Impact of Structural Variations on Pre-Hollow/Micro-Porous Yarn's Tensile and Physical Properties

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ABSTRACT

In the present study impact of structural variations on pre-hollow/micro-porous yarn's tensile and physical properties were investigated in view of their processing and ultimate product quality. The results show that: the core pre-hollow yarns and doubled pre-hollow yarns possessing continuous polyvinyl alcohol (PVA) filaments are better in tensile behavior than blended pre-hollow yarns which contain discrete PVA staple fibers. The doubled pre-hollow yarns were found to have the lowest unevenness, thick places, thin places and total imperfections followed by blended pre-hollow and core pre-hollow yarns, while blended pre-hollow yarns showed lowest number of neps. The core pre-hollow yarns exhibit lowest hairiness followed by blended pre-hollow yarns and doubled pre-hollow yarns. Use of double roving during spinning is beneficial for improving yarn strength, unevenness imperfections and hairiness in all the pre-hollow yarns.

INTRODUCTION

Recently hollow/micro-porous yarn spinning technique and fabric quality thereof have attracted attention to many textile yarn and fabric producers [1-2] and research workers [3-7]. The use of hollow yarn in the fabric is a technique used to increase the bulk of fabrics without increasing weight, thus improving fabric physical properties such as softness, bulkiness and thermo-physiological properties. It is important to note that for making the hollow yarn fabrics; bi-component pre-hollow yarn is used to make the fabric; thereafter one component (e.g. polyvinyl alcohol) is dissolved from the pre-hollow yarn at the fabric stage [8,9].

It may be noted that the PVA fiber is soluble in water at about 60°C [3,8]. In the extended study conducted by Mukhopadhyay *et al.*[9], the pre-hollow yarn fabrics were boiled (hot washed) in water for 25 minutes to remove the PVA portion of yarn.

In most cases core-sheath type of hollow yarn is used; however, other types of structurally variant micro-porous structures can also be produced [9]. The said variation in the yarn structure can have a significant effect on the performance of yarn during knitting or weaving and quality of the fabric. In general, yarn properties such as tensile behavior, unevenness and imperfections play an important role in process performance and also the final product [10]. Yarn hairiness affects not only the quality of products, but also the productivity in spinning and weaving/knitting [11]. The hairiness of yarn affects fabric appearance, generation of neps during winding due to rubbing of hairs, fabric handle and thermal insulation of the fabrics [12].

In the yarn, the tensile behavior (tenacity, extension and work of rupture) depends on the nature and structural arrangement of constituent fibers in the yarn [13]. In addition continuous and discrete length of fibers also affects the yarn strength. The unevenness of the yarn depends upon the number of fibers in yarn cross section, variation in fiber fineness and inclination of the fibers to the yarn axis [14]. The imperfections of the yarn depend upon spinning process and fiber length; whereas the hairiness depends upon fiber length, the number of fibers in yarn cross section, fineness of yarn, spinning system and post spinning operations [12]. Each operation increases yarn hairiness due to the rubbing action of yarn surface over various machine elements.

There are few studies available which are related to properties of friction spun core hollow yarns [3-6] and ring spun micro porous hollow yarns by blending method [7]. However, there is dearth of literature on the impact of structurally different pre-hollow/microporous yarns on yarn tensile and physical properties. Researchers [3,7] found that the strength of pre-hollow/pre-microporous yarns is better than that of equivalent (normal) cotton yarns which in turn leads to improve spinning and weaving efficiency. Das *et al* .[6] studied the contribution of individual core and sheath component on the tensile properties of DREF-III viscose yarn; and found that the major proportion of the load component is generated from the interaction of core and sheath. Ishtiaque *et al*. [7] reported that, the specific volume reduces with the increase in the PVA content in pre-hollow yarns. The tenacity of pre-hollow yarns increases with the increase in the PVA content.

However, the above studies do not provide complete and comparative knowledge about the impact of various structurally different pre-hollow/ micro-porous yarns on tensile and physical properties. Further the impacts of using single/double roving system on the said properties of pre-hollow yarns are not known. The pre-hollow yarn's unevenness, imperfections and hairiness were not studied earlier. In this study, it is attempted to investigate the impact of various structurally different ring spun pre-hollow yarns/micro-porous yarns on tensile and physical properties of pre-hollow yarns. The impact of using single and double roving in pre-hollow yarns was also evaluated.

MATERIAL AND METHODS

Material

Six structurally different pre-hollow/micro-porous yarns were prepared as per the sample plan given in *Figure 1*; using 20 % PVA fibers and 80 % cotton fibers at the ring frame (*Table I*): core yarns, blended yarns and doubled yarns were made by using single roving and double roving. The constructional particulars are given in the *Table II*. Cotton fibers (J-34), PVA multi-filament and PVA staple fibers were used as raw material for preparation of the samples. Raw material details are given in *Table III*.

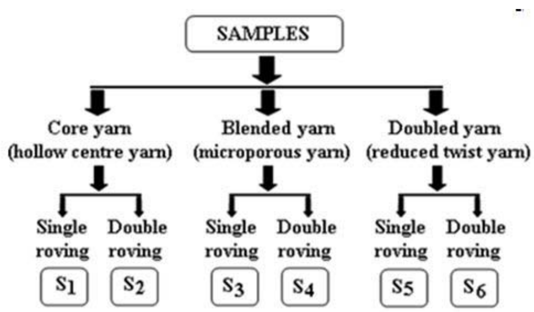

FIGURE 1. Sample plan.

TABLE I. Pre-hollow/microporous yarn samples particulars.

Sample Type	Material used	Roving used	Yarn constructional characteristics
S1	80 % cotton at sheath and 20% PVA filament in core	Single roving	core yarn
S2	---do---	Double roving	---do---
S3	80 % cotton and 20% PVA staple fibres blend	Single roving	Blended yarn
S4	---do---	Double roving	---do---
S5	80 % cotton (single roving ordinary yarn) and 20% PVA filament yarn	Single roving	Doubled yarn
S6	80 % cotton (double roving ordinary yarn) and 20% PVA filament yarn	Double roving	---do---

TABLE II. Yarn constructional particulars.

Parameters	Nominal value
Linear density of pre-hollow yarn	31.5 tex
Linear density of hollow yarn	24.6 tex
Twist/cm (at ring spinning)	7.5 (Z-twist)
Twist/cm (at doubling)	4.3 (S-twist)
Roving hank for single roving	843.6 tex
Roving hank for double roving	421.8 tex

The core pre-hollow yarns were prepared by introducing 20% PVA multi-filament (56.40 denier having 21 monofilaments) in the core of the cotton strand (80%). The blended pre-hollow yarns were produced by blending 80 % cotton with 20% PVA staple fibers (41 mm). The doubled pre-hollow yarns were prepared by doubling the normal cotton yarn with PVA filament (20%); using *cheese winding machine* and *TFO twister* giving about 60% of ordinary-yarn twist in opposite direction. Each yarn was made by using a single and double roving at the spinning stage. All yarns were wound in cones on an *Autoconer* having a splicing device with open gauge setting. Thus a total of six structurally different pre-hollow yarns were prepared for the study.

TABLE III Raw materials detail.

Cotton (J-34 S/G)		PVA Multifilament Filament		PVA Staple fibers	
Property	Value	Property	Value	Property	Value
2.5% span length (mm)	28.32	No. of filaments	21	Fiber length (mm)	41
Fiber fineness (dtex)	1.84	Mono filament fineness (dtex)	2.98	Fiber fineness (dtex)	1.66
Bundle strength (gpd)	2.94	Strength (gpd)	3.35	Strength (gpd)	5.84
Elongation (%)	9.5	Elongation (%)	11.46	Elongation (%)	21.36
Uniformity ratio (%)	46.2				
Short Fiber Content (%)	6.3				

Testing Methods

The tensile properties of the pre-hollow yarns were measured as per ASTM D 2256-02 Standard Test method [15]. For tensile tests, a total 150 tests per sample (about 30 tests each from five packages) were tested for error percentage much below 4% at the 95% level of confidence. For measurement of yarn unevenness, imperfections and hairiness, a *UT4-S Uster Labexpert Evenness Tester* was used. For unevenness, imperfections and hairiness properties, 25 tests per sample (5 tests each from five packages) were performed. The thick places (+ 50%), thin places (-50%), and neps (200%) are expressed in number of imperfections per km. The yarn hairiness is expressed as hairiness index (total length of hairs per unit length of yarn). Before testing, the material was pre-conditioned in standard atmospheric conditions as per ASTM D 1776-04 Standard Practice [16]. The standard atmospheric conditions were maintained during testing.

RESULTS AND DISCUSSION

The impact of structure in various type of pre-hollow yarn on yarn properties; the tensile properties (tenacity, elongation and work of rupture), unevenness, imperfections (thick, thin, neps and total imperfections) and hairiness are presented in *Figures 2-10.* The results are statistically evaluated and all the interpretation is based on 95% confidence level [17].

Impact Of Pre-Hollow/Micro-Porous Yarn On Tensile Properties

It can be seen from *Figure 2* that among the pre-hollow yarns, the core pre-hollow yarns have highest tenacity followed by doubled pre-hollow yarns and blended pre-hollow yarns. The highest strength in case of core pre-hollow yarn is due to the straight and continuous PVA filament in the core which provides highest effective strength to the yarn. In case of doubled pre-hollow yarns, as PVA filament is in spiral form; therefore its contribution towards the yarn strength is less than that of core spun pre-hollow yarn. However, in spite of higher tenacity of PVA staple fiber, the strength of blended pre-hollow yarns is lowest among all yarns. The utilization of fiber strength in discrete form largely depends upon fiber length, surface properties of constituent fibers and twist in the yarn. In pre-hollow yarns, using double roving in place of single roving during spinning is beneficial as the double roving pre-hollow yarns provide higher strength than single roving pre-hollow yarns.

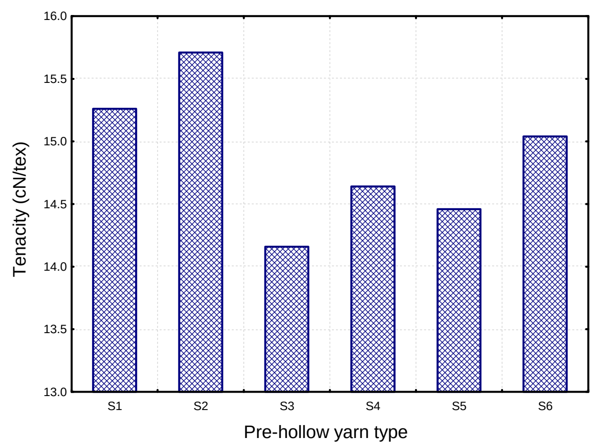

FIGURE 2. Impact of structural variation on strength of pre-hollow yarns.

As regard the elongation behavior, the doubled pre-hollow yarns show highest elongation followed by core pre-hollow yarns and blended pre-hollow yarns (*Figure 3*). The highest elongation in case of doubled pre-hollow yarns is due to spiral shape of the PVA filament with the yarn structure which was formed during yarn doubling. In core pre-hollow yarns, the PVA filament in the core of the yarn directly contribute to elongation of the yarn. In spite of higher elongation of PVA staple fibers (*Table III*), the blended pre-hollow yarns show lowest elongation because the discrete PVA staple fibers provide lower effective elongation. The breaking elongation of double roving pre-hollow yarns does not differ significantly (at 95 % confidence limit) from single roving pre-hollow yarns.

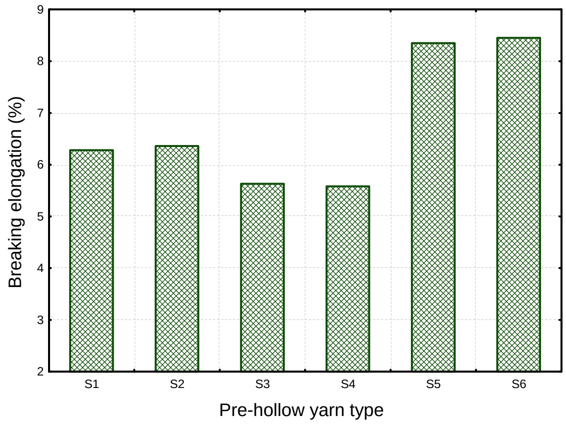

FIGURE 3. Impact of structural variation on breaking elongation of pre-hollow yarns.

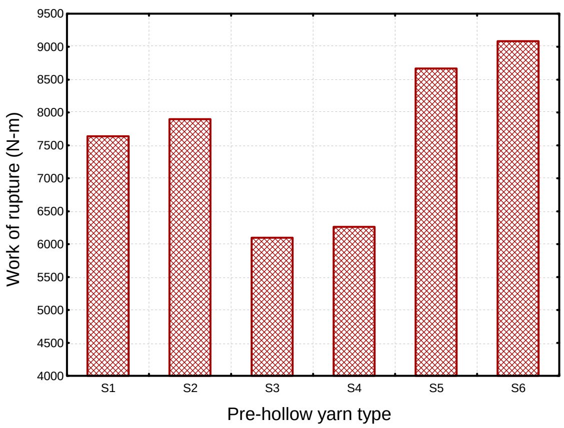

FIGURE 4. Impact of structural variation on work of rupture of the pre-hollow yarns.

The work of rupture, which indicates toughness of the material, is related to several factors such as constituent fiber's strength, elongation, fiber/filament orientation and packing. It can be seen from *Figure 4* that doubled pre-hollow yarns exhibits highest work of rupture followed by core pre-hollow yarns and blended pre-hollow yarns. The magnitude of work of rupture is influenced by yarn stress-strain characteristics; and it appears that high elongation in the case of doubled pre-hollow yarn ultimately leads to higher value of work of rupture. It has been also noticed that the double roving pre-hollow yarns show higher work of rupture than single roving pre-hollow yarns due the higher strength of double roving pre-hollow yarns.

Impact Of Pre-Hollow/Micro-Porous Yarn On Unevenness And Imperfections.

Among the pre-hollow yarns, the lowest Uster value was found in doubled pre-hollow yarn followed by blended pre-hollow yarns and core pre-hollow yarns (*Figure 5*). In doubled pre-hollow yarn, doubling process improves evenness in the yarn. In the blended pre-hollow yarns, both cotton and PVA fibers are in staple form and laid in discrete manner in the yarn which provides higher unevenness than doubled pre-hollow yarns. However maximum unevenness in case of core pre-hollow yarns may be attributed to the spinning system wherein PVA filament is introduced at the front roller nip. The positioning and presence of filament at the spinning triangle might cause disturbance in fiber movement resulting higher unevenness.

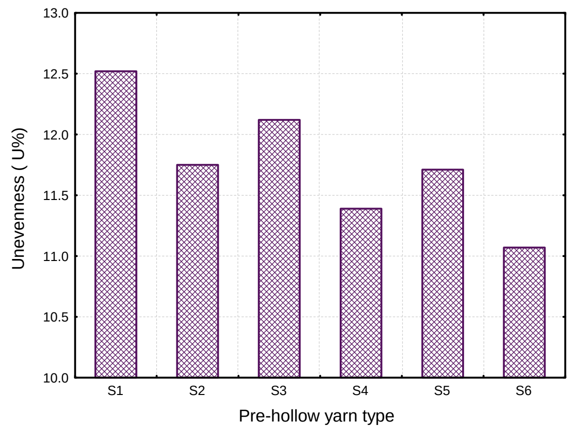

FIGURE 5. Impact of structural variation on unevenness of the pre-hollow yarns.

Similar to the above trend, the doubled pre-hollow yarns have lowest value of thick and thin places followed by blended pre-hollow yarns and core pre-hollow yarns (*Figures 6-7*). However, the blended pre-hollow yarns show the lowest number of neps, whereas the core and doubled pre-hollow yarns do not have any significant difference in their neps levels (*Figure 8*). The higher neps in the core pre-hollow yarns may be due to the presence of PVA filament at the delta zone which might disturb the flow of fiber during yarn formation. Higher values of neps in doubled pre-hollow yarns can be attributed to the additional operations such as cheese winding and doubling, which enhance the nep levels due to rubbing action of yarn with various machine parts.

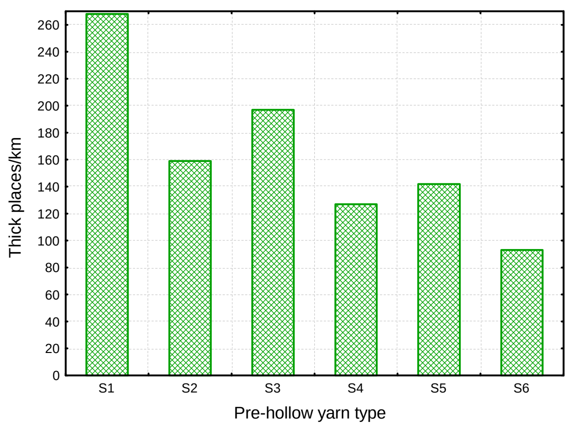

FIGURE 6. Impact of structural variation on thick places of the pre-hollow yarns.

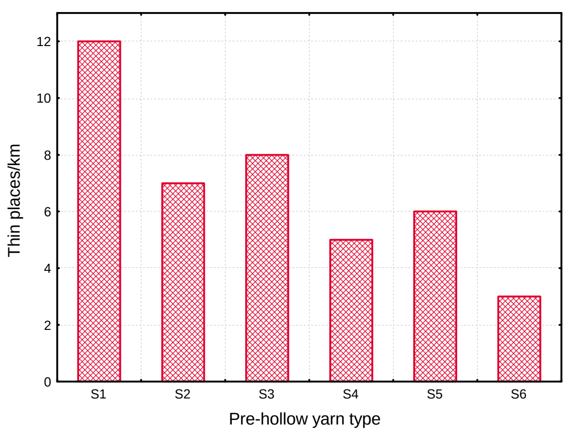

FIGURE 7. Impact of structural variation on thin places of the pre-hollow yarns.

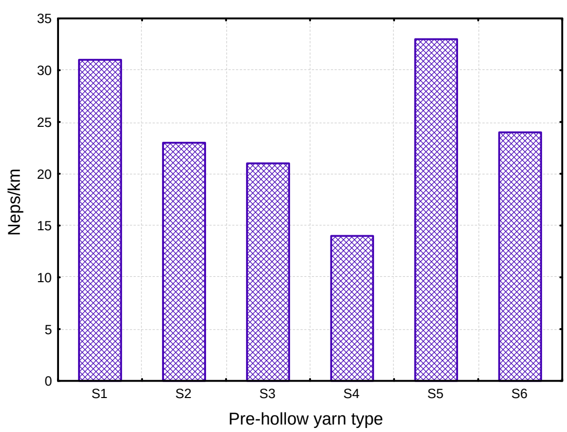

FIGURE 8. Impact of structural variation on neps of the pre-hollow yarns.

As regard total imperfections (thick places (+50%), thin places (-50%), and neps (+200%), the doubled pre-hollow yarns exhibit the lowest imperfections followed by blended pre-hollow yarns and core pre-hollow yarns (*Figure 9*). The double roving pre-hollow yarns have lower unevenness and imperfections (thick, thin and neps) than single roving pre-hollow yarns due to the effect of doubling.

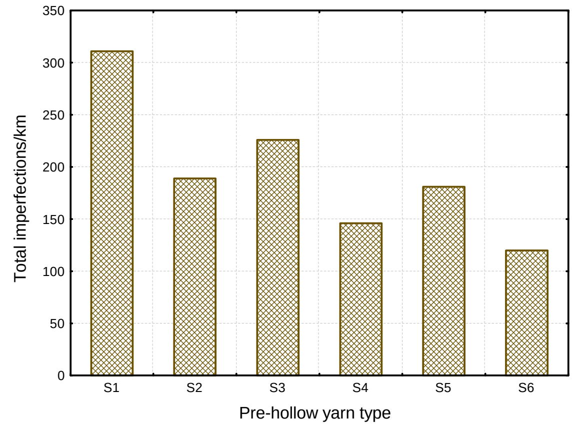

FIGURE 9. Impact of structural variation on total imperfections of the pre-hollow yarns.

Impact Of Pre-Hollow/Micro-Porous Yarn On Yarn Hairiness.

It can be seen from *Figure 10* that the core pre-hollow yarns have the lowest hairiness index followed by blended pre-hollow yarns and doubled pre-hollow yarns. The low hairiness in the core pre-hollow yarns is due to the use of filaments with cotton fibers which reduces the number of fibers in yarn cross-section hence the number of fiber ends. The blended pre-hollow yarns have higher number of fibers in yarn cross sections as the fine PVA staple fibers (*Table III*) enhance the number of fiber ends which increase the hairiness. However the highest hairiness in the doubled pre-hollow yarns may be attributed to the doubling process as it requires higher number of intermediate processes (i.e., cheese winding and doubling at TFO). Although the number of fibers in the yarn cross-section is lower than blended pre-hollow yarns but due to yarn rubbing with various parts of the machine increase the level of hairiness. The double roving pre-hollow yarns have lower hairiness than single roving pre-hollow yarns because the use of double roving is helpful for better binding the surface fibers in the body of the yarns during spinning.

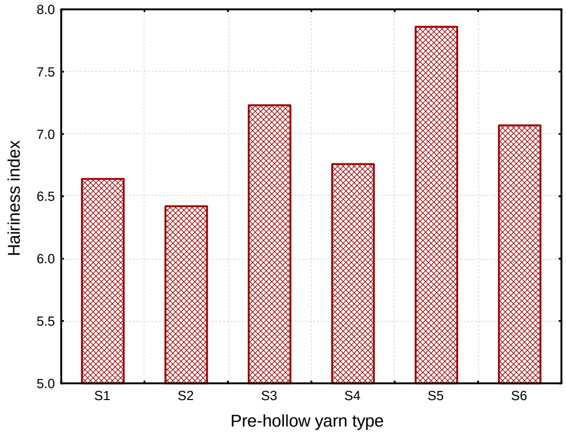

FIGURE 10. Impact of structural variation on hairiness of the pre-hollow yarns.

CONCLUSIONS

Based on the present study, the following conclusions can be drawn:

1. The core pre-hollow yarns have the highest tensile strength, followed by doubled pre-hollow yarns and blended pre-hollow yarns. While, doubled pre-hollow yarns exhibit the highest breaking elongation and work of rupture followed by core pre-hollow yarns and blended pre-hollow yarns.
2. The doubled pre-hollow yarns show the lowest unevenness, thick places, thin places and total imperfections followed by blended pre-hollow yarns and core pre-hollow yarns. However, among the pre-hollow yarns, the blended pre-hollow yarns have the lowest level of neps. The core pre-hollow yarns and doubled pre-hollow yarns do not have any substantial difference in their nep values. Core pre-hollow yarns show the lowest hairiness followed by blended pre-hollow and doubled pre-hollow yarns.
3. The benefit of using double roving during spinning is mostly found in all the pre-hollow yarns properties except in breaking elongation. There is no significant difference in yarn breaking elongation among single and double roving pre-hollow yarns.
4. On comparative assessment, the doubled pre-hollow yarn can be adjudged to be the best as it shows highest breaking energy and elongation and good strength. The yarns also have the lowest unevenness, thin places, thick places, total imperfections and acceptable hairiness. It may be added that in the extended study [9], the impact of structural variations in hollow/micoporous yarn on heat and moisture transport properties of fabrics has been investigated. However, all these studies have been conducted only on ring spun yarns and fabric; the study may also be extended to friction spun pre-hollow yarns.

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