has a discernible effect on denier. The increase is small and is proportionate to the number of intermingled points inserted due to yarn compaction (see also Section 5.3.3.3).

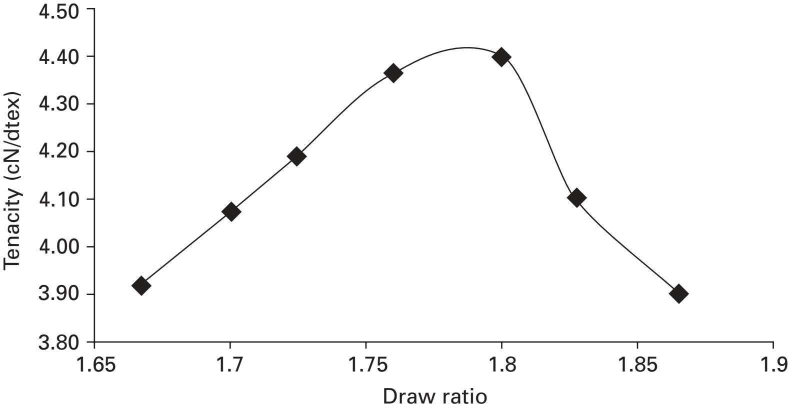
The denier can be altered by changes in draw ratio, but the degree of change that can be applied is governed both by the stability of the process on the texturing machine and other considerations. These are yarn tenacity, elongation, dyeability and textured broken filaments, all of which are influenced by the draw ratio. Table 5.1 illustrates some of the changes observed in both the yarn and process conditions when changing draw ratio.

The graphical representation of some of the data from Table 5.1, shown in Figs 5.1–5.3, gives a clear indication of the effect of draw ratio on the physical properties of the textured yarn. Of particular interest is the graph displaying the measured yarn tenacity plotted against the draw ratio. This clearly shows the effect of extending the yarn above the optimum value to the point where physical damage is incurred, thereby provoking a marked deterioration in its tensile strength. It is shown by a rapid fall off in breaking strength.

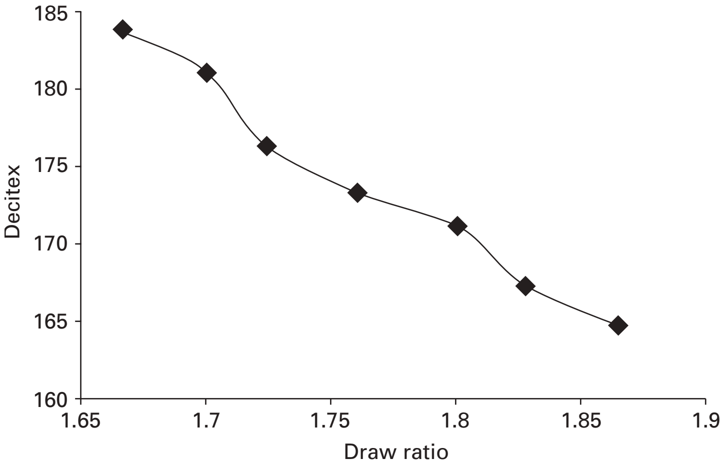
As tenacity is a relative value, calculated from the breaking load and the measured denier, increasing the draw ratio reduces the denier and



5.1 Elongation vs draw ratio. Courtesy of UNIFI Textured Yarns Ltd.



5.2 Tenacity vs draw ratio. Courtesy of UNIFI Textured Yarns Ltd.



5.3 Decitex vs draw ratio. Courtesy of UNIFI Textured Yarns Ltd.

Table 5.1 Effect of changes in draw ratio on process conditions and yarn properties. Courtesy of UNIFI Textured Yarns Ltd

Draw ratio	1.667	1.700	1.724	1.760	1.800	1.828	1.865
Pre-draw tension (T_0) (g)	34.8	39.9	43.5	46.20	57.6	58.3	64.4
Draw zone tension (T_1) (g)	52.1	57	62.7	65.50	77.4	79.5	89.9
Below spindle tension (T_2) (g)	59.8	66.1	68	73.60	78.9	83.3	86.1
Tension ratio (T_2/T_1)	1.15	1.16	1.08	1.12	1.02	1.05	0.96
Winding tension (T_3) (g)	16.5	26.0	22.9	30.00	26.4	26.0	33.2
Breaking load (cN)	720.0	738.0	739.0	757.0	753.0	687.0	643.3
Elongation (%)	23	22.9	22.4	19.2	18.8	15.2	13.8
Denier	183.7	181.1	176.4	173.4	171.2	167.4	164.8
Tenacity (cN/dtex)	3.92	4.08	4.19	4.37	4.40	4.10	3.90
Skein/shrinkage (%)	12.5	11.5	10.6	13.7	8.3	8.5	7.6
Residual torque	3.8	3.3	3.3	2.9	3.4	3.6	2.4

Machine constants
Yarn type (292 Spun dtex) 167/34 nominal round cross-section.
Throughput speed 700 m/min
2 m contact primary heater

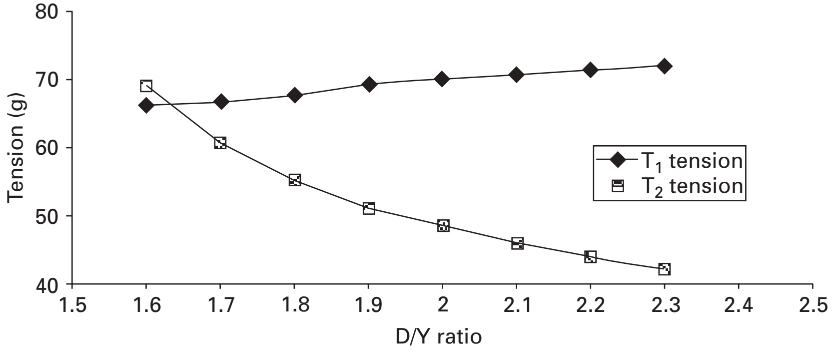
increases the degree of molecular orientation, thereby developing strength in the yarn until the point is reached where it becomes overextended.

The data above also shows the effect of increasing draw ratio on the skein shrinkage or crimp developed in the yarn. This is a phenomenon associated with the increase in molecular orientation. As the orientation increases, the capability of the polymer chains to buckle and deform under the influence of heat is reduced, thereby restricting the degree of shrinkage that can be developed.

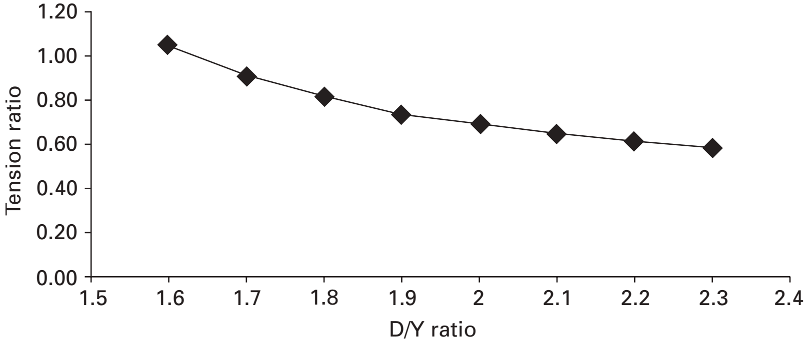
It should also be noted that the D/Y ratio has a discernible effect on the percentage elongation of the textured yarn, and a minor effect on the resultant denier. Increasing the D/Y ratio means that the discs are rotating faster and more twist is inserted into the yarn. This changes the elongation due to the increased twist in the yarn, which is trapped between the input shaft of the machine and the friction unit, and has the effect of shortening the yarn and effectively increasing the draw ratio or stretch (see Table 5.2 and Figs 5.4–5.6). On fine denier hosiery yarns in particular, increases in D/Y ratio can be used as an effective measure to prevent surging due to instability in the thread-path between the input shaft and the twist-insertion device.

Table 5.2 Effect of D/Y ratio on yarn parameters. Courtesy of UNIFI Textured Yarns Ltd

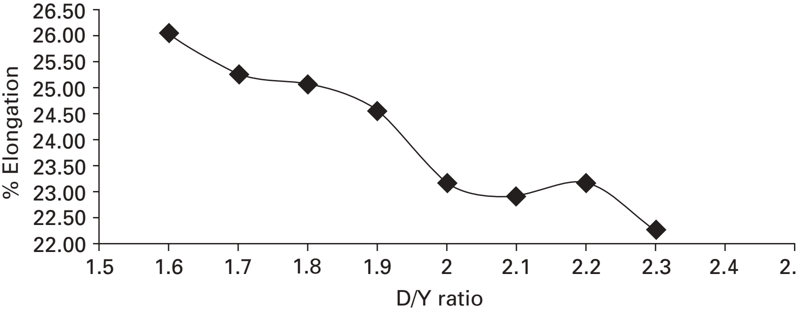
D/Y ratio	T_1 tension	T_2 tension	Tension ratio	Elongation (%)	Bk load (cN)	Denier	Tenacity (cN/dtex)
1.6	66.2	69	1.04	26	759.5	177.6	4.28
1.7	66.6	60.7	0.91	25.25	748.7	177.4	4.22
1.8	67.7	55.4	0.82	25.05	735.3	177.2	4.15
1.9	69.4	51.2	0.74	24.54	737.7	177.3	4.16
2	70.2	48.7	0.69	23.16	734.6	177.3	4.14
2.1	70.8	46.1	0.65	22.91	740.2	176.8	4.19
2.2	71.5	44.1	0.62	23.16	743	176.8	4.20
2.3	72.2	42.3	0.59	22.29	744.6	176.2	4.23



5.4 D/Y ratio vs thread-line tension. Courtesy of UNIFI Textured Yarns Ltd.



5.5 D/Y ratio vs tension ratio. Courtesy of UNIFI Textured Yarns Ltd.



5.6 D/Y ratio vs % elongation. Courtesy of UNIFI Textured Yarns Ltd.

5.3.2 Production of combined or plied yarns by use of air-jets during texturing

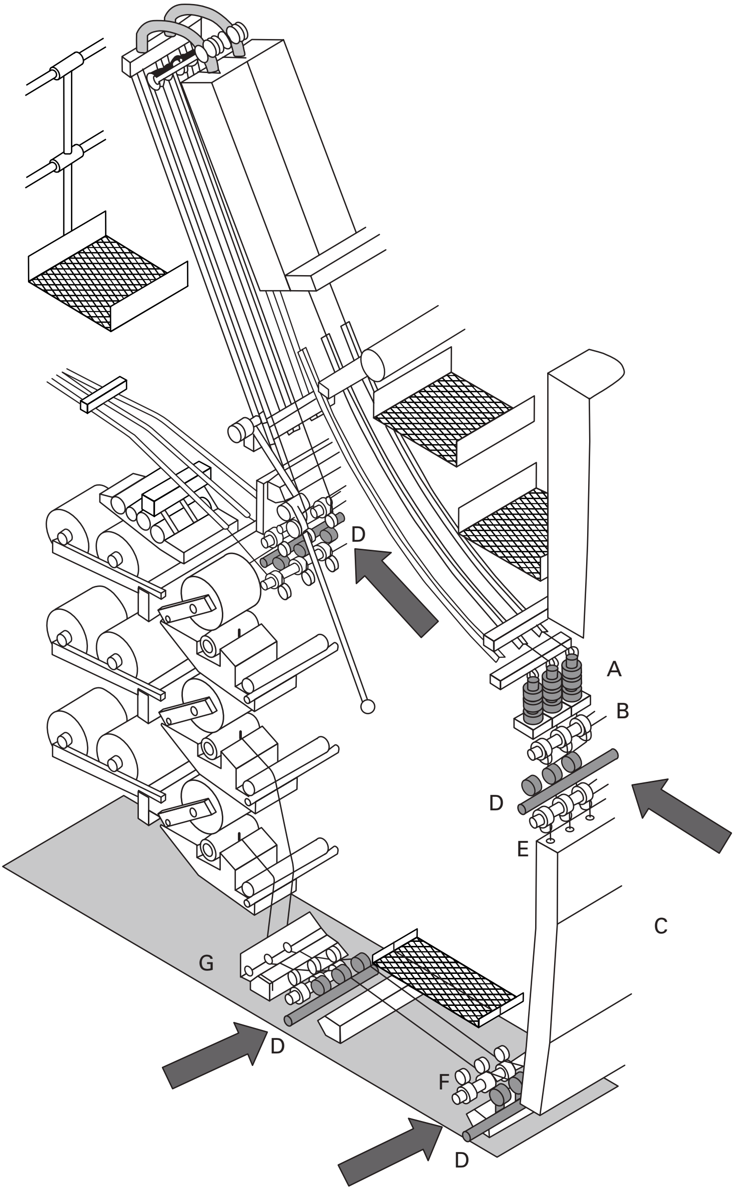
For many end uses the denier available from a single-end or -ply yarn (the older word fold is sometimes used to mean ply) is not sufficient for the fabric construction. In these cases it would be usual to combine or ply two or more ends together on the texturing machine. Such yarns find use in automotive, woven apparel, narrow fabric, upholstery and industrial fabrics.

These yarns usually come in combinations of two-, three- and four-ply, and it is usual for the twist inserted in the yarn to be balanced as far as possible. Indeed the production of two-ply yarns with balanced twist is one route towards the production of a torque-free yarn.

Ply	Twist insertion
2	S + Z
3	S + Z + S or Z + S + Z
4	S + Z + S + Z

There are of course exceptions to these combinations. For example when producing a yarn destined for further processing on a two-for-one twisting machine, all ends that are combined or plied together would be of the same twist. There are other fabric constructions for which yarns of the same twist direction may be combined.

Dependent on the design of the machine the separate ends of yarn may be combined either above or below the second heater of the machine (Fig. 5.7). Intermingling (or interlacing or entangling) jets are used to combine and lock together the yarn ends. The jet may be located before or after the second heater (see Section 5.3.2.1). For some end uses the air-jet may be



5.7 Alternative intermingling jet positions. A) Friction unit. B) Centre shaft of machine. C) Secondary heater. D) Intermingling jet. E) Second intermediate shaft (optional). F) Drive shaft to control second heater overfeed. G) Oil application roll. Courtesy of Barmag-Saurer Group.

omitted. This would be the case for yarns which will go for subsequent twisting operations, where the presence of the intermingled points inserted by the air-jet would be detrimental to the finished fabric appearance. The intermingling stage is also omitted if the yarn is destined for further processing by air-jet (see Chapter 7).

Note: The term 'intermingled yarn' is quoted in *Textile Terms and Definitions*, Tenth Edition, published by the Textile Institute. However, the process of intermingling a yarn by using an air-jet has assumed many different names over the years. They are commonly referred to as intermingled, mingled, interlaced, tangled or entangled yarns. Even the term 'twist substitute' has been used, since from the earliest stages of their development intermingled yarns were indeed used as substitutes for twisted yarns in woven goods. Similarly, the actual points in the yarn at which the filaments are intermingled together have assumed various names. They are commonly known as mingle points, knots, nodes, nips, tack points or simply entanglements.

5.3.2.1 Use of air-jets during the texturing process

Reasons for their use

The basic question that must be asked is why intermingle or interlace a yarn at all? Textured yarns are intermingled for four main reasons:

1. To hold the yarn bundle together in the case of two-, three-, or four-ply yarns. This enables them to be processed at higher efficiencies in weaving or knitting.
2. Single-ply yarn is intermingled, particularly in warp yarns for weaving, in order to hold the individual filaments together as a tight, cohesive bundle. This helps to prevent yarn damage as the yarn passes through the reeds on the loom. Previously these yarns would have been twisted, sized or both before warping.
3. Yarns can be lightly intermingled purely to help the yarn unwind from the package.
4. Lastly, a special type of jet can be used to produce a detorque yarn, i.e. a single-ply yarn with no residual torque.

Range of jets available

The range of intermingling jets commercially available is enormous. Many specialised component manufacturers offer a broad spectrum of intermingling jets within their product ranges, for example *Fibreguide*, *Heberlein*, *Temco*, *Slack*, *Parr* and others. Each one has its own unique geometry which is used in conjunction with various operating tensions and air pressures to impart the required characteristics to the yarn.

When choosing which type of intermingling jet will be used for a product, the following points must be considered:

1. What is the end use of the yarn? Woven, knitted, raschel, etc.
2. What type of fabric will be made from the yarn? Warp or weft faced, cut pile, etc.
3. Will the process be economically viable? Compressed air is very expensive!
4. What fibre type and what filament denier are employed? Generally polyamide is easier to intermingle than polyester due to its lower stiffness and the lower the filament denier the easier it is to intermingle the yarn.

5.3.3 Intermingling jets

5.3.3.1 How is intermingling defined?

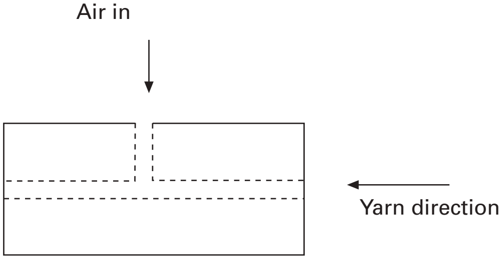
Commonly two criteria are used to define the type of intermingling present in a yarn. These are the number of knots per metre of yarn (kpm) and the strength (stability) of these knots (% retention). Sometimes the number of knots is termed 'nip intensity' or even 'nip density'. As the name suggests, the knots per metre is purely a physical count of the numbers of interlace points inserted in a metre of textured yarn, though to measure them the tension at the point of measurement must also be defined.

The percentage retention is a measure of the strength of the inserted knots, i.e. their resistance to removal, assessed by counting knots before and after the application of a known load or extension to the yarn (see Section 8.3.5.2). This value gives an indication of the ability of the intermingling to survive subsequent yarn processing and to provide the required protection from damage.

Of equal importance when talking of intermingling is to consider the open length of yarn between the intermingled knots. Indeed some would argue that this is the most important criterion, since it is this open length and the consistency of the intermingling that can directly affect how a yarn will process during fabric construction.

5.3.3.2 Mechanics of intermingling

Much has been written about the mechanics of intermingling in various technical journals. It is not the intention here to explore the actual mechanism by which a yarn is intermingled in detail, rather to try to give a brief



5.8 Non-forwarding intermingling jet.

'users' guide', by considering what is required in a yarn and then how this is achieved. However, a basic guide to the principles of intermingling and jet design is included.

The simplest jet comprises no more than a block of metal in which two holes, or channels, are drilled to meet at right angles (see Fig. 5.8). One channel runs the complete length of the block to transport the yarn and the second meets it at right angles for the air supply.

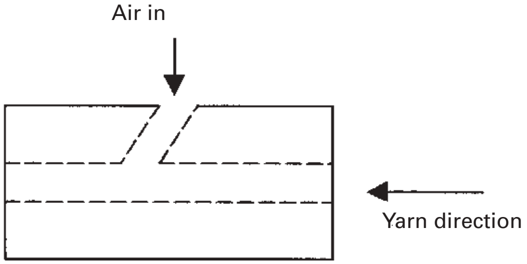
There are jets of this type still being produced but over the years there have been huge advances in the design of jets and many complex designs now exist with wide variations in the cross-sectional shape of both the yarn and air channels.

These changes have been aimed at increasing the efficiency of the jet both by increasing the frequency and strength of the knots and also by reducing the air consumption, so making the jets more cost-effective to operate.

Yarn channels are commonly available in circular, triangular, semi-circular and rectangular cross-sections, though other cross-sections are available. The shape of the actual air orifice, where it enters the yarn channel, is usually of circular or elliptical cross-section though some jets have been manufactured with rectangular or trapezoidal air holes.

In a forwarding jet, as the name suggests, the air stream is angled in the direction of the yarn movement such that it imparts a forwarding action to the yarn. This means that this type of jet can operate at a much higher yarn overfeed through the jet than one where the air stream intersects the yarn path at right angles. In this case the tension on the yarn within the jet is reduced. The air inlet channel is usually set at an angle of 8–12° from the perpendicular, in the direction of yarn travel (see Fig. 5.9).

As with all aspects of texturing machines, the design of intermingling jets has become more specialised over the years. The very earliest designs were crude in both engineering design and manufacture. Now they are much more specialised with designs of both yarn and air channels being tailored towards specific processes and end uses. Though this has the advantage of allowing the yarn manufacturer to choose the optimum intermingling jet



5.9 Forwarding intermingling jet (air flow in the same direction as yarn path).

for the process, it has the converse effect of forcing the purchase of a wide range of jet sizes to meet all requirements. No longer is it possible to purchase a universal intermingling jet, one that can cover a wide range of products simply by modifying machine parameters such as yarn speed, yarn tension (overfeed through the jet) and jet pressure employed. This has become a luxury that is no longer available. The consequence of greater specialisation by intermingling jet manufacturers has been to force the yarn producer to spend more and more time in the search for the optimum process. As a result of this increased specialisation by the jet manufacturers, it has become increasingly important for the technologists to specify the production parameters carefully to enable a viable return on investment in both time and equipment to be made.

Some intermingling jets, particularly those designed for use on high-speed processes, are now offered as dual or 'tandem' jets which have two distinct and separate intermingling nozzles mounted upon a common body. A type also exists which has two air inlets into a single body.

Not only has the design of the yarn and air channels been advanced over the years but also the materials and methods of construction have been improved. From the early use of mild or hardened steel, jets are now available made from ceramic or tungsten carbide materials in which the shape of the air orifice, in the case of the latter, may have been formed by spark or wire erosion.

The earlier jets manufactured were of the closed type, i.e. the yarn had to be threaded through the jet before the thread-line could be started to run. It soon became apparent that jets of this type were impractical in a manufacturing environment. Consequently jets of the open type were developed. These jets differed by having a narrow slot cut into the yarn channel into which a running thread could be inserted. There was a small penalty to pay when using jets of this type in that their intermingling efficiency dropped slightly. However, this was tolerated due to the speed and ease with which the running thread could be put into production.

Jets are now available which offer the best of both worlds. The most common is that which can be opened for ease of threading but can then be closed to ensure optimum working efficiency. One example of this type is the *Heberlein SlideJet.* This jet, along with others of this type, also has the advantage that, when opened to allow threading, the air supply to the jet is automatically cut off so further aiding threading and avoiding the waste of compressed air.

5.3.3.3 Factors affecting level of intermingling

Obviously the level of intermingling present in a yarn is not only dependent on the type of jet but also on the process conditions, location of the jet on the machine and the operating pressure of the jet. The two main parameters by which intermingling level is monitored, i.e. knot count and knot retention (or strength), are both affected by these factors. General rules that can be applied to the level of intermingling in false-twist textured yarns are as follows:

1 Increasing the air pressure will increase the number of mingle points inserted into the yarn. This is true to a degree, dependent on which type of jet is being used. There is a point at which increasing the air pressure has no effect, since there is a limit to the rate at which intermingling can take place as well as a lack of sheer physical space to insert any more knots. Should the air pressure be increased further, the degree of intermingling may in fact reduce. This is because so much air is being forced through the jet that the air stream causes too much turbulence within the yarn chamber and instead of intermingling the filaments, it blows them apart.

2 Increasing the size of the air orifice in the jet increases the knot strength but reduces the overall number of knots inserted per metre. This holds true for jets made by every manufacturer and is due to the physical law that the strength comes from the length (as well as the tightness) of the knot. Longer knots mean that there is less in each metre of yarn.

An obvious disadvantage of having too large an air orifice is that the air consumption, at any given pressure, is increased, making the jets more expensive to operate. Also the increase in volume of air at high pressure can cause filament breaks with sensitive products such as cationic dyeable or microfilament yarns.

3 The overfeed of the yarn through the jet determines the yarn tension, which will also influence the number of intermingling knots inserted per metre of yarn. The yarn tension has an optimum value and can be high enough to have a negative effect by preventing the filaments from being

intermingled at all. Conversely, if the tension on the yarn is low enough within the jet, due to an overfeed which is too high, then the air stream can just disrupt the filaments rather than intermingling them.

4 Jet geometry in this instance is taken to mean the input and output angles of the yarn at the jet. This is most relevant when using forwarding jets of the type manufactured by *Heberlein* and *Fibreguide* among others. With this type of jet the air channel is angled so that the air stream imparts a forwarding action to the yarn (see Section 5.3.1).

The ideal input and output angles of the yarn to the jet will vary according to the design of the jet but angles in the region of 20–32° are not unusual with jets of this type. These angles before and after the jet help to stabilise the yarn path by holding the yarn against the side of the air inlet allowing the air stream to work at its maximum efficiency. Because of this, a great deal of thought has to be put into designing a suitable bracket for mounting the jet on the machine, whether the intermingling jet is situated above or below the second heater, so that the jet can work at its maximum efficiency. Some manufacturers supply their jets with input and output guides fixed to the body of the jet such that they are fixed in the optimum position. Even in this case, care must still be exercised in fitting them to the machine.

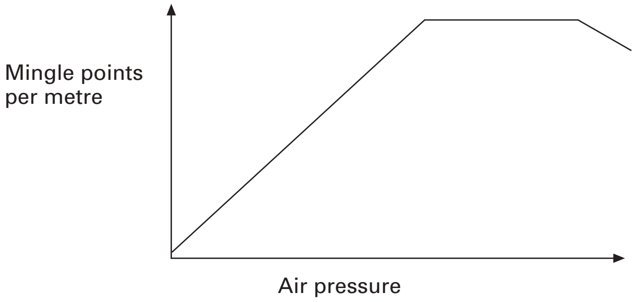
5 Intermingling jets mounted in the centre of the machine, i.e. above the second heater, give a product with a higher degree of retention, or knot strength, than if the same jet is at the bottom of the machine at the same air pressure and overfeed. The reason for this is that as the yarn shrinks in the second heater, the shrinkage effect occurs preferentially in the open yarn lengths between the intermingle points, due to better heat penetration in these areas. This has the effect of giving each individual knot more strength, as yarn shrinkage in the open lengths tends to shorten them locking the intermingling knot more securely into the yarn.

6 Obviously of paramount importance is the correct choice of jet. The overall intermingling characteristics required, the denier of the product and its production speed will all influence the choice of jet type for the process. These factors will help determine which jet is required with respect to air orifice size and yarn channel diameter.

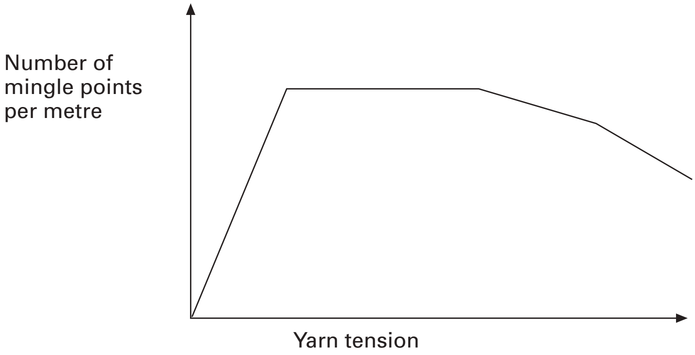
Figures 5.10–5.13 show the type of empirical relationships to be expected as the air pressure (bar) supplied to the intermingling jet and the yarn tension within the jet are increased.

5.3.3.4 Effect of intermingling on yarn characteristics

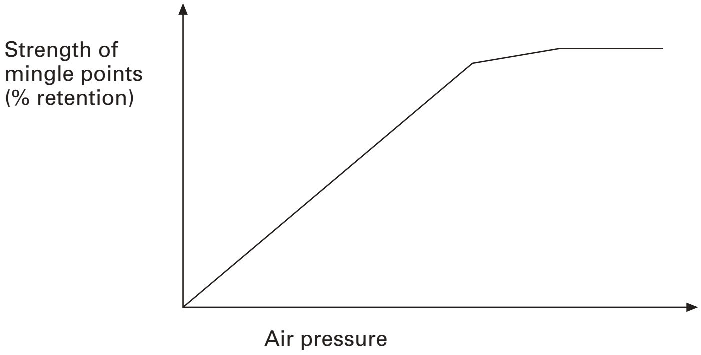
As the yarn is intermingled the action of inserting the mingle points in the yarn has a small but discernible effect upon the physical properties of the yarn. The effects on the different physical properties are shown below.



5.10 Mingle points per metre vs air pressure.



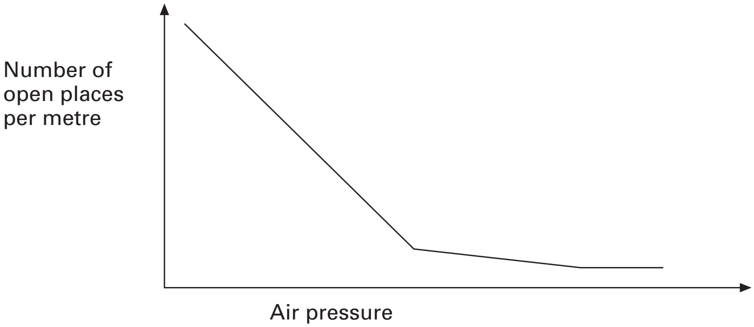
5.11 Mingle points per metre vs yarn tension.



5.12 Strength of mingle points vs air pressure.

Loss in tenacity

Tenacity is a relative value calculated from the breaking load of the yarn and its denier (see Sections 8.2.2.7 and 8.3.2.1). The denier of the yarn increases with the number of intermingling points per meter of yarn



5.13 Number of open places per metre vs air pressure.

inserted due to yarn compaction. This increase in denier has the effect of lowering the calculated values of yarn tenacity (see Figs 5.14 and 5.15).

Loss in percentage elongation at break

Loss in elongation can also be related to yarn compaction and, in particular, to the degree to which the individual filaments are bound to each other by the intermingling action. The tighter the degree of intermingling the more difficult it is for the individual filaments to move relative to each other when subjected to a stretching action (see Fig. 5.16).

Loss in yarn skein shrinkage

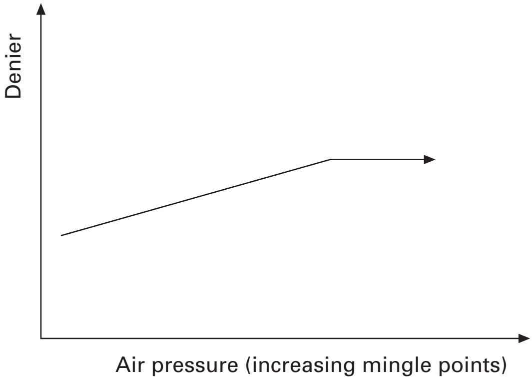
Here again yarn compaction is the cause of the resulting loss in yarn skein shrinkage. The intermingling point effectively acts to restrict the shrinkage or crimp in the yarn, the open lengths of yarn being much more susceptible to the effects of heat than the dense mass of the actual knot (see p. 173 and Fig. 5.17).

Coefficient of friction

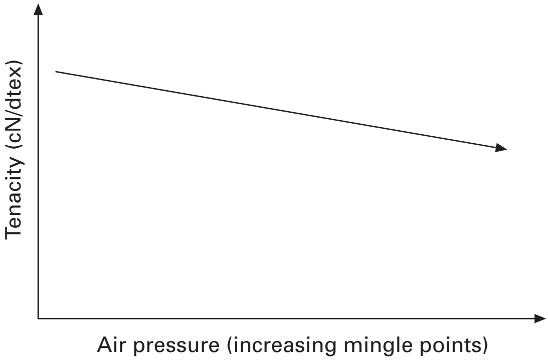
In addition there will be a small reduction in the overall diameter or thickness of the yarn bundle, with the overall cross-section of the filament bundle assuming a more circular form. This is also due to yarn compaction. Correspondingly, a small reduction in the coefficient of friction of the yarn is observed due this reduced surface area (see Fig. 5.18).

5.3.4 Use of an air-jet to produce torque-free yarn

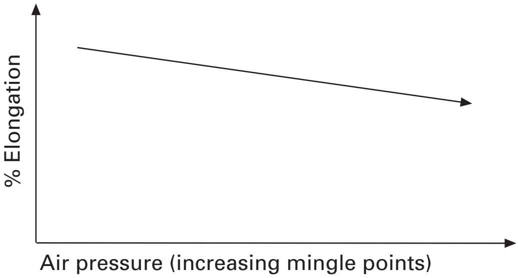
As mentioned above, one route towards the production of a torque-free yarn is the combination of two yarns of opposite twist giving a yarn with



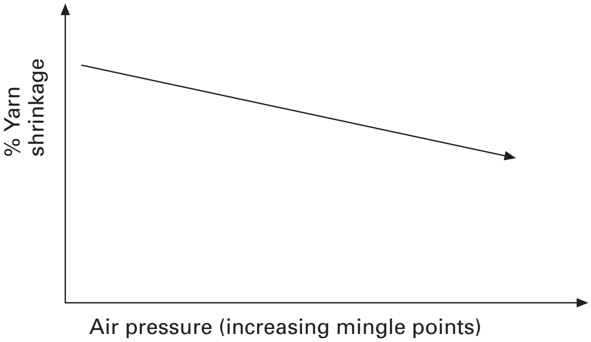
5.14 Denier (decitex) vs air pressure.



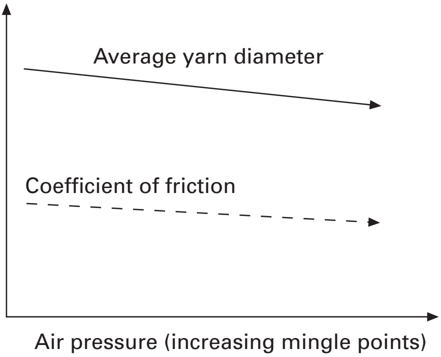
5.15 Tenacity vs air pressure.



5.16 Elongation vs air pressure.



5.17 Yarn shrinkage vs air pressure.

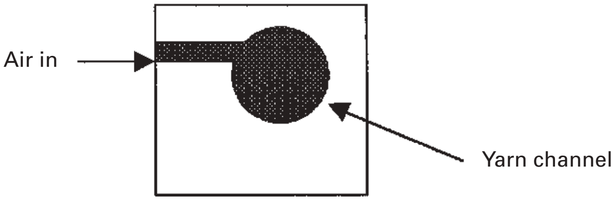


5.18 Yarn diameter and coefficient of friction vs air pressure.

no residual torque. This method has many drawbacks but the most obvious one is the loss of production on the texturing machines by effectively halving the number of packages per doff.

One method of overcoming this is to use an air-jet that inserts a twist into the textured yarn opposite to that imparted by the friction unit. This means that all available ends on the production machine can be employed to produce a single-end yarn. The type of jet used is most commonly referred to as a detorque jet. The twist in the yarn is generated by having the air channel offset from the centreline of the yarn channel, i.e. it no longer intersects at right angles but almost tangentially (see Fig. 5.19).

This offset creates a swirling action inside the jet chamber, which is opposite in direction to the twist previously inserted by the friction unit. It is usual for this type of jet to be reversible so that it can counteract both S and Z twist. These jets are always mounted below the secondary heater, the twist imparted by the jet being set into the yarn by the heat applied in the secondary heater. *Heberlein, Fibreguide* and others manufacture jets of this type.



5.19 Detorque jet.

These detorque jets do not impart any intermingling action on the yarn. This can be a disadvantage in some applications. Thus it is common to operate a detorque jet in tandem with an intermingling jet, usually with separate air supplies as detorque jets would normally operate at significantly lower air pressures than intermingling jets. In this case the detorque jet is usually placed between the exit from the second heater and the intermingling jet so that it can operate to maximum effect by having a more open yarn structure on which the air stream can impact.

5.3.5 Yarn skein shrinkage

5.3.5.1 Double- or single-heater yarns

As mentioned in the previous chapter, textured yarns can be supplied as either single-heater (stretch or high-elastic) yarns or they can be subsequently heat treated on the texturing machine to reduce the amount of shrinkage left in the yarn to produce double-heater (set) yarns. The degree of shrinkage in the textured yarn supplied to the customer is determined by the end use of the finished fabric. Typically woven apparel and knitted goods, both warp and weft knits, are made from double-heater yarns. However, where a degree of stretch is required in the fabric, single-heater yarns would be supplied. These may find uses in upholstery fabrics or in stretch garments. Stretch yarns may also be used in fabrics where a high degree of cover is required. One typical end use where stretch or high elastic yarns are employed is fine denier polyamide yarns for ladies' hose or socks.

5.3.5.2 Factors affecting yarn skein shrinkage

The two major factors that affect the final yarn shrinkage are the amount of heat applied to the yarn on the texturing machine in both the primary and secondary heaters and the overall denier. In addition the filament denier of the yarn itself is also a factor as this affects the ability of the applied heat to penetrate the yarn bundle uniformly.

Heat applied

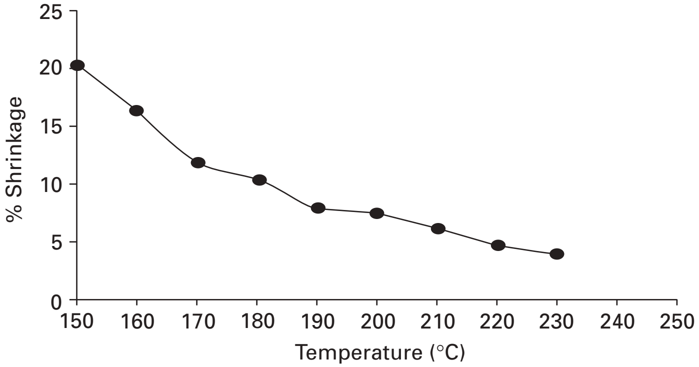
The heat applied by the primary heater to the yarn in the texturing zone has a significant effect on the shrinkage of the textured yarn and could, in isolation, be used to control the level of finished yarn shrinkage. However, it must be remembered that the heat applied in the first heater also has a significant effect on texturing performance with regard to yarn breaks, dye uptake and textured broken filaments. Often, dyed knitted sleeves are produced from yarn made at various first-heater temperatures, and are examined to ensure that the temperature is an optimum for uniform dye uptake. It is usual to find a small range of temperature where dye uptake is more uniform and choosing a process to operate within this heater temperature range results in a less critical situation given the small variations in heater (and hence yarn) temperature that occur in practice. Thus the first-heater temperature is normally set to allow for optimum manufacturing efficiency and uniform dye capability and the shrinkage obtained is accepted at this temperature or, if necessary, adjusted by changing the residence time on the heater, i.e. throughput speed.

The final yarn shrinkage is therefore adjusted to its required value by changes in the temperature of the secondary heater. This heater (see Section 4.3.4) would normally operate in a range of 150–240°C when of the vapour phase type or at higher temperatures if of the short, non-contact type. The residual skein shrinkage of the yarn reduces as the second-heater temperature increases. This is shown in Table 5.3 and Fig. 5.20 for the set of values: yarn type 1/167/34 (150 denier); round cross-section at 700 m/min; first-heater set-point 210°C.

Note that the results gained show not a linear but an exponential type of fall off in yarn shrinkage.

Table 5.3 Effect of changes in second-heater temperature on skein shrinkage value. Courtesy of UNIFI Textured Yarns Ltd

Second heater temperature (°C)	% Skein shrinkage
Ambient (single heater)	34.7
150	20.3
160	16.3
170	11.9
180	10.4
190	7.9
200	7.5
210	6.2
220	4.8
230	4.0



5.20 Yarn shrinkage vs second-heater temperature. Courtesy of UNIFI Textured Yarns Ltd.

Table 5.4 Effect of second-heater overfeed on skein shrinkage. Courtesy of UNIFI Textured Yarns Ltd

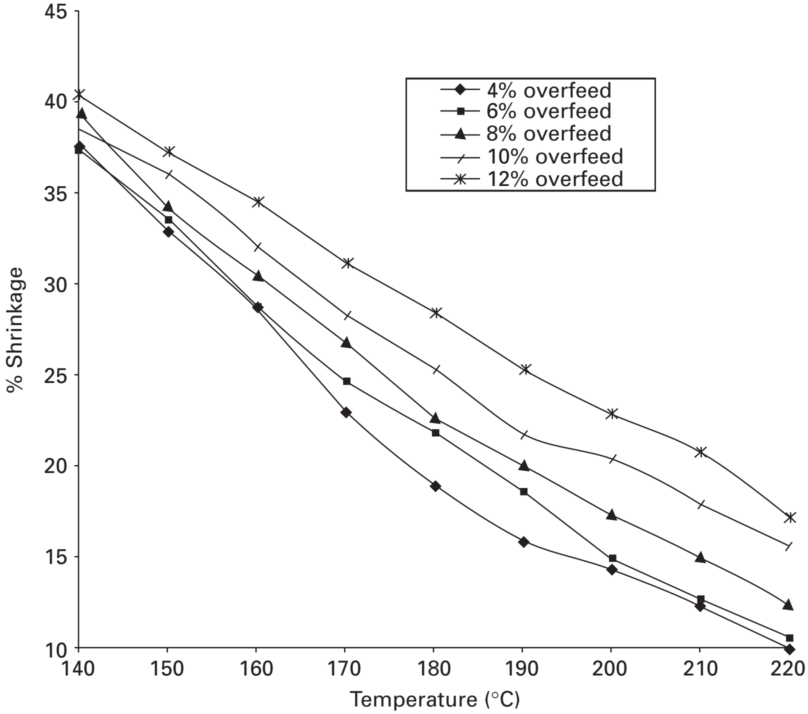
	Second heater temperature (°C)								
% Skein shrinkage	140	150	160	170	180	190	200	210	220
4% overfeed	37.4	32.8	28.6	22.9	18.9	15.9	14.3	12.3	10.0
6% overfeed	37.2	33.4	28.7	24.6	21.8	18.5	15.0	12.7	10.6
8% overfeed	39.3	34.1	30.4	26.7	22.6	20.0	17.3	15.0	12.4
10% overfeed	38.4	35.9	32.0	28.3	25.3	21.7	20.4	17.9	15.6
12% overfeed	40.3	37.1	34.4	31.1	28.4	25.3	22.8	20.7	17.2

Yarn tension through secondary heater

It is not only the heat which affects the degree of measured shrinkage in the finished yarn; the tension at which the heat is applied also has a discernible effect. The tension on the yarn through the second heater is governed by the speed of the drive shaft below the heater relative to that of the shaft immediately above the heater. This relationship is commonly known as the second heater overfeed. The effect of changes in overfeed is illustrated in Table 5.4 and Fig. 5.21 for the set of values shown below: 167/34 (150 denier) polyester yarn produced at 800 m/min.

Secondary heater surface

When considering the effect of the second heater a third variable exists which only applies to those heaters of the enclosed-tube type. This is



5.21 Skein shrinkage vs second-heater percent overfeed. Courtesy of UNIFI Textured Yarns Ltd.

the internal surface of the second-heater tube. It is possible to purchase machines in which the second-heater tube has three alternative surfaces.

1 **Straight walled** – i.e. having the same internal diameter for the whole of its length.
2 **Pinched** – i.e. the tube has its internal diameter changed at regular intervals along its length by having 'pinch points' in the wall of the tube which reduce its internal diameter at the point at which the pinch is inserted.
3 **Hybrid** – i.e. the tube is constructed such that one half is a straight walled design and the other half is of a pinched type.

Effectively what the pinch point does is to reduce the amount of surface of the tube available for heat transfer into the yarn, thus increasing the residual yarn shrinkage for any given combination of temperature and overfeed. This is particularly apparent in the *Barmag AFK* machine where the second heater is curved, which gives a positive contact between the yarn and the wall of the second-heater tube.

5.22 Mingle yarn structure.

Effect of intermingling

As mentioned previously (see Section 5.3.3.3) the degree of intermingling present in the yarn has a discernible effect on the final, measured yarn shrinkage. As the number of entanglement points per metre increases, so the measured shrinkage of the yarn decreases. The intermingling knot itself binds the individual filaments together so effectively that the ability of the filaments to shrink under the influence of heat is greatly restricted (see Fig. 5.22). The open lengths between the intermingled points are the regions in the yarn where the degree of shrinkage is most apparent.

5.3.5.3 Effect of filament denier

For any given yarn the filament denier decreases as the number of filaments present in the POY increases. This, in turn, leads to a more compacted, denser filament bundle as the yarn passes through the primary heater due to the high level of twist imparted to the yarn. This has two consequences:

1 It is difficult to obtain uniform heat penetration through the yarn bundle, since the filaments on the inside receive less heat than those on the outside.
2 This in turn leads to a decrease in end-to-end uniformity of shrinkage around the machine and possibly to high dye-reject levels.

For these reasons yarns with a low filament denier are usually run at low machine speeds allowing greater residence time on the primary heater and therefore more uniform heat penetration.

5.3.6 Changes in bulk

Inserting more twist into the yarn during its residence time on the primary heater can increase the bulk in the textured yarn. This is commonly accomplished by increasing the number of discs used on the friction unit or by increasing the D/Y ratio, i.e. the rotational speed of the discs. This method works best with fine denier yarns, especially those polyamide yarns employed in the manufacture of ladies' hose. When using this method of generating extra bulk in the yarn to produce improved cover in the fabric, the additional twist inserted is limited by constraints of process stability and the generation of tight spots, i.e. short lengths of yarn that exhibit real twist.

5.3.7 Lustre modification

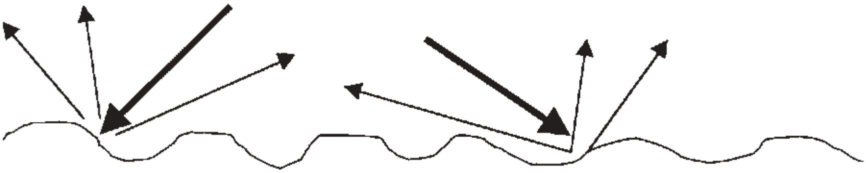
The lustre of the finished yarn is determined by two factors, these being the amount of titanium dioxide (TiO_2), sometimes referred to as a dulling agent, present in the polymer and the filament cross-section to which the POY is spun. The higher the amount of titanium dioxide present, the more matt (or dull) the fibre will appear. Also, the more irregular, i.e. further from a round cross-section, the duller will be the fibre appearance. Hence hexalobal and octalobal spun-filament cross-sections produce a yarn which has flatter, or matt, fabric sheen. This is due to the reduction in light reflected from the surface of the yarn back to the eye. The lustre of a fibre may be enhanced by changing the nature of crimp, or texture, present in the yarn and by doing so altering the manner in which light is reflected from the surface of the fibre. Commonly, there are two methods used to achieve these required changes in crimp character:

1 A lower or leaner crimp can be achieved by means of the friction unit in either of two ways:

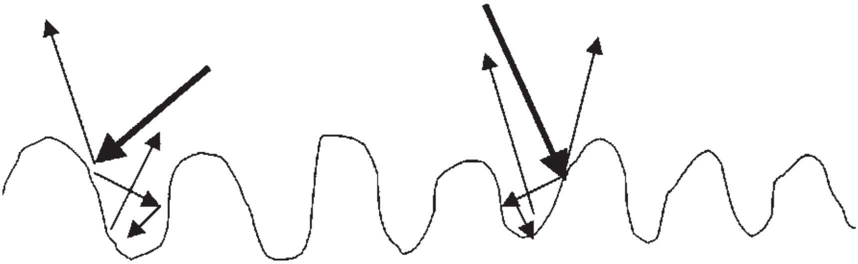
  a by employing a low D/Y ratio, i.e. low friction unit rpm which results in increased tension ratios being observed; or
  b by reducing the number of friction discs employed on the friction unit disc stacking;

  As described respectively in Sections 4.2.9.1 and 4.2.9.3, Both of these methods result in a lower degree of crimp or texture in the yarn (see Fig. 5.23).

2 The yarn may be produced by a more usual method of twist insertion and the resultant crimp or texture in the yarn reduced by using very



5.23 Low crimp light reflectance. The bold arrow indicates incident light and the faint arrow indicates reflected light.



High crimp; low light reflectance; the light tends to bounce around within the wave-like structure of the fibre, instead of reflecting directly back towards the eye

5.24 High crimp light reflectance. The bold arrow indicates incident light and the faint arrow indicates reflected light.

high temperatures in the secondary heater thereby resulting in a very low shrinkage yarn with a correspondingly lean crimp (see Fig. 5.23).

Both of these methods may be used singly or in combination, the final route chosen being dependent upon achieving the required properties in the yarn with an acceptable manufacturing efficiency. By using this type of process it is possible to impart to the yarn a brighter and more lustrous appearance by reflecting more light from the surface of the fibre back towards the eye of the observer.

Conversely the opposite of the above may be desired to achieve a high degree of crimp or texture and high shrinkage. Both of these result in yarn having a more matt appearance by reducing the amount of light reflected back to the eye. However, the effect in achieving a more matt appearance is much less marked than in achieving a more lustrous appearance (see Fig. 5.24).

5.4 Spun-dyed yarns

Spun-dyed yarns, or solution-dyed yarns as they are sometimes called, bring a particular set of problems when being processed on texturing machines. These yarns are produced by injecting metered amounts of pigment, e.g. carbon black for black or grey colours, into the polymer during the spinning process. The amount that is added to the polymer stream determines the depth of shade of the final product. Carbon black is a very aggressive material and this has a detrimental effect on all ceramic surfaces on the texturing machine. These are abraded severely by the yarn, particularly in those areas of the machine where the processing tensions are the highest. This wear is accelerated the greater the amount of carbon present.

Wear on the ceramic guides has a discernible and detrimental effect on the process. High rates of wear on these components are associated with increases in the number of broken filaments and yarn breaks. This means that these guides must be replaced frequently and the associated cost of production increases proportionally. The high rate of attrition on ceramic has another knock-on effect. Where on-line monitoring is employed then obviously the wear on the ceramic sensing head will be high. These are very costly to replace and therefore it may be advisable to replace them with a sapphire surface or to run spun-dyed yarns without any form of on-line monitoring (see Section 8.3.1.2).

If it is decided to dispense with on-line monitoring an increased effort in process control is required if the customer is to be protected from physical faults that may appear in the fabric. This is doubly important when checks on knit sleeves are the only (and expensive) option for checking for physical yarn faults. Moreover any fault that is present may not necessarily be found in the small portion of yarn knitted (see Section 8.3.4).

5.5 Common modified polymers

Possibly the two most common modified polymers encountered during false-twist texturing are used to make the yarn dyeable using cationic dyes or to impart flame-retardant properties. These yarns may be processed as an unmodified polymer with the exception that lower primary-heater temperatures are normally used. This is due to the lower tensile strength of these products and to their susceptibility to textured broken filaments.

5.6 Composite or combination yarns

Composite or combination yarns are usually produced on machines that have been modified by the addition of one or more extra feed shafts. These shafts are usually situated in the input zone between the creel and the first heater on the texturing machine. The creel itself may also be modified to accommodate extra feeder-yarn packages, sometimes of different types. This set-up may be further enhanced by the addition of hotpins or other heating elements between two of the yarn feed shafts in this zone (see Section 4.5.3).

Major texturing machine manufacturers such as *Barmag, Murata, Teijin Seiki, RPR* and others now supply machines with these modifications. When used in conjunction with a double-density machine format the options become increasingly attractive from the point of view of reducing manufacturing costs.

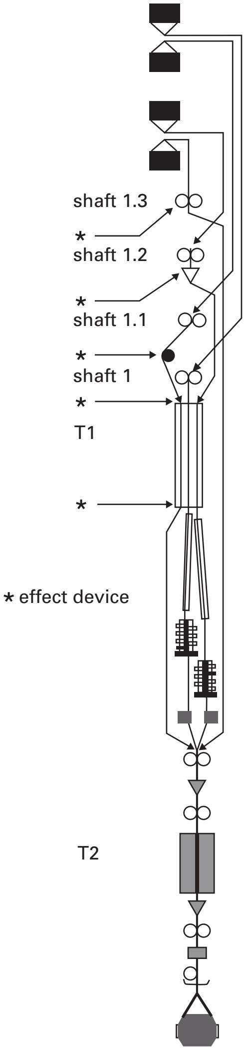
A composite yarn is, as its name suggests, one composed of two different fibre types. These may be of different chemical structure, i.e. a combination of polyester with polyamide yarn, or may be a combination of a disperse with a cationic dyeable polyester. Perhaps more commonly, it is a combination of two yarns having the same chemical structure but which, by being processed under different conditions, can be given tone-on-tone effects, a differential shrinkage, alternate light and dark dye shading or core-and-effect properties. These effects give a fabric appearance that is far removed from one constructed totally from conventional false-twist textured yarn.

Composite yarns are produced by employing various thread-paths in and around the input zone of the machine. There are many feasible combinations. Some of those that are commonly employed are described below.

1 Differential draw ratio. This is where two similar or different fibres are combined by running the input shafts of the machine at different speeds. Therefore two separate draw ratios are applied effectively.
2 Overfeed. This is where the first input shaft of the machine runs at a standard draw ratio for one component of the combination and the second shaft runs at a faster speed than the centre shaft of the machine, thereby overfeeding that component instead of drawing it.
3 Use of a stepping device that can feed one component of the pair into the machine at a variable rate.
4 Use of feed yarns with different levels of molecular orientation; here the effect is similar to running a differential draw ratio but magnified.
5 Use of an intermingling type of jet in the zone between two of the additional feed shafts so that the yarn components are combined before processing on the machine.
6 Using a hotpin or other heating element in the zone between two of the additional feed shafts. One or both ends are wrapped around the hotpin so that changes take place in the crystalline structure of the fibre before processing in the texturing zone of the machine.
7 Use of an additional twisting device such that one or more components are fed into the machine in a highly twisted condition.

There are patented methods (e.g. by *Barmag* and *Wykes*) whereby the use of extra feed shafts on the machine allows *Lycra* to be fed into the machine and combined with textured yarn during the manufacturing process rather than in a separate and costly stage. It is also possible to use these feed shafts either to bypass the twist-insertion device completely or possibly to employ different modes of twist insertion on different thread-lines.

With such an arrangement of shafts and either heating elements or air-jets, it is possible to employ various techniques to generate effects in both yarn and fabric. It may prove that only one or two are viable commercial processes. However, these products may be a useful addition to the port-folio, since not only do they generate income but they also make the customers aware that in the yarn manufacturing plant constant development efforts are being



5.25 Possible layout of multishaft machinery. Courtesy of Barmag-Saurer Group.

made to generate new and improved products; an important commercial consideration. The layout of such a machine is shown in Fig. 5.25.

5.7 Oops! What went wrong?

In this section some of the common problems encountered in a texturing plant will be examined and their possible causes discussed. For ease of use these will be taken in alphabetical order.

5.7.1 Break rate

The break rate, or the numbers of yarn breaks experienced per unit weight of textured yarn produced, is a constant concern in any texturing plant. Yarn breaks cause short packages, lost production and increased labour and packaging costs. The causes of high yarn breaks can be categorised broadly as follows:

1 poor quality POY feed yarn;
2 incorrect processing conditions on the texturing machine;
3 inadequate or poor maintenance on the texturing machine.

Little can be done to compensate for the poor quality of POY feedstock, other than attempt to segregate the affected spinning packages before they reach the texturing machine. If this is not possible, the texturing machine should be run at a slower speed so that the number of breaks in a given time period is lower.

Reasons for poor quality POY that may contribute towards high break rate are:

1 POY broken filaments;
2 incorrect or variable spin-finish level;
3 variation in the POY filament cross-section;
4 package build faults;
5 variation in orientation or denier;
6 handling damage;
7 poor housekeeping in the extrusion plant;
8 yarn packages without tails.

Reasons for high break rates that are process-related can be as follows:

1 excessively high draw ratio;
2 excessively high primary-heater temperature;
3 incorrect D/Y ratio leading to yarn coming out of friction unit;
4 process speed too high, causing instability and surging.

These can be minimised by adjustment to the process specification.

Machine and / or maintenance-related problems might include some or all of the following:

1 worn or damaged ceramic surfaces in the creel or texturing zone of the machine;
2 wear or physical damage apparent on yarn transport systems such as *Casablanca* aprons, nip rolls or any other yarn contact surface;
3 incorrect twist-stop design or material (where applicable);
4 poor thread-path alignment;
5 worn or damaged polyurethane discs (where applicable);

6 incorrect break sensor delay time leading to phantom cuts for no apparent reason;
7 faults with automatic doffing systems, where fitted. These may be related either to machine or process specifications.

Also, it must not be forgotten that the operators can have a discernible effect upon the yarn break rate, particularly when the splicing of the POY packages is not carried out correctly so that breaks occur when the splices pass through the machine.

In some instances there will be no single cause for high yarn break levels. This will often be the case. The way to cure the problem of high yarn break rates is to look at all aspects of the process. Walk the machine, look at what is happening, gather and analyse the data to find the major contributing factors. These must then be addressed. A logical step-by-step approach is the key to success in resolving such problems.

5.7.2 Broken filaments

Textured broken filaments may be related either to the yarn type, POY contributing factors, to mechanical damage within the thread-path or to the settings of the texturing machine on which the yarn is produced. Yarns that are classified as either microfilament or having a low filament denier will be more prone to exhibit this fault that those having coarser filaments. A microfilament yarn is taken as less than one filament denier. Those having filaments between 1.0 and 1.3 filament denier are often classified together with microfilament yarns. Also, in cases where the polymer itself has been modified, such as for cationic dyeable polyester, a higher number of textured broken filaments are likely than with yarn produced from standard polymer.

POY contributing factors may be related to:

1 variation in the uniformity of individual filament cross-sections in the POY bundle;
2 a low spin-finish level;
3 Non-uniform linear density.

Process parameters on the texturing machine that may contribute to high broken filament numbers may be any or all of the following:

1 primary-heater temperature too high;
2 draw ratio too high;
3 throughput speed too high;
4 intermingling jet pressure too high (especially in conjunction with high secondary-heater temperature where the jet is placed at the exit of the second heater).

An examination of the texturing machine itself may reveal a mechanical contribution to the high number of broken filaments. This would be:

1. worn or damaged ceramic surfaces;
2. wear on cooling plates;
3. dirty primary heaters;
4. damaged twist-stops or wrong material used in the design of the twist-stop (where applicable).

Again, the prudent technologist will go and look at the machine and personally assess the situation. Armed with this knowledge and the physical test data of the textured product, the parameters on the texturing machine will be adjusted so that they are at an optimum for the process. If the source of the broken filaments is outside the control of the technologist as far as process parameters are concerned, then all that can be done is to remove the problem by replacing worn machine components or by segregating faulty POY supply packages.

5.7.3 Bulk variation

Variations in the bulk level of the textured yarn may be classified into two separate categories, either end-to-end variation around the texturing machine or along-the-yarn-length variability. In many instances these problems can be attributed to the same cause. The cause may be the throughput speed of the process, which, if it is too high, allows insufficient time for even heat penetration within the primary heater. This is particularly likely to occur on yarns with low filament denier, the twisting action on the yarn creating a very dense yarn bundle. The dense core of the yarn means that it is more difficult to ensure even heat penetration throughout, the filaments in the centre of the bundle receiving less heat than those on the outside.

Other causes of bulk variability may be low draw ratio or incorrect rate of twist insertion for the particular process. This may be remedied by changing either the D/Y ratio or the number of friction discs employed.

5.7.4 Dye variation

Dye variation may be seen in two forms, either an overall drift in shade towards light or dark dye or an increase in end-to-end variation around the machine. A drift in dye shade within a product can usually be attributed to some change in the polymer from which the POY has been spun. More usually seen within a textured product is an increase in end-to-end variability around the machine. This can have several causes, some of which are POY related and others which relate to the texturing process parameters.

Such factors as dirty primary heaters or wear associated with polyurethane discs can contribute to overall changes in dye shade within a product.

End-to-end variation in dye shade around a texturing machine will lead to an increase in the number of packages segregated for light, dark or streaky dye. Light-dyeing yarn is usually associated with either the molecular structure of the POY or with extrusion conditions on the spinning machine. Another cause can be inadequate heat transfer on the texturing machine as a result of an error in threading the machine by the operator so that the yarn is not exposed to the correct primary heat. Or there could be a problem within the heater itself.

Dark dye ends with uneven dye uptake can be attributed to several causes. The affected position on the texturing machine must be examined, as well as possible POY effects, to determine exactly what is the problem. Possible causes of dark dye ends are as follows:

1 disc ejection on the texturing machine (yarn comes out of the friction unit);
2 yarn rolling out of or off the cooling plate;
3 yarn not fully drawn, through a fault with the input or centre feed shaft on the machine;
4 poor heat transference to the yarn caused by dirty heaters or an incorrect specification;
5 surging, incorrect texturing specification or lack of uniformity in the POY.

5.7.5 Intermingling faults

Faults with intermingling can be broadly classified into two groups, those that involve the properties such as the frequency or strength of the intermingling knot and those that are concerned with an irregularity or unevenness of intermingling along the length of the textured yarn.

5.7.5.1 Knot frequency and strength

If problems with the knot frequency and strength are noted, the first question that must be asked concerns the selection of intermingling jet for the particular process being employed. Factors such as the overall denier of the textured yarn, its filament denier and the speed of the process must be taken into account when choosing a jet in combination with a specific product. If these questions have been answered in the affirmative, the process conditions at which the jet is operated must be examined. Trial work is usually necessary to determine the optimum condition of air pressure, yarn tension, speed and jet location for each individual process.

5.7.5.2 Irregularity of intermingling

By irregularity of intermingling is meant the presence of short or long gaps in the textured yarn where no interlace is present. Some of the reasons for this are described above in Section 5.7.5.1 but there are two other possible causes to be taken into account here. One is general housekeeping on the machine. Are the intermingling jets dirty and becoming blocked so that their efficiency is impaired? Secondly is the age of the intermingling jet a factor? Yarn is abrasive and over a period of time wear can be become apparent in the yarn chamber of the jet to such an extent that its efficiency becomes impaired.

5.7.6 Package build faults

Most commonly experienced package build faults have been described previously in Section 4.3.6. Please refer to this. Two other faults are commonly though wrongly described as package build faults, these being dirty or damaged packages caused by poor housekeeping and incorrect handling procedures.

5.7.7 Package density problems

Package density is vitally important in the production of yarn destined for dyeing. There are two common types of problem. In one case the overall package density within a production lot is either too high or too low. Secondly, variation from position to position is experienced around the machine.

Accepting that other yarn parameters such as yarn shrinkage and intermingling are correct, the winding tension must be adjusted to correct the overall package density. This can be done by changing the speed of the take-up shaft or, should other considerations allow, by altering the wind angle.

If the problem is a high degree of variation from position to position around the machine, the following parameters must be compared with the specification:

1 initial stroke length correct;
2 taper angle correct;
3 intermingling correct;
4 cradle damping correct;
5 no drag present in system to increase winding tension;
6 thread-path correct;
7 yarn shrinkage correct.

5.7.8 Surging

Surging can be detected by observation of the yarn running on the machine, by looking at the cooling plate, by seeking the characteristic trace shown by on-line monitoring or, lastly, by examining a knitted sleeve. Surging is a transient instability in the thread-line, which manifests itself in a lean untextured appearance of the yarn. Surging can be caused both by the POY feed yarn and by the actual parameters on the texturing machine. Surging conditions can be overcome by increasing the draw ratio employed. A reduction in the throughput speed of the process and an increase in D/Y ratio, particularly in the case of low-denier yarns, can also help.

These remedies are aimed at stabilising the thread-line as much as possible within the texturing zone, where drawing and twist insertion take place. POY can cause the condition of surging as a result of incorrect or irregular spin-finish application. Irregularity of orientation along the length of the yarn can also cause surging.

5.7.9 Tight spots

A tight spot takes the form of a very short length of untextured yarn and is most easily seen by inspecting long lengths of yarn or by examining a knitted sleeve. They can also be detected by on-line monitoring. The causes of tight spots are those mentioned for surging above and the same remedial action should be taken.