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Spinning of synthetic fibres and blends on rotor-spinning machine

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The paper deals with the processing of synthetic fibres and blends on rotor-spinning system. Besides the advantages of man-made fibres, some limiting factors during spinning on rotor machine have been considered. Optimization of surface characteristics and physical properties of man-made fibres are discussed. Finally, the optimization of rotor machine variables to process synthetic fibres and blends is dealt with.

Keywords: Crimp, Fibre finish, Opening roller speed, Rotor diameter, Rotor spinning, Yarn properties

1 Introduction

Commercially available textile fibres have always influenced, to a considerable extent, the production technology as well as the sequence of production machinery in textile mills. Especially, in recent decades, essential changes have taken place in the range of raw materials available to the textile industry and the obvious consequences thereof may be seen at present in the industry. It is expected that in the coming years, natural fibres would be losing their predominance in favour of synthetic fibres. Therefore, future yarn production will be connected with the necessity of processing huge amount of man-made staple fibres and the problem involved will have to be solved by the spinners and machinery manufacturers. At present, the fibre producers tend to favour the manufacturing of coarse and medium count which is evident from the steady growing proportion of 51 mm fibres. Clearly obvious trends, supported by researcher's forecasts, suggest an urgent need for highly efficient, economic machine for the production of yarn from medium length man-made staples.

It is only a matter of two decades since rotor-spinning technology arrived to conquer step by step the sectors of market which up to then had been held by ring-spun yarn. At present, in Europe and USA, 35-40% of all yarns are being produced on rotor-spinning machines. Forecasts suggest that by the year 2000 more than half of all yarns will be produced on this spinning system.

About 24 years back when rotor spinning was taking its first tentative steps, the fibre featuring most prominently in the development of rotor technology was cotton. The first man-made fibre run on a rotor-spinning machine was polyacrylonitrile and since then it has become one of the preferred types fibre for this spinning system. Of the present world production of rotor-spun yarn, about 10% is produced from 100% acrylic fibres. Blends of acrylic fibre and cotton and the blends of polyester fibres with other man-made fibres and cotton also constitute 10% each of the total rotor-spun yarn production.

2 Surface Finish as a Barrier

The volume of production on rotor spinning has increased in recent years which is quite understandable considering the present trend in the production and consumption of textile products. Further aspects contributing to the effort to use the rotor-spinning technology include certain characteristical properties of man-made fibres, viz. strength, cleanliness, evenness in length and fineness, as well as the possibility to modify the fibres for the specific applications and properties required upon the end products, may it be intended for the consumer or the technical use.

Besides such advantages, the man-made fibres are characterized by certain other properties, which can be a limiting factor for the actual rotor technology to a certain degree. As far as the tendency to go on increasing the production parameters is concerned, these properties can represent a limiting factor of basic importance with certain types of fibre. This problem refers basically to their electrical properties determined by the type, amount and uniformity of applied dressing agent, and the aggressivity of the fibres with respect to machine parts which come into contact with the fibres or with the yarn during the spinning process. Further, the electrical properties are related to the resulting yarn strength closely, i.e. exploitation of fibre strength in the yarn, and to the dustiness, owing to which the fibres get damaged and shortened.

The adaptation of rotor-spinning machine for man-made fibres includes two main areas of modification[1]. First, there is a problem of possible build-up of particular matter from spin finish inside the rotor in large agglomeration and then causing ends-down for an obvious reason or by the less obvious effect of altering the frictional behaviour of the fibres against the wall of rotor and thus affecting the twist efficiency[1]. Furthermore, in the self-pumping rotor, there could be a problem with blockage of the pumping holes. Secondly, the optimization of opening roller speed and feed rate of sliver in the opening region, together with modification of teeth of opening roller, as well as the changes in the shape of rotor may be required.

Among the raw materials processed now-a-days, the polyester and acrylic fibres are considered the most important ones. The world-wide production of polyester fibres is increasing much more quickly than that of other fibres. Evidently, it is not the basic fibre strength only that is decisive for the resulting quality of yarn, for its strength in particular, but a set of other properties as well. The fixation degree has an impact upon the yarn strength to a certain extent. The lower the fixation degree, the higher the resulting yarn strength.

A long-term constant quality level of yarns produced also depends upon the condition of spinning unit, mainly of the opening roller, the clothing of which is subjected to different degrees of stress depending upon the raw material processed, with the gradual wear of the clothing. For the yarn of 20 tex, the opening rollers must be changed after 5000 operational hours approximately. After this period, in the serrated clothing there appear cuts in which fibres are caught while rotating together with the opening roller. This increases the number of neps and thick places in the yarn.

It is generally known that the dull materials in particular wear the clothing of the rollers and, therefore, some machine makers do not recommend such materials for processing on their machines at all. It is also known that some fibre producers recommend certain assortment of fibres as suitable for rotor machine in their production programmes. If we pay a close attention to such recommendation we will find out that they include the fibres in gross execution of the fineness up to 1.7 dtex and staple length up to 40 mm.

Under the existing conditions, both the machine makers and the fibre producers have not been able to solve these problems in such a way as to satisfy their common customer (spinner). However, with respect to fibre producers, it must be taken into account that the dull fibres cause a high wear of the rotor machine parts, particularly the opening rollers, owing to the applied dulling agent (TiO_2). The hardness of TiO_2 is considerably higher than that which the makers of the roller clothing guarantee. The question then arises why to consider the similar consequences with glossy fibres too? In these fibres, either TiO_2 is not present at all or in very small amount only (so called micro dull fibres). However, these fibres are treated with dressing agent, the purpose of which is to provide them with the properties needed for good processability at all the steps of fibre preparation and yarn production. There exists a number of dressing agents which not only differ in their compositions but also in the percentage to be applied and in the uniformity of application as well. The finishing agents of the makers who do not take into account the possibility of processing the fibres on the rotor machines, contain high percentage of silicon dioxide. In some cases, the percentage of SiO_2 is as much as 0.18%.

If we consider that the dull and/or semidull fibres containing 0.05-0.15% of TiO_2 are highly aggressive then the glossy fibres can be analogously aggressive too.

2.1 Fibre Finish

Fibre finish goes hand in hand with the fibre crimp and is applied to help processability by modifying the fibre surface friction. It can be used as a lubricant to lower fibre friction, as a cohesive additive to increase friction and also as a means of reducing static charges. If crimp and finish have prime influence on frictional characteristics then it follows that the length of staple required for any processing mean should be compatible with these two parameters. Therefore, by necessity, compensation in crimp and finish would have to be made. Conversely, if characteristics in the final yarn are required that could only be obtained by different crimp levels and crimp amplitude, then modification would be required in either staple length or finish. Therefore, it can be concluded that almost all fibre parameters explained above are interacting with each other and no parameter can be considered in isolation.

The choice of fibre material is always accompanied by the question of surface finish. As well known, man-made fibres can experience a build-up of static charges on the fibre surface during processing and hence the necessity arises to use an effective antistatic agent as well as a lubricant as a surface finish. Better performance comes from synthetic fibres with lubricant level slightly lower than that normally required for ring spinning. More opening roller wrap-ups are encountered when the fibre contains a high lubricant level. However, too low a lubricant level causes static problems at carding and high rotor deposits at spinning. In such cases, addition of an effective anti-static agent (0.05-0.1%) is recommended.

The effect of fibre finish can be more critical in the rotor spinning than in ring spinning[2]. Fibres generally spin better with the right finish than without any finish, but the synthetic fibres should have a minimum add-on on spin finish if they are to be used for rotor spinning[3], because it reduces the possibility of rotor deposits build-up and fibre breakage, particularly in the processing of brittle fibres[4]. In case of fibre finish it is very important to establish, by empirical means, the optimum fibre-to-fibre friction and fibre-to-metal friction[5]. Apparently, a relatively high fibre-to-fibre friction and a low fibre-to-metal friction are required.

3 Physical Properties of Fibres

3.1 Fibre Crimp

Different fibre types have, by necessity, different amount of crimp that can be naturally or mechanically obtained. The crimp is generally put into the various degrees of following two factors:

(a) to help processability through existing frames, and

(b) to modify yarn appearance, be it bulk or lean.

The effect of crimp during spinning process will influence the fibre cohesion, the degree and amount of fibre finish at certain stages of operation, and the number of fibres in the cross-section of a fine yarn. The effect of opening up of fibre illustrates the importance of fibre crimp. A high level of crimp coupled with long staple length can result in high fibre breakage and increased nep formation. In some cases, the amount of crimp required for the processability will obviously influence the selection of staple length for a given denier.

Most synthetic fibres require modification in crimp and finish before they are used for rotor spinning[6]; spin finish is particularly important for 100% synthetic fibres. Less crimped synthetic fibres are preferred for rotor spinning[7-9].

Highly crimped fibre performs poorly in rotor spinning for the following reasons:

(i) they have greater resistance to extraction from the sliver by the opening roller and the resistance can lead to fibre damage and rotor deposits; and

(ii) they produce an uneven yarn because they do not flow smoothly in the transport tube between opening roller and rotor. Further, they do not lie in a compact mass in the rotor groove.

A low crimp friction value is preferable in rotor spinning. In some instances, high wear of machine parts at certain places can result from processing certain man-made fibres and, therefore, the slowest possible speed for the opening roller is generally desirable[10]. The length, crimp level, fibre finish, and fibre characteristics determine how well the opening roller will separate the fibre[4]. The ratio of fibre length to rotor circumference is important since this, together with crimp level, determines the percentage of wrapper and bridging fibres. For short-staple machines, the staple length should be kept below 32 mm and the crimp below 3.9 crimps/cm (ref. 4). Fibre with low crimp gives higher yarn strength, fewer yarn defects, and a reduced number of ends down. Fibre with too low a crimp level on permanence will, however, have a poor card, web cohesion and results in a poorly drawn sliver. Therefore, care has to be taken in order to obtain the crimp balance between sliver preparation and spinning, i.e. the fibre crimp should last through carding, but the drawing process should remove most of it.

3.2 Staple Length

The influence of staple length when using smaller rotor diameter is very important. A rough guide is that the fibre length should not significantly exceed the rotor diameter[11].

In the processing of synthetic fibres, the use of staple length of 30 mm or 32 mm has proved a definite advantage, especially for finer yarns[12-14]. The anchoring of fibres in the sliver is principally achieved by fibre-to-fibre friction, and thus the force required to remove a fibre from the sliver will increase with the staple length. The analysis of spinning results[15] showed that the staple length of 38 mm or 40 mm can be successfully spun even with rotor diameter of 35 mm and with some fibre types even with 32 mm rotor diameter. Fibre length of 32 mm, which appears to be eminently suitable for smaller rotor diameters, produces somewhat inferior yarn quality, the extent of which varies according to the type of fibre used. Fibre length below 30 mm shows a marked increase in irregularity and a clear loss in strength and extension[13]. In this respect, it should be noted that the decrease in staple length, from 40 mm to 32 mm for example, also displays this trend towards inferior yarn properties and yarn breakage while processing viscose fibres.

However, as the fibre length influences yarn structure, the question arises whether a staple length of 36 mm, for example, can be considered particularly suitable for a rotor diameter of 30-35 mm. Experiments need to be considered in this direction in association with the fibre producers.

3.3 Fibre Fineness

While very short staple length does not produce the expected advantages when using small rotors, there is very distinct influence of fibre fineness on spinning performance. This influence is maximum when the yarn counts nearer to the spinning limit (i.e. the minimum required number of fibres in the yarn cross-section) are spun.

Investigations have shown the practicable spinning limit for rotor yarns to be at about 100-110 fibres in the yarn cross-section.

The influence exerted by varying the linear density and length of acrylic and polyester fibres on rotor-spun yarn properties has been investigated[16] and it is found that these fibre properties have relatively more influence on the strength, elongation and irregularity. The fibre flexural and torsional rigidities are important, e.g. it is difficult to spin 40 mm, 3.3 dtex polyester fibre, yet it is possible to spin merino wool on a rotor of 60 mm diameter in spite of the fact that 24 μm wool fibre has linear density of 6.3 dtex. For both acrylic and polyester fibres, the yarn quality deteriorates markedly with increasing fibre linear density[17]. But the strength of rotor-spun yarn was found to be relatively insensitive to fibre length; it hardly changed when the fibre length was increased from 32 mm to 38 mm.

The maximum acceptable fibre linear density for rotor-spinning appears to be about 7.7 dtex (ref. 18). For a wide range of man-made fibre type, it has been found that within the range of 1.7-1.9 dtex, the best spinning performance and yarn properties are obtained with a rectangular staple diagram for staples between 32 mm and 38 mm (ref. 19). Spinning down to 90 fibres in cross-section is possible, but long fibres must be avoided[20]. For polyester fibre, a reduction in fibre length caused a noticeable reduction in yarn strength whereas for acrylic fibre the effect was almost negligible[19].

4 Processing of Dyed Acrylic Fibres

The outburst of activity in Courtelle Neochrome coloured acrylic fibre opens up the prospects of spinning coloured yarns very economically on the recent rotor spinning system[21]. This fibre, available commercially since June 1986, is now being successfully run on the rotor machine. Yarn breaks for 1000 rotor hours vary between 10 and 50 but usually 20-40 and the yield on rotor-spinning machine has been calculated to be 96-98%.

Now, people are looking for the commercial production of cotton type yarn at 1,00,000 rpm rotor speed using 33 mm staple length and 40 mm rotor diameter. It has already been proved flexible to spin the fibre commercially at 75,000 rpm on orthodox rotors; the rotor speed has been raised to 90,000 rpm when using a modified rotor. It is expected that if the draw off tube of 4 mm diameter and rotors of 36 mm and 33 mm diameter are used, then commercial spinning at 1,00,000 rpm will be viable. Some modifications in the design of take-off tube and navels were also suggested. The radius of the alternate tube was reduced from conventional 6 mm to 3.5 mm. It was found that for 40 mm rotor diameter with an increased rotor groove, depth of 1.5 mm, compared to 0.8 mm, gives better results. This is reported to have an important influence on the improvement in yarn regularity.

Courtelle Neochrome fibre for rotor spinning has the following specifications:

Lustre	: Bright only
Linear density (as tow)	: 1.3 dtex ± 3.8% (say 1.25-1.35)
Straight tenacity	: 3.2-4.4 g/dtex
Loop tenacity	: 2.4-3.4 g/dtex
Loop elongation	: 30-45%
Staple length	: 38 mm
Crimp frequency	: 3.5-5 crimps/cm
Crimp contraction	: 15-17%

It is reported that the acrylic fibre for rotor spinning, compared to that for ring spinning, can be prepared and spun with a processing cost saving of about 26%.

5 Breaking Acrylic Tow into Short Staple Fibres

When the man-made fibres first appeared in the market about 60 years ago, they were available to spinning mills only in the form of cut-stock with a staple length corresponding to that of natural fibres and so that they could be processed on the then existing machinery. These cut fibres had to be disentangled and parallelized in the preparatory stage of yarn manufacture, as in case of natural fibres. But since man-made fibres take the form of continuous tow prior to cutting, attempts were soon made to supply this tow to the spinning mills where it could be converted directly into draftable staple sliver while maintaining the original operation of the individual filaments by use of a stretch-break converter in order to eliminate preparatory machine in the spinning mill.

During the last decade the manufacturing of such converter top from man-made fibre tow by the so-called tow-to-top conversion has continuously gained significance[22-25]. Short staple stretch-break converting is mainly practiced in conjunction with OE-rotor spinning in order to process the resulting short-staple tow into yarn in the most cost effective manner.

6 Optimization of Synthetic Fibre Parameters

The increase in rotor speeds during the recent years has extended the manufacturing cost advantage of rotor yarns to the fine yarn counts. Rotor speeds of up to 1,00,000 rpm therefore justify that it is possible to produce yarn counts of up to 12.5 tex economically on rotor-spinning machines.

The increase in rotor speed is accompanied by a reduction in rotor diameter in order to compensate for any deterioration in yarn quality and machine performance that might occur at higher rotor speeds.

Small rotor diameter and fine yarn demand highly objective fibre selection which reyield to staple length, fineness and spin finish. The drawing of fibre in the stages preceding the spinning process needs to be performed very carefully.

6.1 Sliver Quality

The standard and quality of sliver presented to the rotor spinner is of great importance for successful performance in spinning. The drawing process has become a key stage in the spinning process. Fine yarns are very often spun right up to the spinning limit and, therefore, even slight short-term tension peaks in the supply sliver result in a deficiency in the necessary minimum number of fibres in the yarn cross-section, with consequent effect on yarn quality and spinning machine performance. It is important to consider lighter sliver for bulky fibres like acrylic, otherwise it creates problem of choking in feeding zone.

6.2 Influence of Machine Variables on Yarn Characteristics

6.2.1 Opening Roller Parameters

The investigations in rotor spinning have widely shown that the opening roller design parameters are considerably responsible for the spinning performance and resulting yarn properties. The optimum working angle of wire tooth on opening roller is determined by the type of fibres being processed. In general, majority of researchers agree that for man-made fibres the working angle varies from 90° to 100° with relatively lower density of 5-9 teeth per square cm.

6.2.2 Opening Roller Speed

The opening roller design mentioned in the previous section and the opening roller speed greatly affect the opening performance. Many researchers have investigated the effect of opening roller speed on yarn properties and have reported similar general findings. The general trend may be described in a more versatile way that when the opening roller speed is increased at certain level, the yarn spun acquires the optimum end use properties. Thus, the level of opening roller speed varies from fibre to fibre and machine to machine. Any further increase in the speed results in the lower yarn tenacity as a consequence of dominant fibre rupture phenomena and occasionally, higher irregularities and yarn faults. It has been predominantly observed that up to a certain level, above the optimum value, the increase in opening roller speed improves the yarn regularity. The widely recommended opening roller speeds for man-made fibres and blends vary from 5000 to 8000 rpm.

Polyester/cotton blends (67:33 and 50:50) have been studied by Barella and coworkers[26] for the effect of opening roller speeds between 8000 and 13,000 rpm. The results revealed a continuous deterioration in fibre length properties and increase in short fibre percentage with increasing opening speeds. The performance of 50:50 blend is reported to be optimum at the lowest opening roller speed of 8000 rpm.

6.2.3 Role of Rotor-associated Parameters

It is an established fact that the circumferential speed of the rotor plays an important role at the final stage of fibre assembly, which obviously is a function of rotor diameter and speed and plays a very important role in conjunction with other associated parameters during the process of yarn formation.

6.2.4 Rotor Speed

In the attempts to achieve higher rates of yarn production, the researchers are consistently trying to use higher and higher rotor speeds. When using higher rotor speed one must take into account the running characteristics of OE system alongwith the yarn quality data. It is well understood that an increase in the rotor speed demands a corresponding increase in the yarn draw off speed as well as in the rate of fibre feed (while the twist level in the yarn is maintained). At higher rotor speeds, the rate of fibre feed may become so high that the opening roller may fail to cope with the requirement of fibre opening, causing substantial damage to fibre and deterioration in fibre length exploitation in yarn, which may later be reflected in lower tenacity and evenness of the yarn. The deterioration in elongation at higher rotor speeds, however, is attributed to the higher spinning tension resulting from increased centrifugal force on fibre stock and yarn crank due to which fibres in the yarn acquire their position in a more stressed state.

During an extensive study of the effect of rotor speed, using it as the performance limit for different fibres, Stalder[27] also observed that for cotton and acrylic materials, the tenacity of coarse yarns remained unaffected with the rise in rotor speed but fine yarns showed a slight drop in strength. The breaking elongation of cotton and polyester yarns was strongly affected as usual, but this effect was less in the case of acrylic yarns.

Rotor speeds, as performance limits for various raw materials, on suitably modified design of machines, quoted by Laflaquiere[28], are as follows:

Cotton waste	: 60,000-65,000 rpm
Pure cotton	: 70,000-75,000 rpm
Man-made/cotton blend	: 80,000 rpm
Pure man-mades	: Rarely below 80,000 rpm

6.2.5 Rotor Diameter

The rotor diameter plays an equally important role in the mechanics of yarn formation, alongwith its speed. In the recent years, both of these rotor variables have been considered, together with other associated parameters, by researchers for assessment of spinning performance density of different fibres in technological, mechanical and economical speeds.

In considering the rotor diameters the following factors are relevant[29]:

- Maximum safe speed is inversely proportional to the diameter,
- The number of doublings and hence yarn evenness are proportional to the rotor diameter,
- A value of 1.1:1 for the ratio of rotor diameter to mean fibre length is usually regarded as necessary for producing acceptable yarn, and
- The spinning tension is proportional to the square of rotor diameter.

It is recommended to use smaller rotors for cotton yarns to be spun at rotor speeds above 60,000 rpm and a larger rotor for cotton/polyester blend and man-made fibres in general. Man-made fibres have insufficient response to the increased torsional moment in the yarn crank, at higher rotor speeds, where the end break occurred. It is observed that the spinning limit of fibre material shifts towards coarser count with increasing rotor speed.

6.3 Determination of Twist Index

The mechanics of twist insertion in rotor spinning is quite unique. The major factors which affect the twisting of fibre at the point of yarn formation are:

- yarn transverse (or bending) rigidity,
- yarn torsional rigidity,
- the coefficients of dynamic and static friction between the fibres, and
- the coefficient of dynamic and static friction between the fibres and the rotor groove.

The twist index required to impart the necessary stability to the spinning process when using small rotors and high rotor speeds is a frequently discussed controversial point.

As far as the determination of index of twist (α_{min}) is concerned, it can be proved that as a function of rotor diameter, the greater the rotor diameter, the lower the α_{min} (ref. 29). Lower indices are a basis of favourable spinning conditions. Nevertheless, lower α_{min} index is only partially responsible for spinning stability, as the fibre properties and the spinning elements adopted substantially influence the spinning performance. With the fibre types available, it has been established that with equal yarn fineness, rotor size and rotor speed, the twist indices required for a staple spinning process vary by as much as 20%.

A 20 tex yarn was spun from 1.3 dtex/40 mm spun-dyed fibre with 35 mm rotor diameter and 90,000 rpm rotor speed. The twist index was carried between $\alpha = 95$ and $\alpha = 115$ whilst it was possible to spin these fibres with standard delivery ducts at twist indices between $\alpha = 105$ and $\alpha = 115$. With other fibres, it was found necessary to incorporate a supplementary twist-blocking element in order to guarantee machine performance.

Therefore, it can be concluded that the best possible results from the rotor machine do not only depend on the characteristics of the machine, but strong influences are also exerted by the choice of raw material to be spun, its preparation and the proper adjustment of the machine parameters. The judicious combination of rotor diameter, rotor speed and proper selection of opening roller speed and withdrawal tube, partly in relation to fibre type, length, fineness, finish and crimp level, play an important role to get the best possible results on rotor spinning machine.

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