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Review Article

Review on Study Behavior of Fiber Migration

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Abstract

Fibre migration, which is expressed by various parameters and indices, depends on fibre properties, the characteristics of the fibre assembly, and the processing conditions. The fibre properties include length, degree of elasticity, stiffness and fineness. Short, coarse and stiffer fibres move out of the core towards the sheath, while long, fine and flexible fibres move towards the core. Strongly crimped fibres are also found predominantly in the sheath. In blends of fibres with substantially different processing characteristics, preferential radial migration occurs; one component of the blend is found primarily in the core and the other component mostly near the surface. Fibres at high tensions are tried to relieve their tensions by migrating to the core. Relatively slack ones are displaced outwards. In ring spinning, the fibre tensions are generated in the delta zone where the fibres leave the nip of the front drafting rollers and pass into the twisted yarn.

Keywords: Fibre migration; Migration pattern; Fibre properties; Fibres leave.

Introduction

Fiber Migration describes the variation of radial position of a single fiber or filament as it moves along and around the yarn axis. Migration is permanent movement of fibers from center to side or vice versa based on the behavior of twist direction [1, 3]. The ideal migration pattern is defined as one in which the fiber migrates regularly & uniformly from outside to the center of the yarn and the back to outside in such a way that the density of packing of fibers in the yarn is constant throughout the yarn. Fiber migration can be defined as the variation in fiber position within the yarn [2]. Migration and twist are two necessary components to generate strength and cohesion in spun yarns. Twist increases the frictional forces between fibers and prevents fibers from slipping over one another by creating radial forces directed toward the yarn interior while fiber migration ensures that some parts of the all fibers were locked in the structure.

Fiber Migration

Migration (used in the former sense) happens as a consequence of the twisting mechanism and is not controllable during the textile process. The emigrational behavior of fibres provide detailed information on the configuration of fibres or filaments in the yarn and how the filaments are packed in concentric shells of the yarn [3].

Owing to their different characteristics, the fibers take up different positions in the body of the yarn. Grouping arises mostly during drawing. Thus, long fibers are often located in the core, since they exhibit more cohesive friction, and therefore higher resistance to the draft, and remain in the interior. Short fibers are often found on the yarn exterior. This tendency is reinforced by fiber migration (wandering of the fibers), since the fibers do not always stay in the positions they first take up. For example, if any traction of power (even minimal) acts on the yarn, highly tensioned fibers of the outer layers press inward wholly or partly (the fiber ends, for example). In doing so, they press out the lower-tensioned fibers from the interior [18]. Migration takes place from the sheath to the core and vice versa. Such migration is, of course, most prevalent during yarn formation but still occurs after yarn formation is completed.

When the smallest forces are exerted on the yarn, e.g. during bending, tensile loading, etc., the persisting tensions in the fibers constituting the yarn lead to continuation of the process of fiber migration even after the completion of yarn formation. For example, the

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short fibers work their way to the surface and are then partly rubbed off [19]. Moreover, some fibers in the body of the yarn lose their helical dispositions during fiber migration; this effect is more prominent the shorter the fibers and the more random their arrangement.

In addition to its dependence on length, fiber migration is dependent upon degree of elasticity, stiffness, fineness, crimp, etc. Short, coarse, stiff fibers move out towards the sheath while long, fine, flexible fibers move towards the core [4]. Strongly crimped fibers are also found predominantly in the sheath, since they can exert greater resistance to binding-in. Fiber migration should be adequately taken into account in determining the composition of blends.

Technique of fiber migration

Tracer fiber technique

This technique involves immersing a yarn, which contains a very small percentage of dyed fibers, in a liquid whose refractive index is the same as that of the original undyed fibers. This causes the undyed fibers to almost disappear from view and enables the observation of the path of a black dyed tracer fiber under a microscope [5, 6]. Dyed fibers are added to the raw stock before spinning to act as tracers. This technique was introduced by Morton and Yen. Or a small proportion of colored fiber (less than 1%) adds to the stock from which the yarn is spun. It is essential that the properties of the colored fibers should by identical or almost identical with those of the main stock of uncolored fibers then the colored and uncolored fibers are twisted together to form yarn [8]. This yarn is immersed in a liquid of the same refractive index as the fibers. As a result, the uncolored fibers in yarn become almost transparent, whereas the colored can be easily seen. Now the fiber in the yarn is observed in a micro projection and thus migration is measured.

Cross sectional method

In this method first the fibers in the yarn are locked in their original position by means of a suitable embedding medium, then the yarn is cut into thin sections, and these sections are studied under microscope [9]. As in the tracer fiber technique, the yarn consists of mostly undyed fibers and a small proportion of dyed fibers such that there is no more than one dyed fiber in any yarn cross-section.

Migration due to tension variation

Migration due to tension variation has been postulated by Morton. Since the length of the fiber path in a yarn increases from the core to the surface, the tension in the yarn cross-section will experience a different level of tension depending upon the radial position they occupy, i.e., fibres on the surface will have higher tension than those remaining in the core. Now if the external restraint is withdrawn (i.e., spinning tension becomes zero), the resultant yarn would be one in which the surface fibres remain under slight tension and the core fibres are buckled. This is, of course, the kind of structure that is obtained when a number of filaments are twisted on a twister (Figure 1).

Figure 1. Twisted yarn

The situation is, however, different in continuous spinning or twisting. In this case, a number of filaments are fed by a pair of front rollers to the twisting zone and, at any given instant, some fibres go to the center of the yarn and some take up their positions on the surface. The fibres at the surface will be taut and those remaining in the core will be slack or even buckled. Now it can be assumed that fibres on the surface will try to release their strains by working their way into the core and in doing so, push the core fibres to the outer region. In this way, over a certain interval, the fibres will move radially to relieve the resultant unstable stress.

Onions and co-workers suggested a different migration mechanism based on diameter and length differences of staple fibres. During drafting, the longer components are under higher constraints due to more fibre contact points and tend to pull in or straighten into the centre of the drafting sliver. Where there are differences in diameter in the fibres, the coarser and stiffer fibres can resist the twisting moment for a longer time than the finer ones, and thus tend to come to the outside of the yarn.

Hearle and Merchant have put forward another migration theory, a modification of Morton's tension theory, with their study of a seven-ply structure. They assumed that migration will only take place when the tension on the central ply has dropped to zero and some slack has accumulated. In other words, even though the outer plies may be under higher tension, the central ply will not be displaced as long as it is held taut under some tension in the twisting zone. But when it becomes slack and begins to buckle, it will easily be pushed out and replaced by one of the outer fibres. However, if the tension during twisting is high enough to keep the central ply under tension, migration will not occur.

Gupta and Hamby have put forward a migration theory - a modified form of Hearle's tension theory. They argued that the practical values of twisting tension in ring-spinning or in an up- or down-twister remains much lower than the tension necessary to keep the axial fibre in a tensioned conditions. On the contrary, slackness in the fibres of the inner most layers occurs which creates a situation where fibres can migrate. They assume that somewhere between the layer of slack axial fibres (helix angle = 0^0) and the outer most layers of the highest tensioned fibres (helix angle = α = twist angle), there remains an intermediate layer where the fibres, lying at a certain angle, have zero tension. An equation was proposed showing the relation between the helix angle of this intermediate layer and the twisting tension. They have also related the buckling of the fibres in any other layers, but within the intermediate layer, to the spinning tension [7].

Gupta (neglecting migration due to geometric causes) has proposed yet another migration model based upon Hearle's tension theory of migration. This concerns the tendency of a fibre situated at a given radial position, viz at the surface, in the yarn to migrate as a function of yarn size, twist and axial tension, i.e., twisting tension. The theory argues that a fibre migrates because it develops a force to drive it during processing. This force, termed as migration force, is directed towards the yarn centre in a plane perpendicular to the yarn axis. The force has been shown to depend on twisting tension, yarn twist (helix angle) and yarn Tex (yarn radius). It shows that for a given twist multiplier, a fibre in a fine yarn would develop a higher force driving it to migrate than a similarly located fibre in a coarse yarn [10, 11].

Geometric mechanism

Hearle and Bose have described an alternative geometric mechanism which, in fact, was a by-product of their larger investigation on the nature of ribbon twisting. They claim that this mechanism may either combine with or replace the tension mechanism.

Yarns are often regarded as twisting in the form of cylindrical bundles of fibres, but they may also twist in the form of flat ribbons. Indeed, it is much more common in practical twisting operations for the yarns to be presented as a ribbon rather than a cylinder [13].

With the geometric migration mechanism, there will be differences in paths followed by the fibres depending on their positions in the yarn before twisting. Fibres on the outside would show a very marked migration, but those originally near the centre of the yarn would take up an intermediate position in the wrapped structure and would show little or no migration. This may explain the difference in the migration correlograms found by Riding.

Gupta has further described that the migration due to the geometric mechanism could include components due to the presence of producer twist as suggested by Hearle and Bose as well as the deviations of regular, irregular or random nature in fibre paths from that parallel to the fibre bundle axis.

It should be noted that the geometric mechanism would be expected to give a regular migration because of the regularity of the producer twist and the mode of formation of the wrapped structure [14]. On the other hand, the tension mechanism can be expected to produce a more random migration.

Hearle, Gupta and Goswami have suggested that the two migration mechanisms are not mutually exclusive. If ribbon twisting occurs then the geometric mechanism must basically be present. However, if the frequency of migration provided by the mechanism is not sufficient to prevent buckling of the filaments, then the tension dependent mechanism will be superimposed upon it [15].

Variables affecting fibre migration

The various properties which are likely to influence fibre position in yarn can conveniently be considered in the following groups:

1. Fiber related factor
2. Yarn related factor, and
3. Process factores

Fibre factors in spun yarns

Fibre material, cross-sectional shape and fibre mechanical properties are inherent characteristics of a given type of fibre. In most cases, however, fibre friction may not be an inherent property since it can be modified by a suitable finish. In fact, fibre type, staple length and denier are the three basic parameters which can reasonably determine the migration pattern.

On the other hand, it is found from the literature that the effect of fibre mechanical properties on migration is complex and sometimes even a contradictory one.

Morton's experiments with viscose and acetate blends reveal that the latter fibres predominate on the surface of the yarn [13]. Apparently, the fibre with higher tensile modulus would be expected to lead to a greater tangential or hoop tension in the fibre helices, leading to inward migration. However, Hearle and Gupta observed that a difference of 45 per cent in the initial modulus of red and black spun-dyed tracer fibre of the same type (bright staple rayon, 38 mm and 0.17 tex) had no appreciable effect on its radial position.

In another experiment on the effect of fibre length, Morton observed that the shorter fibres tend to migrate towards the surface.

Fibre factors in continuous filament yarns

Migration applied to continuous filament yarn is very limited. Hearle and Goswami have reported the observations of filament size and number on migration behavior. With acetate, nylon and polyester yarns, they concluded that decrease in filament size decreases the migration and this is more pronounced in the case of nylon yarns [12]. However, Riding's experiments show that the migration pattern is independent of filament size as well as filament number. In contrast to this, Hearle and Goswami have shown that there is appreciable decrease of migration with decrease in filament number for both nylon and acetate yarns.

Yarn factors in spun yarns

Yarn count, amount of twist, blends proportion and fibre tangle, all might reasonably be expected to affect the fibre migration (Figure 2).

Figure 2. Different twist level yarn

The effect of yarn count was studied by Morton. He stated that the greater the number of fibres in the yarn cross-section, the greater is the obstruction which each fibre has to overcome in migrating through a given fraction of yarn radius. In other words, greater tension differences should be created among the fibres in coarse yarns in order to produce the same effect.

The influence of the amount of twist has also been studied by Morton. He observed that an increase in the amount of twist decreases the interval between reversals of the helix envelope. Similarly, Hearle and Gupta and Gupta demonstrated that rapid irregular migration occurs in spun yarns and migration increases with increase in twist. They also showed that frequency of migration has almost a constant relation with frequency of twist which is, in fact, in good agreement with Morton's findings. Furthermore, Hearle and Gupta and later Gupta have shown experimentally that roving twist has influence on the migration in spun yarns. This is based on the theory of ribbon twisting as described before.

Gupta and Hamby, working with staple fibre yarn, have shown an interesting phenomenon of fibre migration. Using statistical techniques, they concluded that migration behavior of a fibre depends, to a large extent, on its average radial position in the yarn. Fibres which stay close to the yarn axis show a high rate of short term migration together with a high intensity and low deviation from their average position. On the other hand, fibres whose average position is close to the yarn surface show the least tendency to migrate. However, the fibres which occupy intermediate layers show a tendency to undergo complete cycles of short term migration around the intermediate position.

Yarn factors in continuous filament yarns

The effect of twist on migration in continuous filament yarn has been studied by Riding, Hearle and Gupta and Hearle and Goswami. In general, they have shown that twist has a marked effect on migration which increases with increase in twist. In addition, Hearle and Gupta suggest that migration in continuous filament yarn is made up of a rapid irregular migration superimposed on slower regular migration. It has also been shown by Riding and later by Hearle and Gupta that in the case of continuous filament yarn producer twist controls the migration period.

The effect of the mechanism of twisting has been studied by Hearle and Goswami and Gupta. Hearle and Goswami used rectangular and cylindrical spacers. The position of the tracer filament in the spacer was varied between centre, left and right. It was very difficult to draw any firm conclusions from their results; however, migration intensity was found to increase drastically when the yarn was twisted without spacers.

Gupta concluded from his results that about half of the total migration in commercial yarns must arise from causes whose origin does not lie in the operation of buckling and geometric mechanisms, i.e., it must have come from some undetermined causes. This, of course, supports the earlier conclusion by Hearle and Goswami that migration increases drastically when the yarn is twisted without spacers. Similarly, when only a tension mechanism was made operative, the magnitude of migration was found to be quite small. Gupta concludes that 25 per cent of the total migration observed in commercial yarns comes from the tension mechanism and the other 75 per cent or more from geometric and random causes. This lower value associated with the tension mechanism, he argues; arise from the high surface frictional restraints of the filaments.

Processing factors for spun yarns

Processing factors include yarn manufacturing systems (ring spinning or core-yarn spinning, open-end spinning, etc), machine geometry, machine settings and possibly the type of twisting, ie, ring-traveller system or spindle or friction twisting in the case of texturing. In the case of multi-roving spinning, the position of the roving bobbin with respect to the roller nip has also some effects on migration as shown by Morton and Boswell and Townend. For his study Morton used the tracer fibre technique and Boswell and Townend used rovings of different colours. Their experiment showed, with triple roving spinning, that fibres from certain roving bobbins did show a tendency to predominate at the yarn surface but Morton found this effect is negligible with his double roving spinning. Differences in colour shades have been observed by Boswell and Townend, when the positions of two coloured rovings were interchanged.

The effect of twisting tension has been studied by Hearle and Merchant. They calculated a theoretical value of tension needed to stop migration. Experiments on staple fibre yarns by Hearle and Gupta have shown that the effect of twisting tension on migration is small and the level of twisting tension which is found in practice is much less than the value which would be needed to stop migration. This has also been confirmed by Townend and Dewhirst and Gupta and Hamby [16]. The latter have shown that spinning tension and spindle speed influence fibre migration, but to a lesser extent than the radial position of a fibre in a twisted yarn.

The effect of drafting tenacity and drafting ratio on spun yarn migration, as has been reported by Gupta, is insignificant and these contribute very little to the formation of geometric mechanism of migration as proposed by Hearle and Bose [17]. This is possibly because of several irregularities which occur in the drafting zone.

The effect of machine parameters on fibre migration in open-end spun yarns and a comparison between open-end and ring-spun yarns have been reported by Pillay and co-workers and Hearle, Lord and Senturk.

Processing factors for continuous filament yarns

Riding has compared the migration behaviour of statically twisted yarns - where a fixed length of yarn is twisted on a twist tester, model yarn - 100 stands of 75 denier cellulose acetate yarns twisted on an up twister, and actual viscose yarn - a yarn consisting of 201 stands each of 1.5denier. He has shown that statically twisted yarn shows a much greater irregularity in the path of the filaments. In addition, calculation of Morton's coefficient of migration shows that there is less migration in the actual yarn than for the model yarn.

Hearle and Gupta and later Gupta studied the effect of tension on continuous filament yarn and concluded that twisting tension has a marked effect on migration [18]. Unlike staple fibre yarns, where the tension mechanism predominates to give a rapid migration (though this is superimposed on a slow migration which appears to be related to roving twist), in continuous filament yarns both mechanisms (tension and geometric) play a significant part.

Recently, the migrational behaviour of filaments in the twisted thread line, collected from a conventional texturing zone, has been studied by Backer and Yang, though this study is very limited. With the application of the tracer fibre technique, they have reported, for 94/28 polyester yarn, that there is no significant change of migration period in the cold-zone as a result of tension change (achieved by changing the percentage overfed) [19]. But when the cold-zone twist is changed (ie, thread line twist level), migration changes quite considerably. It was also observed that additional filament migration takes place in the yarn upon entry into the heater where a higher amount of twist is realized.

Cannon commented during experimental observations on the filament packing in the case of false-twist draw texturing, that the processing tension and torque in the yarn greatly inhibits the continuous migration with twist build-up which would be necessary to avoid cross-section deformations.

In general parameters for fiber migration are:

a. Staple length of fiber: with the increase of staple length migration will also increase.
b. Tension: with the increase of tension of fiber migration will also increase.

Mode of spinning

Fiber migration in yarn depends on the methods of manufacturing processes

Conclusions

Theoretical study was based on hypothesis that due to this phenomenon tensions of all fibres in yarn become equal. In accordance with the results of theoretical investigations of cross-sections cotton/polyester yarn it was found that the location of different fibres in cross-section of blended yarn depends on the percentage of these fibres in the yarn components and their following properties: density and Young's modulus. With the increasing Young's modulus of fibres of one kind, the mass percentage of these fibres in external layer is reduced. With the reduction of fibres density increases the proportion of the area occupied by these fibres in external layer of yarn. – The obtained formulae can be used for prediction of fibres distribution in the cross-section of blended yarns from any mixtures of heterogeneous components. The usage of the calculation results allows drawing conclusions about the necessity of adjustments in settings of subsequent processing of the yarns.

Conflicts of interest

No conflict of interest.

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