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Influence of yarn structure produced in different spinning systems on the properties of yarn

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Abstract
Ring spinning is the most popular and universal spinning system due to its significant advantages in comparison with the new spinning systems. But the yarn properties are hampered in ring spinning system with the increase of spindle speed and spinning triangle.
It is noted that rotor-spun yarns are weaker than ring-spun yarns due to their structural difference. It has a false twist structure and its appearance, particularly with respect to wrappers.
Overall yarn properties can be improved by introducing of simple mechanical device on conventional ring spinning machine. It also ensures better yarn properties such as hairiness, strength, imperfections, elongation etc. The properties of compact spun yarn compared to conventional ring spun yarn clearly shows differences in tensile and hairiness characteristics. Intuitively one may expect migration to be less for compact yarns because of the more compact yarn formation zone; however, the experimental results clearly show that this is not true and an explanation for the higher migration in compact yarn is given. Siro yarn provides better strength than conventional ring yarn due to the special twisting of siro spinning.

Keywords: Spinning triangle, mechanical device, hairiness, strength, imperfections

Introduction
There are different spinning systems are available to convert the different textile fibers into yarn such as ring, rotor, siro, compact, friction, air-jet etc. The spinning triangle is the most troublesome and weakest zone in the yarn formation process in ring spinning as it increases end breakage, fibre loss and yarn hairiness [1]. The introduction of compact spinning has minimized the negative influence of the spinning triangle in ring spinning [2]. However this changed with the invention of compact spinning. Compact spinning, a new version of the ring spinning process produces substantially better yarn quality and structure [11]. In particular for these yarns fibre migration may be different from conventional ring spun yarns and may account for some the increase in tenacity of compact yarns [12].
Rotor yarns have a different character from ring yarns. The fibres are not so well oriented and are frequently wrapped around the yarn in “belts”. They are not as smooth and as strong as ring yarns but usually are more uniform in their properties. Rotor yarns cannot be spun as fine as ring yarns [8].
Sirospun system can be installed on ring spinning machine with low investment costs. It offers advantages such as eliminating doubling and twisting processes. It provides production increase, lower energy, air conditioning and production costs, provides savings on place and staff due to eliminating some processes [13]. In terms of fibre orientation, the fibres of plied yarn are orientated at right angles to the axis whereas fibres always have an incline to the axis of the sirospun yarn. Therefore sirospun yarn surface will closely resemble a single yarn.
The yarn structure is dependent primarily upon the raw material, spinning process, spinning unit, machine, machine settings, twist, etc. The structure can be open or closed; voluminous or compact; smooth or rough or hairy; soft or hard; round or flat; thin or thick, etc. But yarn structure is not simply appearance. It has a greater or lesser influence on: Handle, strength, elongation, insulating capacity, covering power, ability to resist wear, damage, strains, etc., resistance to abrasion, ability to accept dye, tendency towards longitudinal bunching of fibres, wearing comfort, etc [15].

Material & Methods

Raw cotton fibre has been used for producing ring yarn, rotor yarn and compact yarn. In Table 1 cotton fibre properties have been introduced. Fibre origin was Ivory coast. Fibre parameters were tested in the Mahmud Spinning Ltd. Shafipur, Kaliakoir, Gazipur. Zellweger Uster has been used for measuring the cotton fibre parameters. The raw cotton was tested under standard testing atmospheric conditions at 20 ± 2˚ c and 65% rh.

Table 1: Properties of raw cotton

Cotton fiber properties	Mean value
Nep Content/g	254
SCN Content/g	28
Micronaire value (µ/inch)	3.90
Maturity ratio	0.86
Length (mm)	28.81
Uniformity ratio	81.6
Strength (gm/Tex)	30.1
Elongation (%)	5.1
Short Fibre Index	12.3
Moisture Regain (%)	5.6
Colour grade	White

Methods

To perform this experiment a reputed spinning mill of Bangladesh was selected named as Mahmud Spinning Ltd. Shafipur, Kaliakoir (a concern of Mahmud group). Various types of yarns are produced in this spinning mill such as carded yarn, compact yarn, rotor yarn (oe yarn), slub yarn, core yarn etc. The back process (Blow room, carding) machineries of this mill are Trutzschler (Germany) brand but the drawing frame and simplex machineries are toyota. The ring frame machine is Zinser (Germany) brand and Suessen EliTe mechanical compacting device is used in this machine to produce compact yarn. In this study the raw cotton was processed from blow room to simplex at same process parameters. But to produce 7 Ne, 12 Ne, 16 Ne and 20 Ne yarn, conventional ring frame was used and to produce same count of compact yarn, conventional ring frame was used which are modified by simple mechanical compacting device (Suessen EliTe) of Spindelfabrik Suessen GmbH Germany. SIRO spun yarns are produced on a conventional ring frame. It is produced from two parallel roving, seperated at a distance, are drafted simultaneously in the drafting zone and after they emerged from the front roller nip, they converge to form a yarn by twisting. The siro yarn has been produced in Matin spinning mills ltd. Kashimpur, Gazipur. But to produce above mentioned count of rotor yarn same process parameter and machine (Blow room to Breaker drawframe) has been used. And Auto coro 360 is used for producing rotor yarn.

The following yarn count has been produced from ring-, rotor-, compact and siro spinning. And the TPI (Twist per inch) are as follows and TM was 4.0, 4.0, 4.5 and 4.5 respectively. Different spinning systems have been used for producing following 16 (sixteen) samples.

Table 2: Yarn count and TPI of ring yarn, rotor yarn, compact yarn and siro yarn

Parameter	Ring Yarn				Rotor Yarn				Compact Yarn				Siro Yarn			
Nominal Count (Ne)	7	12	16	20	7	12	16	20	7	12	16	20	7	12	16	20
TM	4	4	4.5	4.5	4	4	4.5	4.5	4	4	4.5	4.5	4	4	4.5	4.5
Calculated TPI	10.6	13.90	18	20.1	10.6	13.90	18	20.1	10.6	13.90	18	20.1	10.6	13.90	18	20.1

Following process flowchart has been carried out for the production of conventional ring yarn, compact yarn and siro yarn:
Mixing and Blending→Carding→Breaker Drawframe→Finisher Drawframe→Simplex→Ringframe→Autocone→Heat set→Ring yarn.

Table 3: Actual yarn count and TPI of ring yarn, rotor yarn, compact yarn and siro yarn

Parameter	Ring Yarn				Rotor Yarn				Compact Yarn				Siro Yarn			
Actual count (Ne)	6.86	11.65	15.5	19.4	6.91	11.75	15.7	19.6	6.86	11.65	15.5	19.4	7.41	12.57	16.24	20.56
Actual TPI	10.48	13.64	17.73	19.8	10.52	13.72	17.8	19.9	10.48	13.64	17.73	19.8	10.9	14.2	18	20.38

Results and Discussion:

Analysis of yarn structure

SEM image:

16 Ne count of ring, rotor, compact and siro yarn has been taken for SEM analysis. Figure 1, 2, 3 and 4 shows the SEM images of ring, rotor, compact and siro yarns used in the study. Figure 1 SEM image clearly shows the helix angle of twist that is responsible for holding the individual cotton fibres together. In comparison with the ring spun yarn, the difference in yarn structure is very evident in this SEM image (Figure 2) of a rotor yarn. Note particularly the wrapper fibres that are perpendicular to the yarn form. Figure 3 and 4 SEM images of compact yarn and siro yarn shows a high degree of similarity to the ring yarn structure.

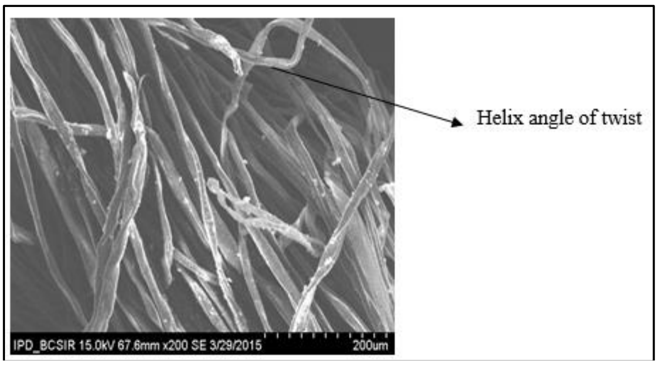

Fig 1: SEM structure of ring yarn (16 Ne)

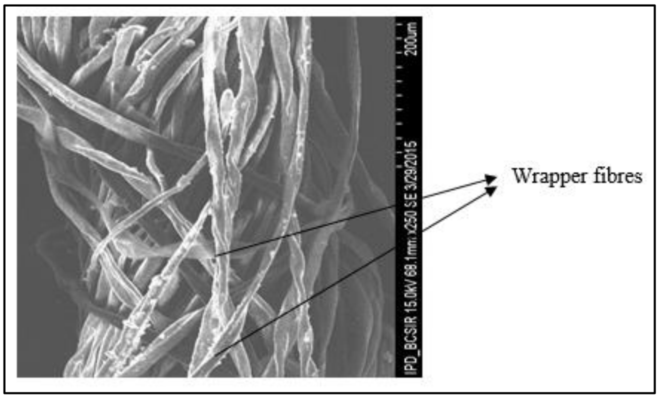

Fig 2: SEM structure of rotor yarn

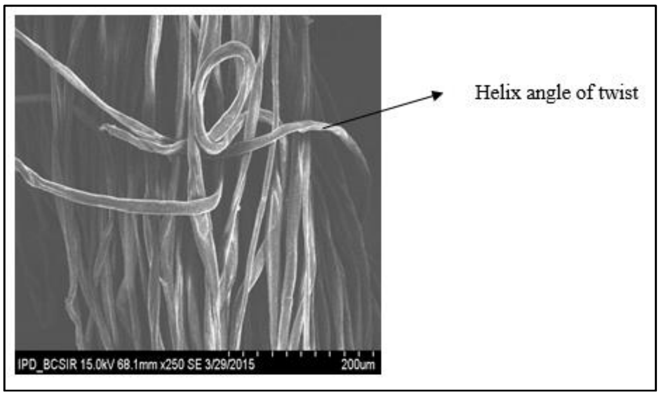

Fig 3: SEM structure of compact yarn (16 Ne)

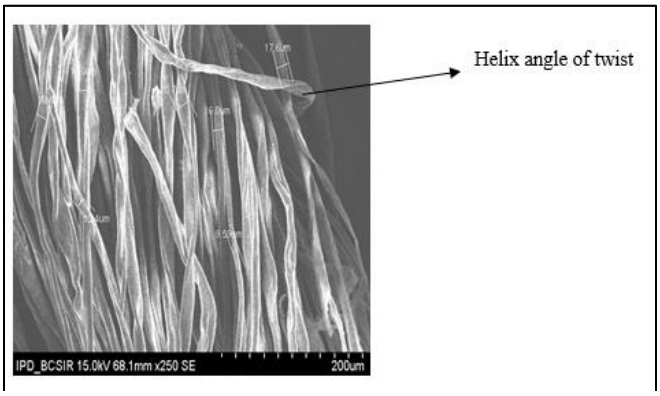

Fig 4: SEM structure of siro yarn (16 Ne)

It is clearly seen that compact yarn has the most even and close structure. Moreover, ring yarn has hairy structure in comparison with compact yarn and lastly rotor yarn has the specific wrapper structure. Compact spinning system eliminates spinning triangle with air guide element mounted on the perforated drum. Individual fibres are straightened and arranged parallel with one another by means of aerodynamic forces. Most fibres in the compact yarns are integrated into yarn body. On the other hand, rotor yarns are known as fibre bundles with wrapper fibres wrapped on parallel fibre core.

Apart from all these advantages mentioned above, the flexibility of the compact spinning system concerning raw material and yarn count is still very high. Although as mentioned above the reduced hairiness offers tremendous advantages in spinning and subsequent process steps there are also some concerns about the negative influence of the low hairiness. The reduced hairiness might lead to a more frequent traveler change since the hairs protruding from yarn body provide some type of lubricating and cooling effect on the traveler and reduce traveler wearing.

It is likely that the higher rate of migration in compact yarns could be beneficial in promoting the high tenacity values of these yarns. The concept behind the compact spinning technology is that the strand of fibers issuing from the drafting system is condensed pneumatically before twist insertion. As a result of this the spinning triangle becomes very small and almost disappears. A close look to the twist insertion mechanism in ring spinning reveals that the rate of migration depends on considerably the size of the free-length zone (spinning triangle). In ring spinning first the size of the fiber strand (roving) is reduced to the desired yarn count by drafting. At the same time the roving twist is removed to a large extent and cohesion within the fibers is mainly lost. Thus the individual fibers lie relatively far apart from each other when they reach the delivery clamping line. Twist is imparted to the fibre strand by the traveler and rises towards the clamping line, but since the width of the fiber strand on the front roller nip line is bigger than that of the yarn, twist never penetrates to the nip line and a spinning triangle forms at the exit of the front roller. When the leading end of a fibre laying outside layers reaches the tie-in point the fibre is subjected to the tensile forces and it elongates. A fibre laying in inner most layers, on the other hand, remains without tension and therefore without elongation. In fact, it might become slack depending on its layer and the slackness in the fibres of innermost layers encourages fibres to migrate during yarn formation. According to the minimum potential energy of deformation law, fibres under stress change their position with fibre under buckling strain. This does not occur till the fibre reaches the tie in point and goes under tension and attains maximum elongation. The same mechanism is present in compact yarns, but a major difference is that everything happens in a very short length. As soon as fibres in the outside layers leave the clamping line they get some tension and reach the maximum elongation and try to migrate to the inner layers. This is because only a very short length of the fibre rapidly becomes stressed (i.e. under tension). Consequently the rate of change of fibre radial position is higher in compact yarns.

The other interesting finding was the amplitude of migration (r.m.s. deviation) was higher in compact yarns, which means the migration in compact yarns is deeper compared to that in conventional ring yarns. As mentioned the diameter of compact yarns were smaller than those of conventional ring yarns. In other words the density of these yarns is higher and consequently the r.ms. deviation values are higher. The higher density would also refer higher fibre to fibre interaction and thus give higher strength.

Influence of yarn structure on yarn properties

From table-4 it can be seen that both Um% and CVm% are less in compact spun yarn and siro yarn. So it can be said that irregularity of compact spun yarn is reduced by using Suessen EliTe unit in conventional ring frame machine. It can be also observed that IPI value of compact spun yarn is less than conventional ring yarn. So imperfections are reduced by using Suessen EliTe unit.

From the following bar diagram it is found that the neps are originated more in ring yarn than rotor yarn. According to the latest Uster Statistics, the number of thick places and neps per 1000 m of yarn are up to 60% and 80% lower in rotor-spun yarn than in ring-spun yarn. However, if the number of imperfections rises above the usual level, this can be attributable to both raw material and machine-related causes. For example, immature cottons are very predisposed to produce neps during processing. However, thick places and neps also occur when spinning elements or other fibre-guiding machine components are worn or damaged. Bent, broken or notched clothing teeth on the opening roller in particular can cause steep increases in the numbers of neps and thick places. Wear or deposits in the fibre guide channel also result in fibres accumulating at these points and being fed uncontrolled to the rotor as larger or smaller clumps of fiber. Depending on their mass, these clumps result either in ends down or if spun in defects in the yarn and the final fabric. According to the above discussion it can be stated that, rotor yarn has less imperfection than ring yarn.

Table 4: Evenness parameter of ring, rotor, compact and siro yarn

Quality Parameters	Ring yarn				Rotor yarn				Compact yarn				Siro Yarn			
	7 Ne	12 Ne	16 Ne	20 Ne	7 Ne	12 Ne	16 Ne	20 Ne	7 Ne	12 Ne	16 Ne	20 Ne	7 Ne	12Ne	16 Ne	20 Ne
Um %	9.00	10.16	11.21	11.74	9.07	9.81	10.16	10.65	7.37	7.74	9.01	9.89	8.28	9.1	10.4	10.74
CVm%	11.39	12.91	14.28	14.99	11.49	12.36	12.83	13.47	9.30	9.76	11.38	12.52	10.21	11.4	12.33	13.37
Thin/km (-50%)	0	0	0	2	0	0	1	2	0	0	0	0	0	0	0	0
Thick/km (+50%)	0	48	115	209	16	11	26	45	3	2	9	35	2.8	6	20	38
Neps/km (+200%)	14	69	214	299	45	69	158	254	1	4	10	29	2.5	8	25	58
Hairiness	9.53	8.14	7.18	5.57	3.76	2.84	3.04	3.23	7.78	5.93	5.28	4.75	8.79	7.5	6.61	5.30

From the above diagram it is seen that, ring yarn is more uneven than rotor yarn. In processing in the spinning mill, the unevenness of the product increases from stage to stage after draw frame. There are two reasons for this. The number of fibres in the cross section steadily decreases. Uniform arrangement of the fibres becomes more difficult, the smaller their number. Each drafting operation increases the unevenness. Each machine in the spinning process adds a certain amount to the irregularity of finished yarn. After draw frame rotor yarn is produced directly from rotor, but in terms of ring yarn it is passed a several process & draft is also imparted. That's why ring yarn is more uneven than rotor yarn.

Tensile properties (single yarn) of ring, rotor, compact and siro yarn

From table-5 it can be seen that compact and siro spun yarn shows better single yarn strength value than conventional ring and rotor yarn.

And it is distinct that the elongation% of compact yarn is higher than conventional ring, rotor and siro yarn.

Table 5: Tensile properties of ring, rotor, compact and siro yarn

Parameters	Ring yarn				Rotor yarn				Compact yarn					Siro yarn		
Count (Ne)	7	12	16	20	7	12	16	20	7	12	16	20	7	12	16	20
Max.Force (cN)	1316	759	550	482	1078	639	478	365	1481	1063	602	530	1430	950	580	510
Extension %	7.87	6.57	5.61	6.57	8.15	6.87	7.18	6.54	9.91	8.92	7.48	7.10	9.40	8.10	6.70	6.96
Time to Break (s)	9.5	7.7	6.3	7.3	8.8	7.5	8	7.1	10.5	9.6	8.2	7.2	9.80	8.6	7.3	6.7

Compact yarn and Siro yarn are claimed to be stronger and less hairy due to the improved fibre binding, and have better yarn elongation, work capacity, yarn irregularity and IPI values compared with conventional ring yarns. The difference in yarn strength, elongation and hairiness values in comparison with conventional ring yarn is higher with carded yarns. As a result, these yarns have tremendous potential to offer several advantages both in spinning and in all subsequent processing stages compared to conventional ring yarns. The ends-down rate in spinning can be reduced, which improves machine efficiency. It is possible to use low quality cotton while maintaining yarn strength equal to the conventional ring spun yarn with the same twist level. The fibre loss and fly contamination is reduced. A smoother, combed–like appearance can be achieved with carded cotton due to less hair. In high-speed winding occurrence of hairiness, neps and fibre dust are reduced due to the higher resistance to axial displacement. In certain applications doubled yarns might be replaced by single compact yarns. In weaving preparation owing to the lower hairiness and higher tenacity of compact yarns, the ends-down rate in beaming is reduced. In sizing the amount of sizing agent can be reduced due to the low hairiness while the running behavior of weaving machines is the same or even better. This results in cost saving in sizing as well as desizing. Due to the better work capacity of compact yarns, in weaving ends down rate can decrease in the warp and in the weft, which in turn will increase the efficiency and reduce the weaving cost. In singeing owing to reduced yarn hairiness, singeing can sometimes be left out, or it can be carried out at a higher speed. In knitting increased yarn strength and reduced formation of fly allow to obtain higher machine efficiency. Reduction in ends-down rate results in fewer interruptions and less fabric faults. In some cases usual waxing in knitting might be omitted. It is possible to produce woven or knitted fabrics with a great strength, high luster and clear structures.

Rotor-spun yarn is superior to ring-spun yarn in terms of elongation at break (%), in contrast to yarn tenacity. Based on Uster Statistics it is apparent that the elongation at break of rotor-spun yarns is higher than that of comparable ring-spun yarns, albeit only marginally in some cases. This is especially positively noticeable in the working capacity of rotor-spun yarn, in that the differences relative to ring-spun yarn are smaller than for count related yarn tenacity.

Ring-spun yarn contains envelope twist, twisting in the fibres from outside to inwards, whereas rotor-spun yarn in contrast has core twist, twisting in the fibres from the inside to outwards. Rotor spun yarn is therefore more voluminous, more open & rougher than ring spun yarn. The fibres in the envelope layer of a rotor-spun yarn can partly escape the twisting action during spinning & therefore take up turns of twist. They thus contribute relatively little to yarn strength & can more easily be rubbed together axially to form slubs etc. Furthermore, the fibres in a rotor-spun yarn are less parallel than those in a ring-spun yarn. The core twist structure & the lower degree of parallelism are the causes of lower strength of rotor spun yarn.

Conclusion

The hairiness tests revealed an essential difference between the ring and the rotor yarn. Rotor yarn is less hairy compared to the conventional ring yarn. Unevenness of mass & their corresponding co-efficient of variation are higher for ring yarn with count than that of rotor yarn. Moreover, Index of irregularity also shows the same trend. Though thick place/km (+50%), neps/km (+200%) are higher in ring yarn, thin place/km (-50%) in ring yarn are less than that of rotor yarn.

The results show that the tenacity of the ring yarns expresses greater value than rotor spun yarn and the elongation% of the ring yarns has a significantly lower value than that of rotor yarn.

Compact yarns are claimed to be stronger and less hairy due to the improved fibre binding, and have better yarn elongation, work capacity, yarn irregularity and IPI values compared with conventional ring yarns.

Due to the special twisting of Siro spinning, more hairiness is twisted into the yarns. That is why siro yarn gives better strength than conventional ring yarn.

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