Influence of fibre properties in air jet spinning

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The properties of fibres used in jet spinning not only affect the spinning performance but also play a significant role in the ultimate yarn quality. The effects of processing parameters and fibre properties are quantified and, in particular, the influences of polyester/cotton blend composition and cotton fibre properties are demonstrated.

Keywords: Cotton fibre, Jet spinning, Polyester/cotton blend, Wrapper fibre, Yarn structure

1 Introduction

Whilst the technology behind air jet spinning can be traced back at least 30 years, the commercial exploitation of the technique for short staple spinning must be regarded as a relatively recent development. Several manufacturers have developed systems for producing air jet yarns but the MJS (Murata Jet Spinning) system is by far the most successful. More recently, the use of air jet technology has been applied to the production of two-assembly wound yarns which are subsequently twisted to yield a two-fold yarn.

Fasciated yarn is a term applied to a staple fibre yarn which is composed of a central core of essentially parallel fibres bound together by wrapper fibres. The technique which is used to create such structures is often referred to as 'twist transference' and relies on the use of a false twisting process, where 'edge fibres' (which are at the outside edges of the drafted strand and are not false twisted) form wrapper fibres as the core of the yarn untwists. Jet spinning is a method for producing fasciated yarns, the essential feature of which being the use of air jets as the false twisting unit.

The original Du Pont patent (Fig. 1) embodied the essential elements for the production of fasciated yarns but never attained commercial success. This is believed to be associated with the need to produce a uniform distribution of wrapper fibre to yield adequate yarn properties. The major difference between the MJS system (Fig. 2) and its predecessor is that the newer system utilizes two twisting jets which operate in contrarotation. This arrangement has been shown, both theoretically and practically, to produce a larger number and better distribution of wrapper fibres which result in a stronger yarn.

Several reports have been published on the comparison of properties of jet-spun yarns with those of ring- and rotor-spun yarns. Investigations have also been carried out into the effect of processing conditions on yarn properties and, to a lesser extent, the role of fibre properties has also been analyzed. The general finding of most of these researchers is that whilst relatively strong yarns can be produced from polyester and polyester-rich blends, with other fibre types the yarn tenacity is significantly lower than that of ring-spun equivalent.

The results reported in this paper represent a part of an ongoing research programme concerned with the theoretical and practical aspects of jet spinning.
Whilst the data were obtained using an experimental unit\textsuperscript{19}, it is believed that the trends exhibited should be reflected in results which can be achieved from commercial machines.

2 Influence of Blend Composition on the Properties of Polyester/Cotton Yarns

Whilst it has been widely reported that jet spinning is restricted to the processing of polyester-rich blends, very little information is available on any systematic study on the effect of blend composition. Puttachaiyong\textsuperscript{15} used various blends of polyester (38 mm, 2.2 dtex) and combed cotton to determine the influence of cotton content on yarn quality. Typical results are shown in Fig.3 from which it may be observed that there is a rapid deterioration in yarn quality with increasing cotton content. A further feature which was also clearly evident from the results obtained in this research was that the yarn properties also appear to be count dependent.

3 Influence of Fibre Properties on the Quality of Cotton Yarns

The results obtained from blended yarns indicate that there is a clear reduction in quality when spinning cotton. It was considered that this is due to 'deficiencies' in the properties of cotton as a raw material for jet spinning and it was believed to be worthwhile to investigate whether the type of cotton played a significant role in the properties of jet-spun yarns. Tembo\textsuperscript{17} assessed the properties of yarns produced from a range of cotton fibres, the properties of which are given in Table 1.

With other spinning systems, such as ring and rotor, it would be expected that the quality of the fibre would be reflected in the quality of the resultant yarn (i.e. longer, finer fibres give the better yarns). It can, however, be observed from Figs.4-6 that jet-spun
<table>
<thead>
<tr>
<th>Staple length mm</th>
<th>Micronaire</th>
<th>Mature fibre %</th>
<th>Fineness dtex</th>
<th>Maturity ratio</th>
<th>Tenacity g/dtex</th>
<th>E%</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>4.4</td>
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<tr>
<td>32</td>
<td>4.4</td>
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<td>76.6</td>
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<tr>
<td>45</td>
<td>3.0</td>
<td>81.3</td>
<td>1.12</td>
<td>0.92</td>
<td>3.69</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Fig. 4—Effect of fibre fineness on yarn tenacity

Yarns fail to exhibit the expected trends. Indeed, none of the normal aspects associated with higher quality fibres appears to demonstrate any benefits to yarn quality and surprisingly it appears that for finer counts the yarn tenacity is higher when using coarser and shorter fibres.

The influence of fibre fineness on yarn tenacity is paralleled by the effect of yarn count on tenacity, as shown in Fig. 7, since both of these factors are linked to the number of fibres in the yarn cross-section. A probable explanation for this effect is that within a particular machinery design, the number of fibres which can be classified as 'edge fibres' (and hence the potential number of wrapper fibres) is fixed. Thus, for finer fibres and coarser yarns, the fraction of wrapper fibres decreases and hence the yarn strength reduces. The magnitude of this effect must be balanced against any potential increase in strength normally associated with the use of higher quality fibres, but from the current results it appears that the influence of wrapper fibre fraction plays the dominant role. The effect of fibre length can also be explained in terms of...
the above mechanism since there is a correlation between the length and fineness of the fibres used and the effect of fibre length is probably a reflection of different fibre fineness.

4 Structure of Jet-spun Yarns and Its Effect on Yarn Properties

Whilst the structure of jet-spun yarns can be idealized as "a core of parallel fibres held together by wrapper fibres", there is a considerable variation in the structure along the yarn length. In particular, there are large variations in the number and type of wrapper fibres and it is thus impossible to assign a singular structure to jet-spun yarns. Several different classification systems have been applied to jet-spun yarns but in the most recent study into the effect of blend composition on yarn strength, the system suggested by Miao was adopted.

The classification which was used to quantify the various structural components along the yarn length (Fig. 8) was:

Class 1: those parts of the yarn which have a regular helical wrapping and in which the core is crimped;
Class 2: those parts which have no wrapping fibres and possess the appearance of a low-twist ring-spun yarn;
Class 3: those parts of the yarn which have a straight yarn core regularly bound with wrapper fibres; and
Class 4: those parts of the yarn which have a straight yarn core bound by irregular wrapper fibres.

Analyses of many yarns were carried out and a typical set of results, which was based on a random selection of 300 sections of yarn, is shown in Fig. 9. It is apparent that the blend composition appears to have only a minor effect on the proportion of each class and whilst the polyester yarn has the highest percentage of Class 1 (which is claimed to have the greatest influence on yarn tenacity) this is only a marginal effect. If the various classes of structure are analyzed more closely it can be seen from Fig. 10 that a major effect of fibre type is that it influences the length of the various classes and thus the polyester yarn has Class I wrappings which are twice the length of those found in the cotton yarn. It was considered that this aspect of structure was the most significant and in order to try to improve the strength of cotton yarns, attempts
were made at increasing the number and extent of the Class 1 wrappers by introducing modifications to the jet design.

The angle of the nozzle in an air jet twister consists of two components which are: tangential to the yarn in order to generate twist; and axial to the yarn in order to suck fibres into the system. It was considered to be appropriate to modify the latter component of the second jet since it was believed that this could result in improved wrapper fibres. Fig.11 gives a summary of typical results obtained when spinning a long cotton (45 mm/1.25 dtex) using different nozzle angles. The most noticeable feature of this figure is the large role played by yarn count and whilst, in general, improvements in tenacity accompany an increase in nozzle angle this is more pronounced for the finest yarn. Indeed, for the finest yarn it was possible to achieve tenacity > 10 cN/tex which is similar to figures claimed by other workers\(^{12}\) but at coarser counts it was impossible to achieve half this figure.

Structural analyses of yarns revealed that the use of a second jet orifice angle of 50° led to an increase in both the number and extent of the Class I wrapping. Typical results for a 15 tex yarn showed a change from 50% proportion of Class I to 67.5% Class I as the nozzle angle increased from 45° to 50°. This was accompanied by an increase in the average wrapping length from 8.12 mm to 10.7 mm. Trials were carried out with other nozzle angles but it was found impossible to spin at a nozzle angle of 35°, and increasing the nozzle angle above 50° produced a drastic reduction in yarn tenacity.

Other modifications to jet designs were also tried but these followed the general trend obtained above in that the greatest effects were achieved with fine yarns and at yarn counts coarser than 15 tex the improvements were only marginal.

Attempts were made to correlate yarn properties to fibre properties using data obtained from trials with different types of cotton, polyester and Tencel fibres. As in earlier trials\(^{17}\), little correlation could be found between the yarn tenacity and fibre length and fineness. A very good correlation was, however, established between yarn tenacity and fibre extension at break (correlation coefficient = 0.99). Whilst this may appear to be an unusual result, a recent paper\(^{20}\) has reported that, when working with modified polyesters, the most significant improvement in yarn tenacity of jet-spun yarns was achieved when using fibres with higher extensibility. This aspect of fibre/yarn interaction could offer benefits for man-made fibres since their properties could perhaps be modified to suit a particular spinning system (e.g. higher extensibility for fibres to be used in jet spinning). Unfortunately, this approach offers very little promise for cotton where, for example, the fibre extensibility is relatively low and unlike for man-made fibres the properties cannot be readily modified.

5 Use of Air Jet Spinning for Producing Two-assembly Wound Yarns

There has been considerable interest in the recently introduced 'jet spin/assembly wind' concept which
produces an assembly wound package for subsequent two-folding. This, therefore, offers the potential for the higher speed production of yarns for two-folding without the need for an additional assembly winding operation. A further potential advantage of the system is that the strength of the final yarn may be influenced by the folding twist and this may compensate for deficiencies in the strength of the single yarns. This could provide greater opportunity for the use of fibres such as cotton, where the single jet-spun yarn is of low strength. Whilst there is very little data available concerning the properties of yarns produced by this route, there have been claims that a further advantage of the system is that the level of folding twist which can be used is lower than that normally used for conventional ring-spun yarns.

The experimental spinning unit, used for earlier trials, was modified to enable two yarns to be spun simultaneously and these were wound together on a single package. Preliminary trials with polyester revealed that for the range of processing conditions used, the properties of the single yarn had very little effect on the tenacity of the folded yarn. A series of yarns were produced from polyester, cotton and Tencel fibres and these were folded with a range of folding twist factors and the results are summarised in Fig. 12. It may be observed that whilst the level of folding twist has very little effect on the tenacity of the polyester and Tencel yarns, there is an improvement in cotton yarn properties with increasing twist. The level of strength which is obtained for the cotton yarn is, however, lower than that for the corresponding ring-spun yarn.

6 Conclusions

Whilst jet spinning may produce acceptable yarns from polyester-rich blends, it is apparent that jet-spun yarns produced from cotton possess very low tenacity.

Modifications in the design of certain critical components can afford improvements in the tenacity of cotton yarns, but the benefits are evident only for fine counts (about 10 tex) and the coarser yarns show very little improvement.

The most important fibre parameter affecting jet-spun yarn tenacity is the extensibility. Whilst this may offer a potential source of improvements in yarn quality produced from man-made fibres, it is possible that this may impose a limitation on the use of jet spinning for cotton fibres.

The use of jet spinning as a precursor to the production of two-fold yarns could offer several advantages. The current work has, however, indicated that for cotton, not only is the level of folding twist important in respect of yarn tenacity, but the two-fold product is weaker than its ring-spun equivalent.

Whilst jet spinning may still be regarded as a novel system, it has no doubt achieved considerable commercial success. This success is restricted to the processing of polyester-rich blends and there is no doubt that the system would gain much greater acceptance if it could produce cotton yarns of acceptable tensile properties. This has stimulated much research but to date this has failed to produce any development which can be used over a wide range of counts. There is no doubt that this research will continue since jet spinning offers the potential of high speed production which can be largely automated, but without the ability to process 100% cotton the application of the system will continue to be restricted.

Acknowledgement

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