Friction spinning—A critical review

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The ability to achieve high twisting rates without the need to rotate the heavier mechanical elements and the low yarn tensions enable very high delivery rates with friction spinning. The soft handle of the yarn, versatility to handle all types of fibres and the core spinning facility are the other merits of this system. However, the low yarn strength, high twist variability, higher hairiness and the restriction to coarser counts are the major drawbacks to be overcome before friction spinning can become commercially viable. The yarn formation is very complex as the angle of deposition of the fibres, suction level inside the drums, surface friction on the yarn tail and the air turbulence have considerable influence on fibre arrangement. Fibres are highly disoriented in the yarn with loops and folds which lead to very low utilization of fibre length in yarn strength. The system becomes unstable when the number of fibres in the cross-section falls below a certain level.

Keywords: Core-spun yarn, Dref-2, Dref-3, Friction spinning, Master Spinner, Open-end spinning, Spinning tension

1 Introduction
The need to rotate the package at the twist insertion rate coupled with rapid increase in spinning tension with spinning speed sets a limit to the spindle speeds achievable in ring spinning. Open-end spinning methods where the open end of the yarn alone needs to be rotated for imparting twist were, therefore, developed to achieve high delivery rates. Rotor spinning which is one of the first methods developed on this principle has well-established itself as an alternate to ring spinning in coarse count range for certain end uses. Friction spinning represents an alternate open-end spinning method to rotor spinning which holds promise of still higher delivery rates.

2 Outline of Friction Spinning
In this system, the fibres from the sliver after pre-opening and individualization are deposited in a suitable form by an air current into the gap between two cylindrical drums rotating in the same direction. Either one or both the drums are perforated and have a suction arrangement inside them to restrain the fibres while they are rolled and twisted. The yarn is formed by the frictional forces between the fibres and the rotating cylindrical surfaces and is withdrawn at right angle to the direction of moving surface. Since the drum diameter is many times higher than the yarn diameter, each revolution of drum imparts a large number of turns to the yarn. So, very high rates of twisting can be obtained without the need to rotate the drum at excessively high speeds. Normally, the yarn is twisted 100 times per turn of the drum. Another advantage of friction spinning is that only the yarn end is required to rotate with angular velocity required for twist insertion while in ring spinning the package with the spindle and in rotor spinning the rotors are also required to rotate with yarn angular velocity. As a result, the limitation to speed from technological considerations is of much lower order than in rotor spinning and there is a good scope for achieving much higher production rates.

The spinning speed in friction spinning in relation to that by other competitive methods of spinning is discussed by Brockmanns as illustrated in Fig. 1. It is observed that friction spinning (Dref-3) and OE friction spinning have a higher productivity than both rotor spinning and air-jet spinning. Friction spinning is, however, restricted to coarse count range.

Another important advantage of friction spinning is the low spinning tension. The low tension accrues from the absence of centrifugal forces in spinning which are present in ring and rotor spinning. The yarn tension values in friction, rotor and ring spinning are compared in Fig. 2. It is observed that the spinning tension in friction spinning is only 20% of that obtained in ring spinning and 14% of that in rotor
spinning. Further, tension variations are also of a lower order. Because of the low tension, end breaks are low in spinning and higher delivery rates are achievable. The low spinning tension has, however, the disadvantage that some of the weak places in the yarn may escape breakage during spinning process and can be a potential source of break during subsequent working.

3 Developments in Friction Spinning

Dref-2 is one of the earliest friction spinning machines introduced in the market around 1977 primarily for long staple fibres. The machine consists essentially of a drafting unit which drafts a number of slivers and feeds the drafted strand to a sawtooth wire covered opening roller. The delivered strand from the opening roller is transported by an air stream into the nip between two perforated drums (Fig. 3). During passage the impurities in the material, because of their weight, take a different flight path and are removed. The suction inside the drums provides the necessary restraining influence over the fibres as they get twisted by the rolling action caused by the rotation of drum to form the yarn. The suction inside the drum also helps to remove dust and trash, thereby contributing to production of a cleaner yarn. Twist is determined by the ratio of suction drum speed to delivery rate. Considerable slippage (60-85%), however, takes place between the yarn and the drum as a result of which actual twist is much lower than mechanical twist. The extent of slippage increases as the yarn count becomes finer. The machine can also be used for producing core yarns. The core filament is fed axially into the spinning zone and the staple fibres delivered from the opening roller are tied in or wrapped over the filament by the false twist generated by the rotating action of the drums. All kinds of filaments, tapes and elastomers can be used as core.

A ‘Parallelistor’ or ‘Paradisc’ was later incorporated into the spinning unit to improve fibre alignment in the direction of yarn axis. This consists of a fan like unit located in the flowline of the opened fibres as they descend onto the yarn forming zone. The unit deflects the fibres and parallelizes them in the direction of yarn axis. As a result, yarn strength is improved while twist factor can be lowered. The speed of the paradisc can be varied from 1500 to 3500 rpm. The power requirements of the machine are 1.2 kW per hour per spinning position, the major fraction of power is for creating the vacuum in the spinning drums. Dref-2 is suitable for spinning 15s-6s Ne at around 150 m/min delivery rate.

Dref-3 is a development over Dref-2 for improving the quality of yarn, productivity and count range. Unlike Dref-2, Dref-3 is not an open-end spinning machine but is a core type friction spinning arrangement. Here, an attempt is made to improve the quality of yarn by laying part of the fibres in an aligned fashion along the direction of yarn axis in
core. The remaining fibres are wrapped round the core fibre. The sheath fibres are attached to the core fibres by the false twist generated by the rotating action of the drums. Two drafting units are, therefore, used in the system, one for the core fibres and other for the sheath material. After drafting in the first unit, the core fibres are laid in the nip between the spinning drums in a direction parallel to the axis of the drums. The sheath fibres after passage through the second drafting unit and a sawtooth wire covered roller are deposited over the core fibres by an air stream and wrapped over the core by the rotating action of the drums (Fig. 4). The yarn delivery rate ranges from 150 to 200 m/min and the count spun ranges from 4s to 18s Ne. While Dref-2 is meant for long staple material, Dref-3 can handle shorter fibres12. The sheath fibres being fed nearly in a vertical direction over the core fibres get buckled. If an oblique fibre feed could be employed12, core/sheath yarns can be made in Dref-3 using only a single sliver instead of a number of slivers for sheath. But the conventional vertical feed is found to give a higher yarn strength than oblique feed. A good amount of fibre breakage occurs in the opening roller in the Dref machine which shortens the long fibres; very short fibres are also removed as waste13. Staple length is reduced by 20-30% as a result of breakages.

'Master Spinner' by Hollingsworth is on the other hand a true open-end friction spinning machine. A single sliver is fed to the machine as in the case of rotor spinning. After being opened and individualized, the fibres are fed in an oblique direction to the axis of the drums2 as against vertical feed in Dref spinning (Fig. 5). The angle of feed is between 10° and 45°. The oblique feed helps to reduce buckling of fibres and enables finer counts to be spun. Further doubling of fibres in the different sub-slivers takes place during yarn formation leading to better yarn uniformity. A suction current is superimposed on the fibre stream to improve orientation of fibres in the collection zone. Though the twist is imparted by two rotating drums, only one of them is perforated and has a suction arrangement inside. The other friction drum has a special surface to provide effective frictional grip. Yarn counts in the range of 10s-24s Ne can be spun with delivery rates between 150 and 300 m/min, depending upon the raw material. The machine is further equipped with an automatic piecing carriage and cleaning system14. The second carriage does the full package and puts in its place an empty tube with starter material. The starter material is also prepared and kept ready on the doffing carriage. A 10-spindle laboratory version of friction spinning machine is also offered by Hollingsworth.

4 Yarn Formation and Structure

The main drawback of the friction spinning is the extremely poor fibre orientation and consequently the low utilization of fibre length in developing strength for the yarn. As the fibres transported by an air current at high speed from the opening roller have to land on relatively slow moving drums, the fibres get buckled and form loops before they are incorporated into the yarn1,15. The mode of landing does not provide much scope for improving fibre orientation. The extent of buckling and disorientation is more with longer and finer fibres. The unfavourable attachment conditions of the fibres to the yarn result in lower strength than that found even in rotor spinning. The drop in strength with increase in gauge length is more marked in friction-spun yarns than in ring-spun yarns because of low fibre orientation and presence of fibre loops.

The torque required to form the yarn in friction spinning is provided by the friction drums that rotate in opposite directions in the vicinity of the yarn and
the frictional drag on the yarn by the drums. The yarn
is held in contact with the drums with a force
dependent upon the air suction created inside one or
both drums. The applied force varies along the yarn
formation zone because of the conical shape of the
yarn tail. Lord et al.\textsuperscript{18} showed that the incoming fibres
are subjected to shear fields set up between the yarn
and torque generating surface and snarls and buckles
while being entrapped into the yarn. Varying
amounts of air turbulence in the system also cause
disorientation of fibres. Johnson and Lord\textsuperscript{17} tried to
simulate friction spinning by using a large-scale
analogue of the same that operated with water as
fluid. They showed that leakage flows in the contact
point between the rotating friction drums and the
stationary inner suction cylinder has considerable
influence on the mode of yarn formation. Cross flows
carry the fibres from ingoing to outgoing roller and
contribute to wrapping of fibre on the tail.

There are basically two types of fibres in the
friction-spun yarns\textsuperscript{19}. One is extended in the axial
direction of yarn with or without hooks and the other
is repeatedly folded back over itself. Such fibres have
a very low fibre length utilization and do not contribute
much to the strength of the yarn and it is, therefore,
important to reduce the proportion of such fibres.
There is also a third type of fibre sometimes found. It
belongs to fibres escaping the yarn tail after initial
contact with it. Such fibres rotate in the nip of the
friction drums for sometime and afterwards get
incorporated into the yarn.

Stalder and Soliman\textsuperscript{19-21} concluded, on the basis
of observations with high-speed cinematograph,
that the yarn does not emerge in conical form as is
normally visualized but is surrounded by a rotating
sleeve of fibres of approximately cylindrical form.
The rotating sleeve is formed by the fibres arriving
from feeding unit. Subsequently, the fibres are transferred
from the rotating sleeve onto the non-rotating yarn core which is axially withdrawn.
Twist is imparted to the yarn by the rotation of fibre
sleeve while fibres are being peeled from it. The fibre
sleeve and the mode of yarn formation are illustrated
in Fig. 6. Because of the varying yarn diameter, twist is
greater in the core than in the surface of the yarn. Lord
et al.\textsuperscript{16} found that the helix angle increases from outer
to inner layers in core friction yarns (like Dref-3). But
on open-end friction-spun yarns, helix angle
decreases from outer to inner layers. The twist
variation across the cross-section of the yarn is
another reason for the lower strength of friction-spun yarn as all the fibres do not share the
load equally. Another problem is the variability in
twist from one spinning position to another\textsuperscript{22}.

As the yarn count becomes finer, the number of
fibres in the sleeve reduces and the incidence of holes
in the sleeve increases\textsuperscript{13}. The chances of yarn tail
losing contact with sleeve therefore increase,
leading to end breaks. Thus, end breakage rate
increases steeply when the number of fibres in the
cross-section drops below a certain level. The
instability in yarn formation as the number of fibres in
the cross-section reduces is the main reason why
friction spinning is restricted to coarse counts. The
minimum number of fibres required in yarn
cross-section to form a yarn is of a higher order in
friction spinning than even in rotor spinning.

The examination of the yarn at the formation zone
with the help of photgraphs with short duration flash
techniques showed that yarn formation in friction
spinning is much more complex\textsuperscript{24-25}. While the fibres
near the tip are loosely wrapped around the yarn tail,
those away from the tip are progressively more tightly
wrapped\textsuperscript{26}. Yarn tail is tapered with a highly unstable
tip. The tail also has an appendage consisting of a soft
inflated mass which rotates around the axis. The core
appears to be projecting into the mass. Twist
distribution in the tail is highly variable with criss
cross fibres having varying helix angle. There is an
intermittent slippage of twist from the tail which adds
to instability\textsuperscript{26}.

Another drawback in friction spinning is the
absence of ‘back doublings’ found in rotor spinning
which even out variations in the input material\textsuperscript{27}.
Periodic air stream variations that are introduced by
virtue of the fact that the opening roller is spirally
clothed with wire introduce mass variations which do
not get evened out because of the absence of back doublings. Periodic strength variations are, therefore, found in the yarn.

Unlike in ring-spun yarns, fibres in friction-spun yarns exhibit migration from outside to inside of the yarn with very little reversal in the direction of migration\textsuperscript{18,27}. But the migration is stronger in friction-spun yarns than in ring-spun yarns. The difference in migrational behaviour may also be partly responsible for the lower strength of friction-spun yarns.

5 Yarn Properties

The properties of friction-spun yarns, ring-spun yarns and other yarns spun on modern spinning systems have been compared by several authors and the findings have been at times divergent because of the differences in raw material and processing conditions. For 20s Ne yarn made from 65/35 polyester-cotton blend, Brockmann\textsuperscript{3} found maximum strength in wrap spinning followed by ring, air-jet, rotor and friction spinning in that order. Thus, the lowest yarn strength is found in friction spinning. Mass regularity is comparable in air-jet, ring- and wrap-spun yarns but friction-spun yarn has a higher irregularity while rotor-spun yarn has a still higher irregularity. The imperfections in friction-spun yarn are lower than in rotor but higher than in ring and air-jet yarns. Further, the friction-spun yarns are more hairy than all other yarns. The yarn is also susceptible to strip back and disintegration upon abrasion. Friction-spun yarns have a low hot air shrinkage and comparable shrinkage in boiling water to ring- and wrap-spun yarns.

Louis\textit{et al.}\textsuperscript{28} compared the strength of 74, 45 and 33 tex cotton yarns produced on ring, BD-200 rotor and Dref-3 systems from cottons varying in one case in staple length and bundle strength and in another case in micronaire and found that the strongest yarns are produced by ring spinning followed by rotor spinning and then Dref-3. Rotor spinning results in the most regular yarn followed by Dref-3 and then ring spinning. Further, the best yarn appearance grade is obtained in Dref-3 followed by ring spinning and then rotor spinning. But Dref-3 yarns are more hairy. Cotton yarns finer than 45 tex could not be spun on Dref-3 at 200 m/min. Spinning performance is better with 70% core and 30% wrap than 50% core and 50% wrap in Dref-3. But yarn strength is better with the latter. The air suction pressure has considerable influence on strength of yarns in Dref-3 with yarn strength showing marked deterioration when suction pressure drops below 70 cm of water.

Padmanabhan and Ramakrishnan\textsuperscript{29} found that the filament core Dref-3 spun yarn is stronger than 100% cotton yarn and cotton core yarn by about 13% and 20% respectively. The higher hairiness in Dref-3 yarns was confirmed by these authors. 100% cotton yarns could not be spun to 18s Ne from J34 and H4 cottons on Dref-3.

Padmanabhan\textsuperscript{29} compared the properties of 100% viscose and 100% polyester yarns made on Dref-3 with ring-spun and rotor-spun yarns made from the same raw material. Maximum yarn strength was found in ring spinning followed by Dref-3 and then rotor spinning. Lower yarn strength found in rotor spinning compared to friction spinning is at variance with the results of other workers and this may be partly because low drafts were used in rotor spinning. The U% and imperfections were lower in ring-spun yarns than in Dref and rotor spinning which is also at variance with the results of other workers.

Polyester/cotton blend yarns made on Dref-3 are superior to ring-spun yarns in strength by 25% but inferior in U%, imperfections, strength uniformity and hairiness. Dref-3 yarns made out of polyester/cotton blends give a lower resistance to abrasion and repeated extensions compared to ring and rotor yarns\textsuperscript{31}. With decrease in polyester component, the abrasion resistance increases while the resistance to repeated extension decreases. In another study on 40 and 60 tex polyester/cotton blends\textsuperscript{32}, friction-spun yarns are found to be more irregular than rotor- and ring-spun yarns in terms of twist and linear density variability. Coarser counts are more regular in terms of mass irregularity but have a higher twist variability.

6 End Use

The soft handle of the yarn and the absence of wrapper fibres give friction-spin yarns an advantage in weft and pile yarns, velvets, blankets, terry towels and knit-goods. Other application areas are cleaning clothes and mops, furnishings, filters and technical fabrics, and secondary carpet backings made of polypropylene. Dref-spun yarns have better dimensional stability and bonding strength with adhesive\textsuperscript{3}. Recycled textile wastes and trimmed selvages from shuttleless weaving can be directly processed into yarn\textsuperscript{7}, thus reducing the raw material cost. Interlinings can be made at lower cost if yarns made in Dref-3 are used\textsuperscript{33}. The advantages are in terms of lower labour costs, reduced waste, lower raw material cost and improved loom shed efficiency. Being ideally suited for preparing core spun yarns, friction spinning can be employed for manufacture of industrial textiles like conveyor beltings, tarpaulins,
awnings, roof coverings\textsuperscript{4}, etc where the core filament will give the strength while the staple fibre covering will provide the adhesion required for the coating. Some attachments are also available for fitting on friction spinning machine to produce slab or fancy yarns\textsuperscript{4}.

7 Future Outlook
Unlike rotor spinning, friction spinning has still not established itself as a viable method of yarn manufacture. The main drawbacks are the lower yarn strength and the inability to spin medium and fine counts. These arise to a large extent from the way the fibres get incorporated into the yarns. Considerable research and development work is needed in this area before this system becomes commercially viable. There are, however, certain distinct advantages in friction spinning which justify further developmental efforts. The spinning tension is very low and very high twisting rates are possible without the need to rotate the drum at higher speeds. The yarn is devoid of wrapper fibres and has a softer handle. The system is also more versatile in handling all types of natural and synthetic fibres.

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