Comparing Quality Parameters of Yarn Produced by Ring, Rotor, and Compact Spinning System

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Abstract

The end use of a garment depends on the properties of a fabric. A fabric property depends on the properties of the constituent yarn. With the diversification of the market, spinners are forced to produce quality yarn. For this reason, conventional hand spinning has been converted to modern system gradually. Ring spinning, Rotor spinning, and compact spinning are widely used spinning system. Ring spinning is the universal spinning system covering the largest area of yarn production. The yarn produced by Ring, Compact, and rotor spinning systems belongs to different structures and properties. Yarn produced Ne 22's, 100% cotton yarn from the above systems, and their properties were tested by UT5 and Titan Universal strength tester. However, this paper focuses on comparing the yarn properties (U%, CmV%, Imperfection, Hairiness, Strength, and elongation) of ring, compact, and rotor spun yarn. Also, it has been observed that yarn produced by compact spinning system revealed highest strength and elongation, least hairiness, and mass irregularity than the other two spinning systems. In addition, it has been observed that rotor spun yarn displayed less mass irregularity than ring spun yarn.

Keywords: Yarn, Textile, Ring Spinning, Compact spinning, Rotor spinning

1. Introduction

According to Textile Institute, “a product of substantial length and small cross-section consisting of fibers and/or filaments with or without twist is called yarn.” A staple spun yarn is a linear assembly of fibers where the individual fibers are small in cross-section and short in length (usually a thousand times longer than diameter). It is held together usually by the insertion of twist to form a continuous strand. It is used for interlacing or inter-looping in processes such as weaving, knitting, and sewing. Spinning is an ancient textile art in which plant, animal, or synthetic fibers are drawn out and twisted together to form yarn. For thousands of years, fiber was spun by hand using simple tools, the spindle and distaff. It is only in the High Middle Ages did the spinning wheel increase the output of individual spinners, and mass-production only arose in the 18th century with the beginning of the Industrial Revolution (Elizabeth & Barber, 1995).

More so, spinning by hand has been in existence for over 10,000 years, but the spinning wheel did not become widely used until the middle ages. Hand spindles had been the primary method of spinning for all thread and yarn production for over 9,000 years. In some parts of the world, hand spinning is still a widely used method of yarn production.

In the most primitive type of spinning, tufts of animal hair or plant fiber are rolled down the thigh with the hand and additional tufts are added as needed until the desired length of spun fiber is achieved. Later, the fiber is fastened to a stone which is twirled round until the yarn is sufficiently twisted. After then, it is wound upon the stone and the process is repeated over and over again.

The next method of spinning yarn is with the spindle, a straight stick that is eight to twelve inches long on which the yarn is wound after twisting. At first, the stick had a cleft or split at the top in which the thread was fixed. Later, a hook of bone was added to the upper end. The bunch of wool or plant fibers is held in the left hand. With the right hand, the fibers are drawn out several inches and the end is fastened securely in the slit or hook on the top of the spindle. Furthermore, a whirling motion is given to the spindle on the thigh or any convenient part of the body. The twisted yarn is then wound on to the upper part of the spindle. Another bunch of fibers is drawn out, the spindle is given another twirl, and the yarn is wound on the spindle and so on.

In medieval times, poor families had a need for yarn to make their own clothes, most especially girls and unmarried women. They would keep themselves busy spinning and the spinsters became synonymous with unmarried women.

Most authors agree that the practice of spinning fibers to form thread and yarns has been in existence for over 10,000 years. The spinning wheel, which is the tool most commonly associated with the art of spinning, was not introduced to Europe until in the late middle ages/early Renaissance. Thus, the drop spindle was the primary spinning tool used to spin all the threads for clothing and fabrics from Egyptian mummy wrappings to tapestries, and even the ropes and sails for ships, for almost 9,000 years.

The oldest actual "tool" used for spinning threads were common rocks. As the first spinners were nomadic tribes from pre-agrarian societies, it is unlikely that they would have carried rocks from camp to camp and would use stones found at each new site for their spinning. A leader thread would be spun by twisting the fibers between the fingers to a desired length. After then, the resulting thread would be tied around the rock. The rock could then be rotated to spin the fibers as they are played out between the fingers. However, spinning with rocks is still done in remote parts of Asia among the nomadic tribes.

Medieval spinners often used a distaff (a stick with a fork or ornate comb on the tip used to hold long-staple fibers while spinning) to hold their fibers while they are spinning with a spindle. This stick was usually held under the left arm according to most pictures – meaning that the spinners would have had to set their spindles in motion with their right hand, and also feed their fiber with the right hand (http://textilelearner.blogspot.com).

Currently, yarn is produced by using different methods. Amongst them, ring, Compact, and rotor spinning are mostly used. Although ring spinning machine is vastly used, it has some limitations such as unevenness and more hairiness that bounds the spinners to choose alternative spinning systems. Rotor was selected to produce more even yarn, and compact spinning gives both even and less hairy yarn. From the multitude of spinning processes developed in recent decades, ring, compact, and rotor spinning have established themselves successfully in the market.

In this study, the various yarn properties like U%, CVm%, Imperfection Index (thick/km, thin/km, neps/km), hairiness, strength and elongation of ring, compact, and rotor yarn are analyzed.

2. Definition of Terms

Spinning: The spinning process basically consists of three stages:

i. Reduction of yarn strand thickness from the supply roving (or sliver) to the required yarn count.
ii. The prevention of further fiber slippage-usually by twist insertion.
iii. Winding on to package which is convenient for handling and which protects the yarn.

Yarn Evenness/Unevenness: Non-uniformity in variety of properties exists in yarns. There can be variation twist, bulk, strength, elongation, fineness, etc. Yarn evenness deals with the variation in yarn fineness. This is the property commonly measured as the variation in mass per unit length along the yarn. It is a basic and important part since it can influence so many other properties of the yarn and of fabric made from it. However, such variations are inevitable because they arise from the fundamental nature of textile fibres and from their resulting arrangement.

U%: The average value of all the deviations from the mean which is expressed as a percentage of the overall mean is called percentage of mean deviation (PMD). This is termed U% by the uster.

CVm%: The coefficient of mass variation CVm% is the ratio of standard deviation of mass variation divided by average mass variation. The higher the CV value, the more irregular the yarn. A coefficient of variation (CV) is a statistical measure of the dispersion of data points in a data series around the mean. The coefficient of variation represents the ratio of the standard deviation to the mean. It is a useful statistic for comparing the degree of variation from one data series to another, even if the means are drastically different from one another.

These are the mass variation calculations along yarn length. Testing machine measures the mass of each centimeter of yarn and U% and CVm% values are calculated using the following formula below and these are used to determine how uniform or even the yarn is.

i. $$U = \frac{1}{\bar{x}} \frac{\sum |x_i - \bar{x}|}{n} \times 100\%$$

ii. $$CV\% = \frac{1}{\bar{x}} \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} \times 100\%$$

C.V.=1.25 P.M.D.

+50% Thick place, –50% Thin place, +200% Neps: The frequently occurring yarn faults are thin place, thick place, and neps. These faults are defined as those deviating from the average value by a pre-determined reference value. Generally these imperfections are measured at sensitivity level of –50, 3, 3. With reference to these levels, a thin place is a region where the yarn cross-section is less than half the cross-sectional size of the average portion. A thick place similarly is that region where the cross-sectional size is bigger by 50% of the average size. A small but sharp thick place is defined as neps. These are the number of faults within one kilometer length, where mass values are taken from each centimeter of length. We considered (+50%) thick place, (-50%) thin place, and (+200%) neps where these values mean average value of mass plus the mentioned percentage of that mass.

Hairiness: Hairiness is characterized by the quantity of freely moving fiber ends or fiber loops projecting from yarn surface. In terms of measurement, hairiness corresponds to the total length of protruding fibers in one unit length of one centimeter.

3. Literature Review

For over seven thousand years ago, spinning was already well established as a domestic craft. At that time and until the early Middle Ages, spinning was an incredibly slow and tedious task. Throughout this period, the spinning of one ounces of cotton into a yarn is suitable for the weaving of what we would now regard as a fairly heavy apparel fabric. Therefore, this would keep a spinner busy for several weeks. A revolutionary change had come in spinning when ring spinning machine was invented by an American named Thorp in 1828, and Jenk – another American – added the traveler rotating around the ring in 1830. In the intervening period of more than 170 years, the ring spinning machine has undergone considerable modification in detail, but the basic concept has remained the same. For many years, any noteworthy further development hardly seemed possible, yet a significant process of evolution took place during this time. The productivity of the ring spinning machine has increased by 40% since the late 1970s. This has been achieved by using smaller ring and cop formats to introduce piecing in the winding department, and this has led to substantial improvements in rings and traveler. Commercial rotor spinning began in 1967 in Czechoslovakia. Furthermore, rotor spinning has been characterized from the outset by incomparably higher production potential than ring spinning and this potential has been steadily increased by the continuous rise in rotor and winding speeds. Rotor-spun yarns have therefore always been successful where they could be manufactured more cheaply than ring-spun yarns and have proved suitable for the range of application in question. Barber and Elizabeth discussed ancient hand spinning, cloth, and society of early times that led to the invention of industrial spinning (Elizabeth & Barber, 1995). Sevda and Huseyin worked on conventional ring, mechanical compact, and pneumatic compact yarn properties. They compared these systems for different count also (Sevda Altas & Hüseyin Kadoğlu, 2012). Momir and Zoran worked on Conventional ring and compact yarn. They have analysed and compared the physical, mechanical, and morphological properties of conventional and compact yarns spun at the same technological and kinematical parameters from the same cotton, cotton/PES, and cotton/viscose roving (Momir Nicolic, Zoran, Franc, & Andrek, 2003). Tadeusz and Danuta presented an analysis and comparison of the parameters of cotton yarn spun on the Fiomax EliTe compact spinning frame from Suessen, and on the PJ 34 conventional ring spinning frame (Tadeusz & Danuta, 2004).

Ring spinning accounts for about 75% of global long and short staple yarn production.The main reason attributed for the success of ring spinning over other spinning system is the superior quality, notable strength, and evenness of ring-spun yarns over those produced by other systems (Gordon & Hsieh, 2007). Other spinning technologies being developed are higher in productivity but are lacking in many aspects of the yarn’s desirable characteristics. Ring spinning remains a popular spinning system due to its versatility in terms of yarn count, fiber type, superior quality, and yarn characteristics as a result of good fiber control and orientation.The major reason that limits the twisting rate is the heat generation due to traveler friction with the stationary ring.

Additionally, the causes of more yarn unevenness in ring spun yarn is due to uncontrolled movement of short fiber in the drafting zone. The fibers in the sliver are not perfectly straight and parallel. When this sliver is passed through drawing rollers, the short fiber causes a succession of an alternate thick and thin place. This is due to their irregular movement through the passage.

The current share of rotor spun yarn is around 20% of total staple fiber yarn production and it is increasing steadily. Open end spinning has the following major advantages compared with ring spinning.

- Elimination of roving stage
- High productivity and low energy consumption
- Large package size

Open end spinning system are designed to overcome some of the problems associated with ring spinning. Twist insertion in ring spinning requires the rotation of the whole yarn package. In open end spinning, only one end of the yarn is rotated to insert twist, which consumes much less energy than rotating a yarn package. Rotor spinning has certain disadvantages too. The main disadvantages of rotor-spun yarn compared to ring-spun yarns are their lower strength and the presence of wraper fibers which adversely affects their handle (Gowda, 2003).

Opening roller of rotor M/C is much more an intensive fiber individualization than roller drafting. This is because roller drafting is restricted by the mechanical draft and there is the inability of drafting rollers to run at high speed. Action of opening roller is similar to that of licker-in card but is more intense because of higher order of speed. Thus, rotor yarn shows better even yarn than ring spun yarn due to improved back doubling.

The yarn produced in ring spinning has good strength and unique structure, but the integration of many fibers is poor and such fibers tend to generate hairiness that does not contribute to yarn strength. Compact spinning offered the potential to create near perfect yarn structure by applying air suction to condense the fiber stream in the main drafting zone, thereby virtually eliminating the spinning triangle (Gowda, 2003).

In conventional ring spinning, fibres in the selvedge of strand emerging from front roller nip do not get fully integrated into the yarn because of the restriction to twist flow by the spinning triangle. These fibres show up partly as protruding hairs or as wild fibres.

The spinning triangle exists because of higher width of the strand as compared to final yarn diameter. Further, the fibres are tensioned to varying extent depending on their position in the spinning triangle. As a result, full realization of fibre strength is not achieved in the yarn.

Furthermore, the hairiness gives a rough feel to the yarn. Variation in hairiness is a source of weft bars and warp way streaks in the fabric. Long protruding hairs from the yarn contribute to multiple breaks in weaving and fabric faults like stitches and floats.

This problem is however solved by applying the compact spinning systems that increases yarn quality. It is carried out by means of narrowing and decreasing the width of the band of fibres. This comes out from the drawing apparatus before it is twisted into yarn, and by the elimination of the spinning triangle. It can be used for spinning both short and long staple yarns.

The compact spinning process produces a new yarn structure, which approaches the ideal staple fibre yarn construction even more closely. This has positive effects on raw material use, productivity, downstream processing, and on the appearance of the product (https://nptel.ac.in/courses/116102038/29).

The purpose of the genuine compact spinning process is to arrange the fibers in a completely parallel and close position before twist is imparted. Compacting takes place in the compacting zone following the main drafting zone of the drafting system.With the invention of compact spinning for the first time, a new spinning process was not aimed at exclusively achieving higher production but at better yarn utilization and quality. Compact spinning system were first presented at the Internatioal Textile Machine Fair ITMA’99. Presently, Rieter Sussen and Zinser company have produced compact ring spinning frames.

Consequently, yarn manufactured by means of the compact spinning system compared with classical yarn is characterized by the following qualities.

- Better smoothness
- Higher lusture
- Abrasion fastness better by 40%-50%
- Hairiness lower by 20%-30% as measured with the use of Uster apparatus
- Hairiness lower by 60% as measured with the use of the Zweigle apparatus
- Tenacity and elongation at break higher by 8%-15%
- Smaller mass irregularity.

4. Principle of Spinning

4.1 Basic Principle of Ring Spinning

The roving bobbins (**1**) are inserted in holders (**3**) on the creel (Figure 1). Guide bars (**4**) guide the roving's (**2**) into the drafting system (**5**), where they are drawn to their final count.

After the resulting thin ribbon of fibers (**6**) leaves the delivery roller, the twist necessary for imparting strength is provided by spindle (**8**) rotating at high speed. In the process, each rotation of the traveler on the spinning ring (**10**) produces a twist in the yarn. Ring traveler (**9**) is also necessary for taking up this yarn onto a tube mounted on the spindle. This traveler – which is a remnant of the flyer on the roving frame – moves on a guide rail around the spindle, the so-called ring (**10**). The ring traveler has no drive of its own; it is dragged with spindle (**8**) via the yarn attached to it.

Twist is imparted by the rotation of spindle and traveler. Then the twisted yarn is wound on a bobbin mounted to spindle.

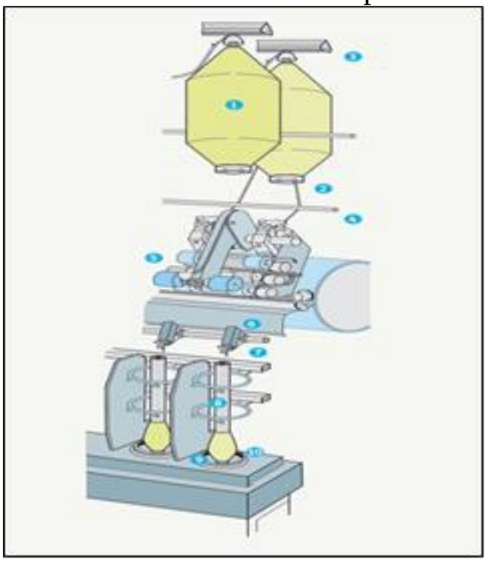


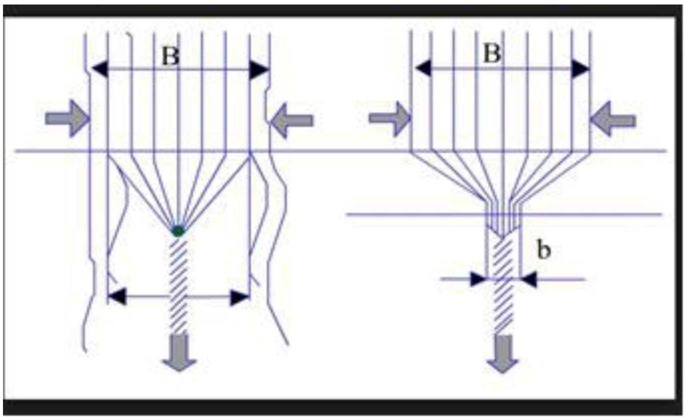
Figure 1. Principle of ring spinning

4.2 Basic Principle of Compact Spinning System

In compact spinning, the width of the fibre flowing ribbon is reduced and becomes almost equal to that of the spinning triangle. The compact spun yarn technology allows more parallelization and condensation of the fibre after the main draft. Thus, the spinning triangle is reduced to a minimum; and therefore, most of the fibres are incorporated in the yarn body (Figure 3). This resulted in exceptionally low hairiness combined with higher yarn tenacity and elongation. These are unique characteristics of the compact yarn.

In the Elite system of Sussen, the condensing zone follows the front drafting roller and it consists of profile tube with suction slot which is placed at certain angle to the flow of fibers, perforated lattice apron and delivery top roller. The lattice apron is driven by delivery top roller, which is then driven by gear drive from the front top roller of the drafting system. The suction under the tube creates the air currents through slot and lattice apron which are responsible for condensing and perfect parallelization of fiber strand. The suction air pressure, size of slot, speed of apron, and number of holds in the lattice apron has an influence on condensing action.

Figure 2. Compacting zone (Suessen Elite)



(a) (b)

Figure 3. Spinning triangle of (a) Ring spinning (b) Compact spinning

4.3 Basic Principle of Rotor Spinning

The rotor spinning machine is unlike any other machine in the short staple spinning mill. It has a range of tasks it has to perform, namely all the basic operations (Figure 4).

- **Sliver Feed:** A card or draw frame sliver is fed through a sliver guide via a feed roller and feed table to a rapidly rotating opening roller.

- **Sliver Opening:** The rotating teeth of the opening roller combs out the individual fibers from the sliver clamped between feed table and feed roller. After leaving the rotating opening roller, the fibers are fed to the fiber channel.
- **Fiber Transport to the Rotor:** Centrifugal forces and a vacuum in the rotor housing causes the fibers to disengage at a certain point from the opening roller and to move via the fiber channel to the inside wall of the rotor.
- **Fiber Collection in the Rotor Groove:** The centrifugal forces in the rapidly rotating rotor cause the fibers to move from the conical rotor wall towards the rotor groove and it is collected there to form a fiber ring.
- **Yarn Formation:** When a spun yarn end emerges from the draw-off nozzle into the rotor groove, it receives twist from the rotation of the rotor outside the nozzle, which then continues in the yarn into the interior of the rotor. The yarn end rotates around its axis and continuously twists-in the fibers deposited in the rotor groove, assisted by the nozzle, which acts as a twist retaining element.

Yarn Take-Off, Winding: The yarn formed in the rotor is continuously taken off by the delivery shaft and the pressure roller through the nozzle and the draw-off tube and wound onto a cross- wound package. Between takeoff and package, several sensors control yarn movement as well as the quality of the yarn. Yarn clearing is also initiated if any pre-selected values are exceeded.

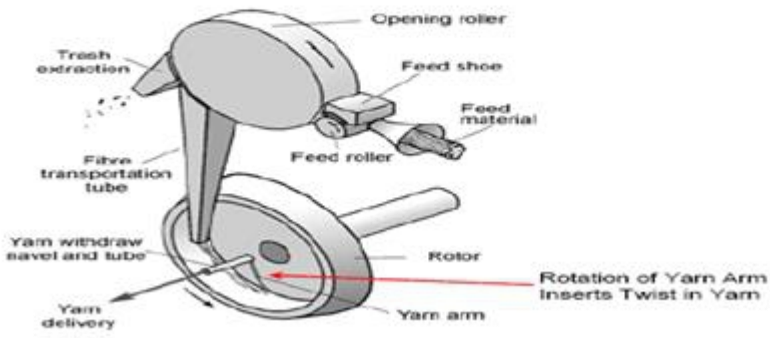
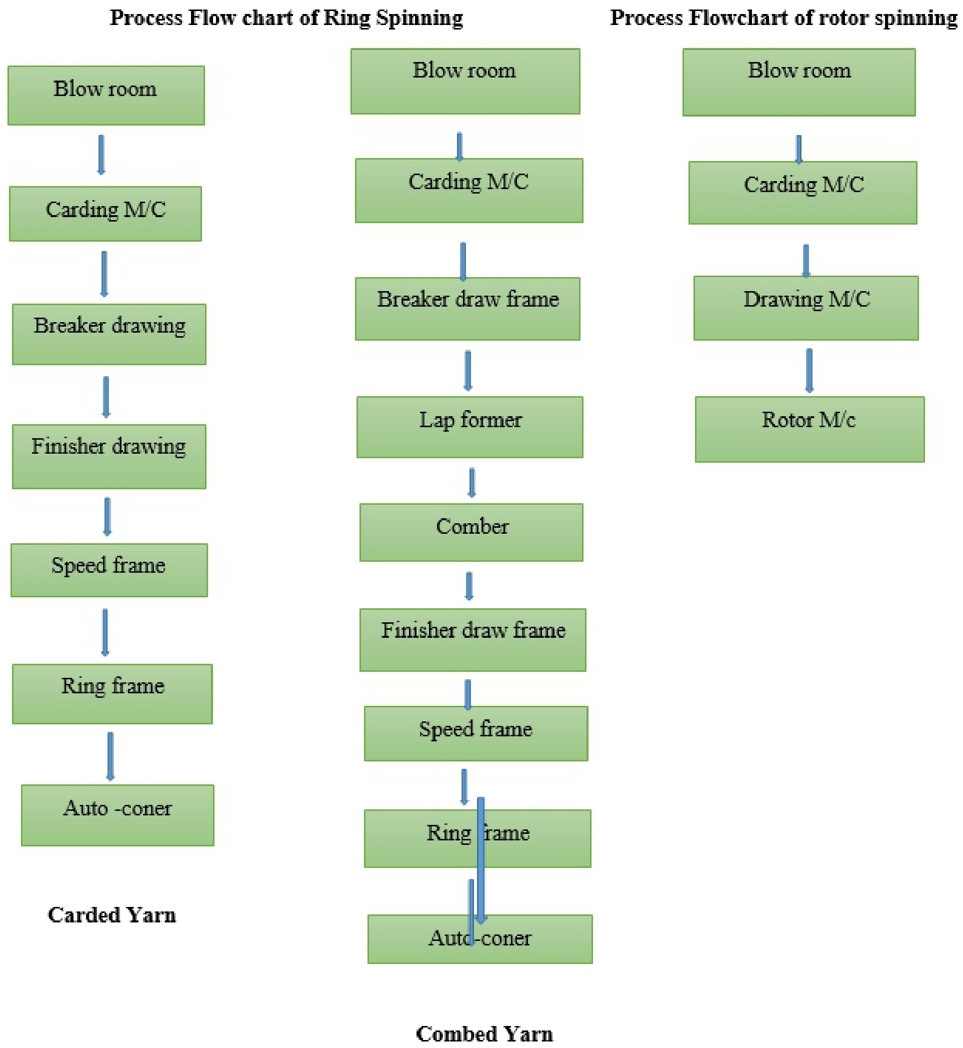


Figure 4. Principle of Rotor spinning



5. Methodology

There are two types of paper work namely; survey type and experimental type. For this paper work, we have used an exploratory (Experimental Type) research. The steps we have taken for this paper work are given below:

- Yarn production
- Sample preparation
- Test

Ne 22 yarns are produced by Ring, Compact, and rotor machines from same raw materials. Produced yarns are then tested by Uster Tester 5 and Titan-Universal strength tester machines. All the production and experiment are done in Youth Spinning Mills Ltd, a leading Textile mill in Bangladesh. Also, a clear comparison is shown among different parameters like U%, CV%, Imperfection Index (thick/km, thin/km, neps/km), hairiness, strength and elongation of ring, compact, and rotor yarn.

Table 1. Process Parameters for Ne 22 ring (carded), Rotor, and Compact Spun Yarn

Parameters	Ring Spinning	Rotor spinning	Compact spinning
Fiber type	**100%cotton, CIS, Uzbekistan**	**100%cotton, CIS, Uzbekistan**	**100%cotton, CIS, Uzbekistan**
staple length(mm)	**28**	**21**	**28**
Fiber fineness (Mic)	**4.1**	**4.1**	**4.1**
Drawn sliver hank grains/yd	**70**	**70**	**70**
Roving hank	**Ne 0.78**	**-**	**0.78**
TM (Twist Multiplier)	**4.7**	**4.7**	
Yarn count	**Ne 22**	**Ne 22**	**Ne 22**

Machines Description

a) Machineries for Yarn Production

Ring Spinning Machine

Manufacturer: Rieter
Model: G 32
Origin: Switzerland
Number of Spindle: 1,008
Spindle speed: 14,500

Rotor Spinning Machine

Manufacturer: Rieter
Model: R 66
Origin: Switzerland
Number of Head: 312
Rotor R.P.M.: 125,000

Compact Spinning M/C

Sussen Elite was attached as an extra arrangement to the Rieter Ring spinning frame G 32.

Machineries for Yarn Testing

- Uster Tester 5
- Wrap reel
- Wrap block
- Lea strength tester
- Electrical balance

6. Result and Discussion

Table 2. Experimental Value of various Parameters

Properties		Ring Spun Yarn	Rotor Spun Yarn	Compact Spun Yarn
Mass Variation	U%	10.26	8.57	7.82
	CVm%	12.83	10.8	9.78
Imperfection	Thin(-50%)/km	3.0	6.3	2.5
	Thick(+50%)/km	98.0	32.8	28.4
	Neps(+200%)/km(Ring); (+280%)/km(Rotor)	135.6	24.7	40.6
	IPI	236.6	63.8	71.5
Hairiness	H	5.37	4.75	3.25
	SDh (standard deviation of Hairiness)	1.15	1.19	1.05
Strength (CSP)		2300	1700	2460
Elongation%		5.55	5.93	6.10

In Table 2, U% of ring, rotor, and compact spun yarn were 10.26, 8.57 and 7.82 respectively whereas CVm% of those spinning system were 12.83, 10.8 and 9.78 respectively. Evenness of compact yarn revealed the highest. Rotor spun yarn displayed higher evenness than ring spun yarn. Mass variation of rotor spun yarn was 16% less, and compact spun was 24% less than ring spun yarn. Roller drafting system was liable to produce more uneven yarn in ring spinning and less irregularity in rotor spun yarn as a result of positive influence of back doubling. Compact spinning offered near perfect yarn structure by applying air suction to condense the fiber stream.

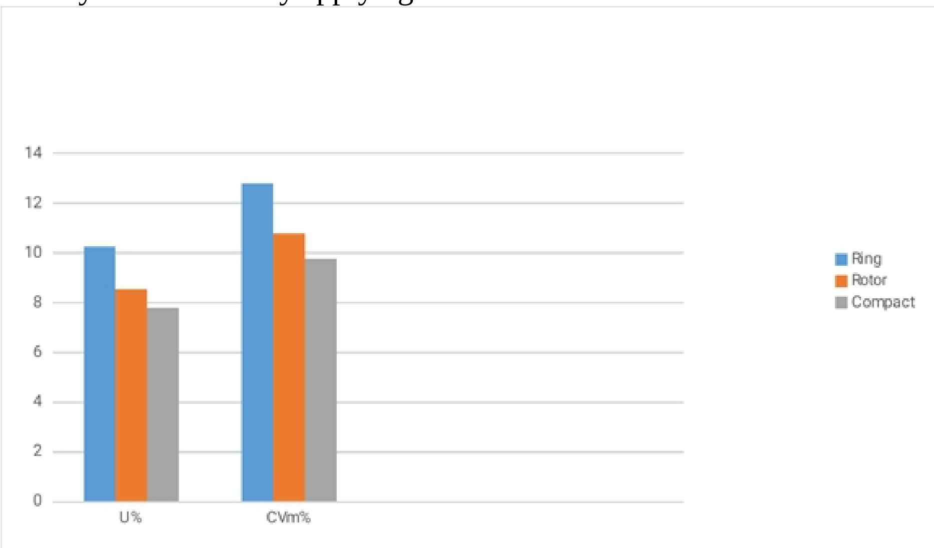


Figure 5. Comparison of mass variation among ring, rotor and compact yarn (From Table 2)

From Figure 6, Imperfection index (IPI) of ring, rotor, and compact spun yarn were displayed 135.6, 24.7 and 40.6 respectively. Rotor spun yarn contained least imperfection over the other two spinning systems. IPI of compact yarn was between ring and rotor yarn. IPI of Rotor spun yarn displayed about 27% and Compact spun yarn displayed about 30% more than Ring spun yarn.

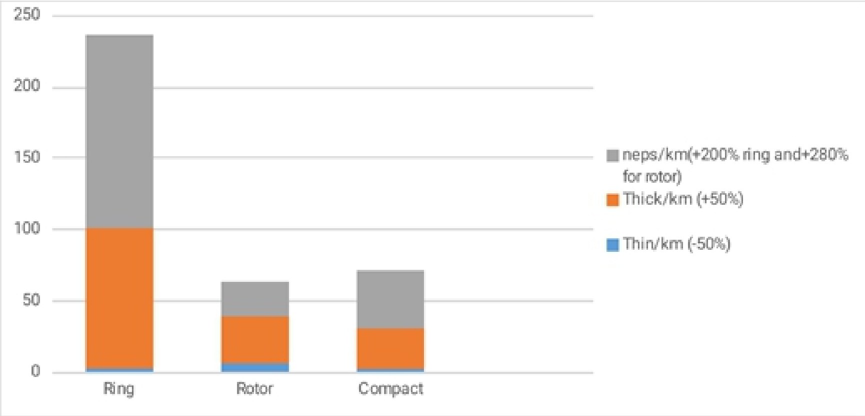


Figure 6. Comparison of imperfection among ring rotor and compact yarn (From Table 2)

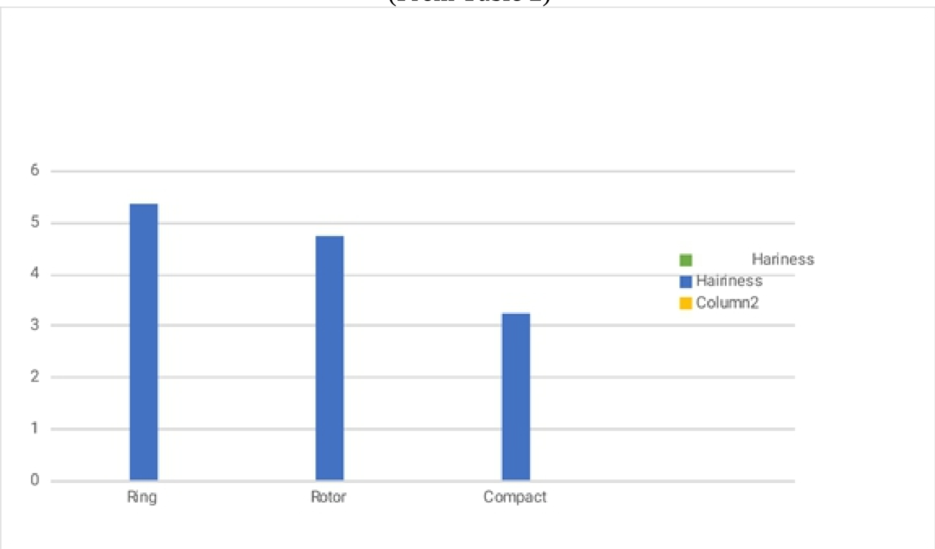


Figure 7. Comparison of Hairiness mass variation among ring, rotor and compact yarn (From Table 2)

In Figure 7, Hairiness of ring, rotor, and compact yarn displayed 5.37, 4.75 and 3.25 respectively. Hairiness of Rotor spun yarn showed about 12% less and for Compact spun yarn about 40% less than Ring spun yarn. The higher hairiness of ring-spun yarns is caused by the uncontrolled passage of edge fibers in roller drafting and friction occurred in balloon control ring. In rotor spinning, the wrapping fibers wound crosswise around the yarn help to "bind-in" loose fiber ends. In the compact yarn, least hairiness was displayed because of the reduced spinning triangle. However, Figure 3 displayed the spinning triangle of ring spinning and compact spinning. Due to larger spinning triangle of ring spinning, all fibers could not take part in the construction of yarn body. It was minimized in the compact spinning that maximum fiber took part in the construction of yarn body. As a result, much protruding fiber or Hairiness occurred from the yarn surface in the ring spun yarn.

Figure 8 shows the Strength (CSP) of ring, rotor, and compact spun yarn at 2,300, 1,700 and 2,460 respectively. Strength of Rotor spun yarn was about 27% less and Compact yarn was about 6% more than Ring spun yarn. Strength of compact spun yarn was the highest, whereas strength of rotor yarn was lower than ring yarn. In compact spinning system, protruding fiber was less. Due to reduced spinning triangle, maximum fiber was incorporated in the construction of yarn body. Therefore, the strength of rotor spun yarn was lower due to its core twist structure.

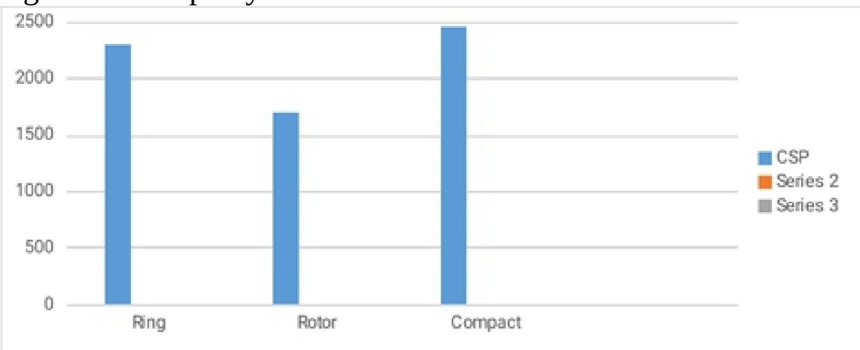


Figure 8. Comparison of CSP mass variation among ring, rotor, and compact yarn

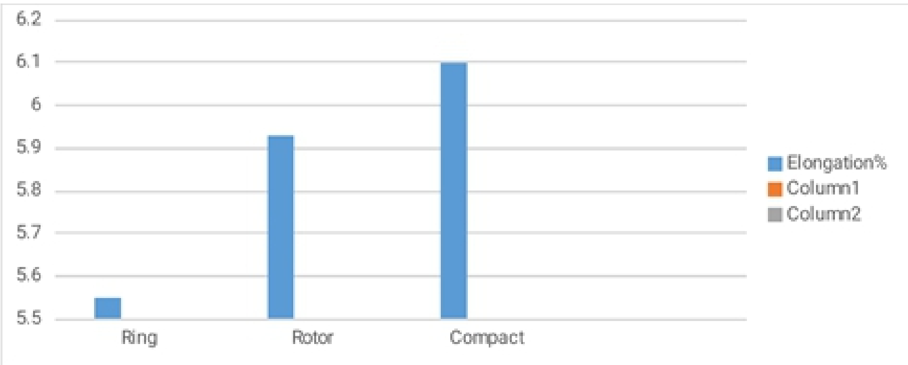


Figure 9. Comparison of elongation% among ring, rotor, and compact yarn

In Figure 9, Elongation % of ring, rotor, and compact yarn were displayed at 5.55, 5.93 and 6.10 respectively. Compact yarn and rotor yarn showed 10% and 7% more elongation than ring spun yarn. Ring spun yarn displayed least elongation because of the much irregularity and much imperfection in the yarn.

7. Conclusion

Spinners always try to produce quality yarn with lower cost. More so, ring spinning is a popular spinning system due to its versatility in terms of yarn count and fiber type. The major limitation of ring spinning however is less productivity. The mass variation and hairiness value of ring spinning is the highest among the three spinning system. The advantage of Rotor yarn is seen in much productivity and it is more even than ring yarn. The main disadvantage of rotor spun yarn compared with ring spun yarns are their lower strength. Compact spinning is the upgraded version of ring spinning. Furthermore, due to the reduced spinning triangle all fiber are incorporated into the yarn body. As a result, compact yarn possesses least hairiness, highest strength, and evenness among the three spinning systems. Considering each side, Compact yarn is the best but it is the most expensive. The choice of specific type yarn depends on the end use and customer demand.

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