10
Retrospect and prospect

10.1 Introduction

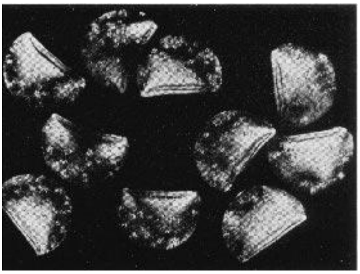
This final chapter covers a variety of topics. First, there are comments on some old methods that are no longer in commercial use, but which may return, perhaps in a variant form, in future. Second, it covers one minor texturing process which is still used. Third, it mentions some related technologies that give texture to yarns, though these do not involve subsequent manufacturing operations on continuous-filament yarns, which is the subject of this book. Finally, the future of texturing is considered, and some recent research, which may have commercial application in future, is described.

Two old processes need only a brief mention. Gear-crimping is an obvious way of imposing crimp by forcing yarn between intermeshing gear teeth which determine the crimp amplitude, shape and period. Trapped-twist texturing is a variant of false-twist texturing in which two ends of yarn are fed into heating and cooling zones where they are twisted together and then removed separately at the end.

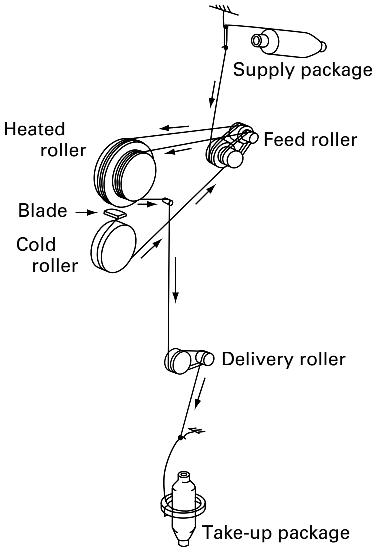
10.2 Past technologies

10.2.1 Edge-crimping

When a fibre is pulled over a sharp edge it curls up, owing to reorientation of molecules near the scraped side. Figure 10.1 shows a photomicrograph, taken through crossed polars, of nylon filaments that have been edge-crimped. The flattening on one side is obvious. The light regions indicate that the molecules are oriented more-or-less perpendicular to the fibre axis and the dark regions parallel to the axis. In a multifilament yarn, not all of the fibres will make contact with the edge. However, bending of a yarn over an edge will cause all the fibres to be bent, generating tensile stress on the



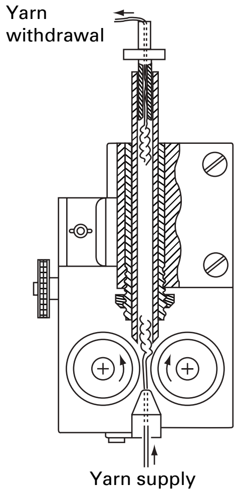
10.1 Filaments from edge-crimped yarn viewed through crossed polars. From Weller (1960).



10.2 Edge-crimping process. From Weller (1960).

outside of the bend and compressive stress on the inside. If the yarn is hot there will be rapid stress relaxation and the fibres will become set in the bent form. Filaments treated in this way will act in the way described in Section 2.6.3. As in false-twist texturing, the restraints on the ends of the yarns prevent the filaments taking up their most preferred form, and therefore stresses are relieved by buckling into another form. Because they want to bend, but are not allowed to twist, they will form alternating helices, as shown in Fig. 2.50.

Edge-crimping was used commercially around 1960. Figure 10.2 shows the arrangement in the *Agilon D* process. Nylon yarn is taken round a hot roller, over a blade and then round a cold roller. At this point, the yarn can



10.3 Stuffer-box. From McCormick (1960).

be taken to the delivery roll for take-up of the production of a high-stretch yarn in which the filaments form tight helices. In the arrangement shown in Fig. 10.2, the yarn continues to a set of smaller feed rolls, which allow it to contract to a limited extent and then to another set of hot rolls. This gives a modified yarn, with low stretch and high bulk.

10.2.2 Stuffer-box crimping

Ban-Lon yarns, produced by the stuffer-box method, were also commercially successful around 1960. Figure 10.3 illustrates the equipment used. Yarn is fed into the bottom of a tube, so that it is forced to buckle, usually in an approximation to a planar zig-zag form. The bottom of the tube is hot and the top is cold, so that the fibres are set in this form. In contrast to false-twist texturing, the fibres are able to take the form in which they have been set.

10.2.3 *Fibre M*

In the 1970s, *Heathcoat* developed a texturing process known as *Fibre M* and used it commercially for several years. The yarns produced were competitive with set-textured, polyester yarns from false-twist processing, though with some difference in character. The process, illustrated in Fig. 6.9, has affinities with jet-screen BCF texturing (Chapter 6), but, after bulking in the jet, the yarn cools in a tube under zero tension. The bulk comes from the asymmetric heating of the yarn in the hot jet, as described in Section 3.2.4. The process uses sequential draw-texturing. POY yarn is drawn through rollers and then fed into a high-pressure steam-jet. It emerges upwards into the tube, is pulled off at the top and goes to take-up. After *Heathcoat* ceased production, modifications of the process were applied by *ICI* in an integrated, yarn spinning (extrusion) and texturing operation, and by *Mackie* in the production of textured, high-denier, polypropylene yarns.

There are two points of particular interest in this process: speed and control. Commercially, *Heathcoat* ran the machines at about 1000 m/min. However, at ITMA 1975 they demonstrated its operation at around 4000 m/min with high-speed winders. The control mechanism operates through action on the steam temperature based on the bulk of the yarn in the tube. The incoming mass flow is governed by the incoming yarn linear density (tex) and its speed through the rollers. The outgoing mass flow is given by the linear density of the bulked yarn, which has contracted due to the fibre crimp, and the withdrawal speed. If the bulk is too great, the linear density will be too high and excess yarn will be removed; the level in the tube will fall. Conversely, if the bulk is inadequate, the level will rise. Consequently a level detector at the top of the tube can act as a sensor, with information fed back to the steam-temperature control. The control mechanism ensures that the yarn produced has uniform bulk, and, provided dye uptake correlates with bulk, uniform dyeability.

10.3 Current technology

10.3.1 Knit-de-knit process and yarns

Of the 12 texturing methods listed in Table 1.1 one of the few still in use is the knit-de-knit process. As the name implies, this comprises three separate stages, namely knitting on a single-feeder knitting machine of small diameter, heat-setting the knitted sleeve in a steam autoclave and then unravelling and rewinding the textured yarn.

Why has it survived into the new century in spite of the cost disadvantage arising from its three separate stages? First the process uses simple machinery, which only requires slight modifications of a single-feed knitting machine and a suitable winder. Second, the textured yarn characteristics are different from those produced by the three processes described in detail in this book.

The knitting machine itself resembles closely the type that is used in laboratories for checking the dye-uptake of textured yarns (see Section 8.3.4). In fact they are interchangeable. In some plants, knit-de-knit machines are used for dye testing. In others, laboratory knitting machines are used for experimental work with knit-de-knit yarns.

However, production machines are usually installed in banks, to facilitate material flow and control. A typical bank would consist of six knitting heads. Because of the simplicity of the process, there has been little development of the machinery used, but with one exception. Since the availability of POY it is now possible to purchase knit-de-knit heads fitted with a pre-drawing unit. In the case of polyester and polypropylene there would need to be a yarn heater between the two draw rolls. In most cases a hotpin of the type used in air-jet texturing would suffice (see Section 7.3.2).

Alfred Buck, whose company are (or were) makers of knit-de-knit machines reported equivalent yarn speeds of up to 720 m/min (Innes, 1980). It is more common for the knitting speed to be set so that yarn is consumed (and hence drawn) at around 500 m/min. This lies well within the performance capability of the standard hotpin.

The process variables consist of the stitch length and the setting temperature. The gauge of the knitting cylinder employed must match the decitex range of the yarns to be textured. Otherwise the major choice that must be made is the type and specification of the feeder yarn. In spite of the paucity of process variables, a wide range of yarns can be textured by this process, provided that a suitable knitting cylinder is specified. Of course, the yarn must be thermoplastic or else no significant heat-setting will be possible.

What are the characteristics that distinguish a knit-de-knit yarn? The setting and unravelling of the knitted loop results in a two-dimensional, wave-like crimp. This differs from both false-twist and air-jet texturing where the filaments are no longer parallel to each other. In fact the yarn does resemble that produced by stuffer-box texturing and indeed by the obsolete gear-crimping process.

Like a stuffer-box textured yarn, the crimp can be removed by a relatively low extension but it also returns on relaxation of the same yarn, provided no heat was applied whilst in its extended state. The second characteristic is the light reflectance that results from the parallel structure of the filaments. This enhances the 'brightness' of a trilobal yarn that has no delustrant. Thus the end uses are predominantly in the knitting industry, where a lustrous appearance is desired.

The properties of the textured yarn should be self-evident from this. Gupta and El-Sheikh (1982) showed that the load/elongation behaviour should result in a higher extension under a given load for a knit-de-knit yarn compared with either a stuffer-box or a gear-crimped yarn. The addition of a drawing unit adds a further dimension to the achievable textured yarn properties. Two ends can be knitted together, one being drawn differently to its partner so that it has a higher residual shrinkage. This means that the bulk is further enhanced during heat-setting.

If there is one lesson to be drawn from the survival of the knit-de-knit process, it is the fact that a process that can be made on modified machinery that is generally available has a much better chance of surviving than one requiring highly developed, specialised equipment. The exceptions that prove the rule are those described in this book. Why? Because the resulting products find a very wide appeal or the process itself proves to be very versatile.

10.4 Related technology

10.4.1 Bicomponent fibres

Another way of introducing crimp is to produce bicomponent fibres. The origins of the method date back over 100 years to waved 'Angel's hair', composed of two types of glass, and it was also used before 1950 on regenerated cellulose fibres. Crimped viscose rayon utilised the fact that the core could be caused to break out of the skin after the initial coagulation of the viscose solution on the fibre surface. Since the introduction of synthetic fibres, bicomponent-fibre yarns have moved from commercial to obsolete in various forms. Piller (1973) listed over 25 producer-textured bicomponent yarns, few if any of which are now in production. However, the advantages of the method ensure its revivals. In 2000, *DuPont* announced a new, nylon, bicomponent fibre.

In order to produce crimpable, bicomponent fibres, the usual method is to feed two streams with different composition to two sides of the spinnerets. Subsequent heat treatment causes differential shrinkage, which forces the fibres to bend. Since there can be no net twist, the filaments form alternating helices with reversals between, as described in Section 2.6.3.

10.4.2 Mixed-shrinkage fibres

A method that is much used for staple fibre yarns, but, in principle, could be applied to continuous-filament yarns is to combine mixed-shrinkage fibres. A particular example consists of acrylic fibres, which have a high shrinkage after stretch-breaking. Mixed shrinkage is achieved by combining relaxed and unrelaxed tows. When the mixed yarn is heated, the shrinkable fibres contract into the core of the yarn and the non-shrink ones form loose buckles on the outside.

10.4.3 Fibre form

Another way in which bulk can be increased, though without crimp and with less effect on texture, is by fibre form. Fibres with complicated shapes will fit together less well than circular fibres, so that higher packing factors result. Fibre volume itself can be increased, without increasing mass, by making hollow fibres.

10.5 New research and development

10.5.1 Activity

Most activity is centred upon increasing the achievable processing speed of false-twist texturing. There are two apparent aims that are being pursued:

1 incremental increases from the current 1100 m/min;
2 targeting speeds of 2000 m/min and over in order to make possible a link with spinning.

10.5.2 Incremental increases

By attention to the three main elements in the texturing zone, namely heating, cooling and twist insertion, and by maintaining the present machine concept, progress is being reported (Schmenk and Wulfhorst, 2000).

High-temperature heaters are fitted to present-day texturing machines (see Section 4.2.7.2). Their limitations have been described. Because the yarn has to withstand a higher ambient temperature and contact with individual ceramic guides rather than a long heater track, new finishes have been made necessary. An alternative approach has been to use a more conventional vapour-phase heater (see Section 4.2.7.1) but filled with a eutectic diphase liquid that has a higher temperature operating range. Such heaters may make fewer demands on the feeder yarn and the spin finishes employed.

Cooling tracks that guide, stabilise and cool the yarn have been used for many years. In order to increase cooling efficiency without extending the cooling zone various methods of intensifying the cooling have been tried. They involve cooling the cooling track, by circulating either air or water through the body. These solutions are not new but are perhaps now being applied seriously for the first time. As far as is known, intensive cooling is both practicable and effective within the range of incremental speed increases that are being attempted.

Similarly work to improve the efficiency of twist insertion is concentrated mainly upon the size, material and profile of the friction discs (see Section 4.2.9.1).

The result of this work has been to lift the achievable speed of texturing to 1500 m/min at least under controlled laboratory conditions. It may be assumed that new and modified machines will enable maximum speeds to be increased from 1100 to 1500 m/min during the coming years.

10.5.3 Target speeds > 2000 m/min

In order to consider the achievement of processing speeds of around or above 2000 m/min, most will agree that new machine concepts need to be considered. The objective of this thinking is to shorten the texturing zone from the present length of several metres to one of between 1.0 and 1.5 m. This should not only reduce the torque level that has to be provided by the friction spindle but also increase the limiting, surging speed. This latter is an assumption that is made widely but, as far as is known, has yet to be proved.

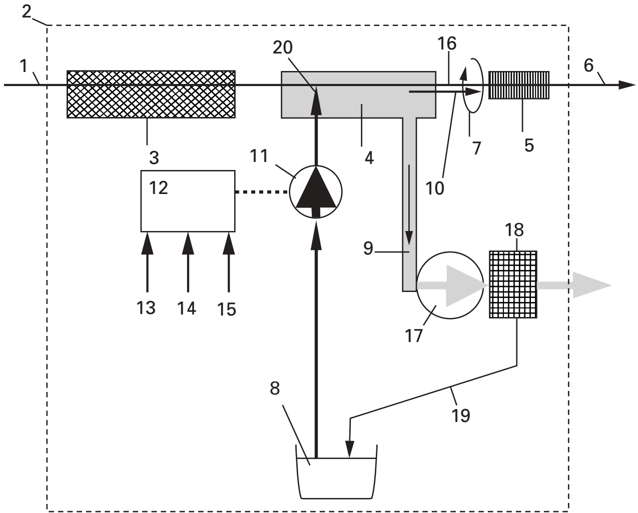
One approach has been to use a steam heater. One such heater, which was developed originally by *Heathcoat* for the *Fibre M* hot-fluid texturing process (see Section 10.2.3), has been used as a primary heater according to Foster (*et al* 1992). The rate of transfer of heat from a superheated fluid such as steam to yarn is very high and enables higher speeds to be used.

Why is it then that hot air is favoured over steam in many BCF processes (see Section 6.3.7)? This probably dates back to the early days of producing BCF yarns from nylon in the USA. It was found that textured nylon that had been heated by steam and subsequently dyed showed a greater tendency to dye shade changes in the Florida sun than if the same yarn had been heated using hot air. At this time nylon was the predominant textured carpet yarn in the USA where the industry grew rapidly. Thus hot air was preferred and there has been as yet no compelling reason for this to change.

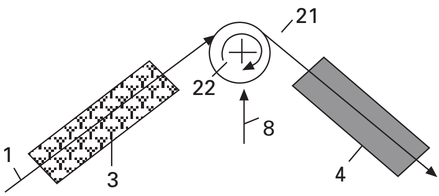
A second approach to the intensive heating of yarn during a short time period is to use the type of heated godet roller that is widely used for drawing immediately after spinning (see Section 6.2.3). One such 'concept' machine was shown by *Retech* at the ITMA exhibition in 1999 (Jaeggi, 1999). This type of heated godet is proven and the necessary spin finishes are well known. The initial cost may be higher compared with a conventional contact heater. On the other hand the achievable processing speeds and the fact that godets, like contact heaters, can be used to process more than one thread-line, reduces this apparent cost disadvantage. Since godets are already in widespread use for heating all types of fibre, it is logical to attempt to develop texturing processes using the existing process technology. This applies both to the roll surface specification and to the types of finish that are applied to the fibres before they reach the godet. So there are at least two types of heater that are capable of heating a yarn but which take up a few centimetres of space rather than 2.0–2.5 m.

Similarly work on intensive cooling has resulted in at least two cooling units which are able to cool the thread-line in a matter of centimetres. In one case this is achieved by the direct action of circulated water in a sealed chamber (Foster, 2001). The work at UMIST has shown that if the yarn is finish free when it reaches the spindle, the yarn tension is lower.

In research at ETH in Zurich, Meyer (2001) and his team have concentrated on improving the efficiency of fluid cooling in such a way that the twist insertion is enhanced, Fig. 10.4. Referring to this figure, water plus finish [8] is applied directly [20] to the heated and highly twisted yarn in a cooling zone [4]. An amount of finish [10] remains on the yarn after partial evaporation, which both protects the yarn and improves the effectiveness



10.4 Cooling by direct action of water in false-twist texturing process. From Meyer (2001). 1) Filament yarn; 2) Texturing machine position; 3) Heating zone; 4) Cooling zone; 5) Twisting unit; 6) Textured yarn; 7) Twist; 8) Fluid; 9 and 10) Vaporised residues; 11) Dosing pump; 12) Pump drive; 13) Yarn speed; 14) Yarn temperature; 15) Electrical resistance; 16) Yarn segment; 17) Vapour extract; 18) Condensate; 19) Condensate return.



10.5 Use of a twist stop in false-twist texturing process. From Meyer (2001). 1) Filament yarn; 3) Heating zone; 4) Cooling zone; 7) Untwisted yarn; 8) Twist stop; 21) Twisted yarn; 22) Free rotation of twist stop.

of twist insertion. In order to ensure that a proportion [10] of the total liquid is applied to the highly twisted yarn [7] and does not condense [9] the application is achieved by means of a metering pump [11] with an independent drive [12]. Process parameters such as the yarn speed [13] and its temperature [14] are part of the pump drive control input. Furthermore, to monitor the finish applied, the electrical resistance of the yarn [15] is measured at a point [16] before the twisting unit.

The first stage of yarn cooling follows as a result of the evaporation of the cooling fluid [8]. To prevent pollution of the air around the threadline, fume extraction [17] together with a condensate return [18 and 19] is recommended. In order to maintain constant processing conditions, the fluid [8] is cooled to below room temperature.

Figure 10.5 illustrates the function of a twist-stop situated between the heating and cooling zones of the false-twist texturing process. In order to ensure a stable threadpath in the cooling zone of the process, the twist at the outlet of the heating zone [3] is held back by a twist-stop [21] of a known type, consisting of a rotating divergence roll [22]. The cooling fluid [8] is applied to the yarn [1] immediately after the twist-stop, but preferably at the divergence roll [21] itself.

Provided the yarn is hot when it reaches the twist-stop, twist-setting is achieved by inserting the maximum twist at this point, and then cooling the yarn before untwisting in the friction spindle. The lack of twist in the yarn on the heater and the resulting open structure of the yarn will cause faster heating. The result of this is that texturing speeds of up to 2000 m/min have been achieved.

A further aspect of this work is that, whereas a proportion of the applied cooling fluid is retained by the yarn as a lubricant, any excess after condensation and lubrication is recycled.

The final piece of the jigsaw is the insertion of twist at very high speed. Much of the work to date has centred upon the further development of the stacked disc or friction spindle. A spiral spindle with integral yarn cooling has been reported by Callhof (2000) from RWTH Aachen.

At UMIST work is proceeding to perfect a twist insertion system based on fluids (Foster 2001). This holds much promise, because it should be capable of providing the required level of torque, unlike air. There is also a neat symmetry in a new process involving superheated steam for heating and a second fluid both for cooling and twist insertion.

10.5.4 Authors' comments

Work to increase the processing speed of the false-twist texturing process, whether by stages or by a leap of faith into the 2000 m/min range can only be commended. Like motor racing there is always a considerable and beneficial spin-off that results in improvements to existing machines and processes.

There are considerable obstacles to the achievement of speeds at or over 2000 m/min, not least the need for a machine maker to provide the resources required to convert laboratory rigs into commercial machines. The costs may not be justified for a doubling of speed. The real challenge would be to match current winding speeds in excess of 5000 m/min. Technical factors include the fact that any process that requires heating and cooling of a thermoplastic yarn must take into account that molecules do not change their structure instantly. There may be a point at which the texturing zone is simply too short, so that the time required for the yarn to be successively heated, cooled and twisted exceeds the elapsed time. There are examples that can be quoted from the drawing and relaxing of thermoplastic yarns after spinning that bear this out. Certainly the results will vary from fibre to fibre. In comparison with conventional heating and cooling there is no doubt that the use of certain fluids will result in a much more rapid transfer of heat to or from the yarn at high speeds. However, any fluid that comes into direct contact with a yarn is going to wash off some of the applied lubricant together with monomer and other impurities. This opens up a new can of worms!

Now that automatic doffing is a proven technique not only at spinning but also after texturing, one of the objections to high-speed processing has been removed. Handling techniques have been developed to enable spinning and winding to be operated at over 5000 m/min and the BCF process shows that a spinning, drawing and texturing process can be operated successfully at speeds approaching this level.

Does it make sense to integrate spinning with false-twist texturing? Perhaps not for yarns of below 500 dex. The loss of flexibility and the difficulties involved in maintaining product quality with such a complex process militate against its widespread use in the near future. But that does not mean that it will not be attempted. Advanced sensing techniques linked to computer control may enable quality to be maintained and allow processing parameters to be automatically changed to provide product variety. There may well be niche products that lend themselves to an integrated process. Indeed production of the *Mitrelle* ® yarn launched by *ICI Fibres* some years ago used a steam-heated *Fibre M* ® jet in direct line with spinning at speeds of over 6000 m/min. New integrated processes may well appear as a result of the demand for BCF yarns in ever finer counts. This will inevitably revitalise efforts to combine spinning with false-twist texturing. Who knows?

There are also challenges for academic research. If the comparative ignorance of synthetic fibre fine structure, its formation and its link to properties and performance were replaced by scientific understanding, a new generation of feed yarns might become available. Linked to this is the need to have better models of heat-setting – and to know which of the various suggested mechanisms occur in reality. The mysteries of modern physics may be involved in fibre structure formation and modification, if there is any validity in Hearle's (1994) speculation that these processes may involve quantum superposition. For the false-twist process itself, there would be benefit from knowing how the process operates in the post-surging mode. If this was understood, it might be easier to find ways of avoiding it and so increase the speed at which the pre-surging mode breaks down and surging starts. Finally, advances in CAD/CAM will come in the 21st century. Computer models will lead to a numerically predictive, engineering design approach to textile processes and products, in place of the traditional empiricism of trial and error.