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Comparison between physical properties of ring-spun yarn and compact yarns spun from different pneumatic compacting systems

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A comparative study pertaining to physical and mechanical properties of ring-spun yarn vis-à-vis compact yarns spun using three different compacting systems has been reported. Rieter (K-44), Toyota (RX-240) and Suessen (Fiomax) spinning machines have been used and the condensing process of the fibres in the yarn cross-section as per these compact spinning systems is accomplished pneumatically. Thus, a yarn of linear density 5.9 tex (100 Ne) is spun on the spinning systems using Egyptian cotton of the type Giza 86. One way Anova together with least significant difference are employed to feature the means of the properties of spun yarns and a significant difference among them is observed. According to the performed statistical analysis, there is a significant difference between ring - spun yarn properties and each of the pnuematic compact spun yarns. These compact-spun yarns are also found to differ significantly in terms of their physical and mechanical properties; however, they are all found superior to the ring-spun yarn.

Keywords: Breaking strength, Compact spinning, Compact-spun yarn, Ring spinning, Physical properties, Yarn imperfections, Yarn hairiness

1 Introduction

In conventional ring spinning, the zone between the nip line of the pairs of delivery rollers and the twisted end of the yarn is called the "spinning triangle". This represents the most critical part of the ring spinning system. In this zone, the fibre assembly contains no twist. The edge fibres play out from this zone and make little or no contribution to the yarn tenacity. Furthermore, they lead to the familiar problem of yarn hairiness[1].

In compact spinning, the spinning triangle is almost eliminated and almost all fibres are incorporated into the yarn structure under the same tension. This leads to significant advantages such as increasing yarn tenacity, yarn abrasion resistance and reducing yarn hairiness[2,3].

The compact spinning method forms a different yarn structure. The most evident properties of these yarns are their high breaking strength, high elongation and low hairiness[3-7]. Other yarn properties such as yarn unevenness and thin/thick places etc. are comparable to the conventional ring-spun yarn. The structure of the compact spun yarn offers many advantages in the further yarn processing. It is thought, for example, that by using these yarns, the size amount necessary for either warp preparation or weaving performance can decrease by 50% and the weaving efficiency can increase due to decreasing the pollution caused by the fibre fly[8-11]. A decrease in size amount as a result of the usage of compact yarns also decreases the cost of the desizing process, besides the cost advantage achieved in the sizing process[9].

As a result of improvement in yarn structure, various compact spinning designs by different textile machinery manufacturers are in common practice. The main difference among these systems is the condensing unit. Most of compacting systems are confined between pneumatic and mechanical compacting systems. For instance, in Air-Com-Tex 700 by Zinser, a perforated apron is added to the classical drafting system of a ring machine, while ComforSpin by Rieter uses a perforated drum to condense fibres in the drafting region. On the other hand, the EliTe system from Suessen differs significantly from both systems[12].

Mechanical compact spinning is an important alternative for compact yarn production. The system is cheaper and less complicated than pneumatic compact yarn spinning systems. Furthermore, there is no additional energy consumption during the spinning process[13].

Most of the studies on compact-spun yarns have been focused on the application of compact spinning

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Table 1—Spinning particulars for conventional ring, Suessen, Rieter and Toyota spinning frames

Parameter	Spinning systems			
	Ring spinning (Platt Saco Lowell)	Rieter –K44 (com-4)	Toyota (RX-240E)	Suessen Elite (Fiomax E1)
Drafting system type	Mechanical	Pneumatic	Pneumatic	Pneumatic
Load in nep point, dN (delivery roller)	12	14	12	14
Back draft	1.24	1.14	1.18	1.20
Drafting gauge, mm	56/70	46/60	46/60	46/60
Spindle gauge, mm	70	70	75	70
Spindle speed, rpm	10500	13500	12500	12000
Ring diameter, mm	42	38	36	38
Traveller count	15	14	12	12
Traveller type	EL1 fHW,15/0	C1ELUDR,14/0	U1ULUDR,12/0	C1ELUDR,12/0
Traveller speed, m/s	23	27	24	24
Delivery speed, m/min	7	9	8	8

to short-to-medium cotton[3,14-16]. Hence, the present study highlights the characteristic variations in finer counts cotton ring-spun yarn and compact-spun yarns caused by different spinning methods. Throughout the work, compact yarns spun from three pneumatic compacting systems, namely Suessen, Rieter and Toyota are compared with the conventional ring-spun yarns in terms of their physical and mechanical properties.

2 Materials and Methods

A standard spinning preparation and modern machinery were used to produce sliver with count 3280 tex and the roving with linear density 211 tex (2.8 Ne) and 82 turns/m (α_e=1.25) from 100% Egyptian cotton of type Giza 86. After that, conventional and compact yarns with a linear density of 5.9 tex (100/1 Ne) were produced under comparable technological and kinematical conditions on the Ring, Rieter, Toyota and Suessen spinning frames. All yarn samples were spun with the same twist multiplier, i.e. 4 twist factor. The spinning particulars of Suessen, Reiter, Toyota and Ring spinning frames are summarized in Table 1.

After yarn production, the quality of yarn samples was tested. Uster hairiness index (UHI), irregularity (unevenness) and imperfection index (IPI) of yarn samples were tested using an Uster tester 3 (UT3) according to standard test method ASTM D 1425. We tested each yarn sample 10 times with 400 m/min test speed for 2.5 min. Tensile yarn properties, namely yarn breaking strength (cN/tex), breaking elongation (%) and work of rupture (N.cm) were measured on the Uster Tensorapid tensile testing machine using the single strand method. The working principle and procedure are described in standard test method ASTM D 2256. Twenty observations were made for each yarn sample and then averages were calculated.

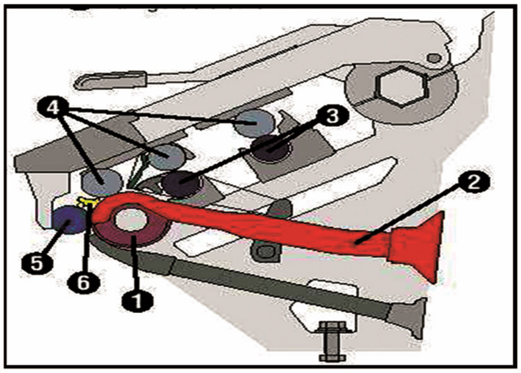
Table 2—Physical and mechanical properties of ring and compact spun yarns

Yarn property	Spinning system			
	Ring	K-44	RX-240	Fiomax
Breaking strength, cN/tex	17.5	22	19.5	24.2
Breaking elongation, %	4.01	4.62	4.41	5.06
Breaking work, cN.cm	115.5	154.7	137.1	181.4
Irregularity, CV%	18.01	16.84	16.61	16.55
Hairiness index	3.03	2.08	2.75	2.27
Thin places/1000 m	178	85	128	90
Thick places/ 1000 m	224	125	190	160
Neps/1000 m	245	160	215	212

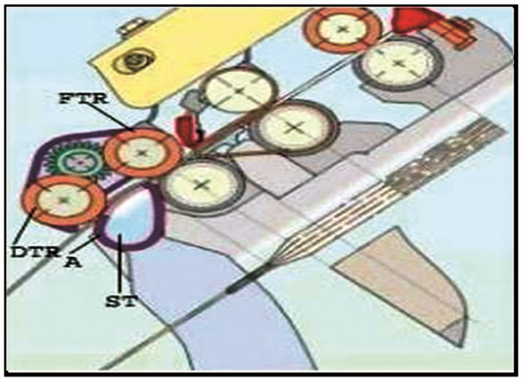
All tests were performed after keeping the yarns in standard atmospheric conditions for 24 h at 65±5 % RH and 20±2°C temperature. The physical and mechanical properties of the used yarns are presented in Table 2.

2.1 Comparison of Operating Principles for Three Compacting Systems

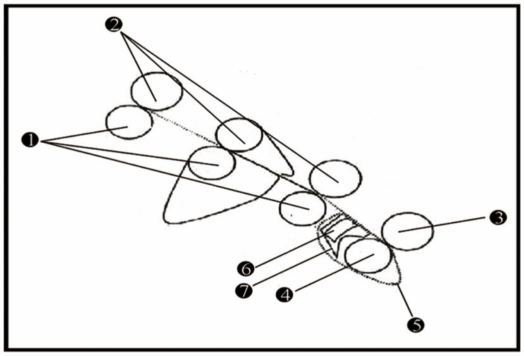
The drafting system of the Reiter compact spinning consists of 3 over 3 rollers drafting, in which bottom delivery roller is hollow and perforated drum with larger diameter using a suction system. Air flow is sucked from the outside to the inside of the drum. Under this air suction, fibres merging from the delivery nip of the drafting unit are held against the drum surface and moved at the same circumferential speed as the drum surface. A second top roller presses on the drum is also used to create a nip between the drum and the top roller that acts as twist stop. This leads to the yarn formation immediately after this nip (i.e. no triangle). The condensation of fibre flow takes place in the intermediate zone between the two top rollers sitting on the perforated drum. Rieter introduced air guide element 6 which results in lateral condensation of the fibres on the perforated drum. This feature greatly assists in providing more fibre compactness both against the drum and in the lateral direction as illustrated in Fig. 1(refs 14, 17).



Reiter K 44 compact spinning draft system
(1-perforated drum, 2- suction system, 3- bottom roller, 4- top roller, 5-nip roller, 6- air guide element)



Suessen Elite Unite
(ST- suction tube, A- lattice apron, FTR- front top roller, DTR- delivery top roller)[23]



Toyota compact spinning principle
(1- bottom rollers, 2- top rollers, 3- top front rollers, 4- mesh apron roller, 5- mesh apron, 6- suction slot, 7- suction bar)[24]

Fig.1—Principles of Reiter, Suessen and Toyota compact spinning systems

Suessen Elite compacting system consists of an additional "drafting zone", which is mounted on a standard 3-roll ring spinning machine (Fig. 1). In this drafting zone an air–permeable lattice apron runs over a suction tube. The suction tube is under negative pressure and there is a slot tilted in the direction of fibre movement for each spinning position. After the fibres leave the front roller nip line, they are guided by means of the lattice aprons over the openings of the suction slots where they move sideways and are condensed due to suction air flow. The openings of the suction slots are at the inclined position to the direction of fibre flow. This helps condensing by generating a transverse force on the fiber band during the transport over the slot and causing the fiber band to rotate around its own axis. The lattice apron carries the fibers attached to it up to the delivery nip line. The diameter of delivery (driven) top roller is slightly bigger than the diameter of the front top (driving) roller. This generates a tension in the longitudinal direction during the condensing process. The tension ensures the straightening of curved fibers, and therefore, supports the condensing effect of the negative pressure acting on the fiber band in the slot area of the suction tube[18-20].

The Toyota compact spinning system (Fig. 1) has an alteration in the 3/3 double apron standard drafting system. This system has a condensing unit which consists of a mesh apron and suction slot. This condensing unit is driven by the front bottom roller with a positive drive mechanism, specially designed by Toyota. The fibre stream that entered in the condensing zone is compacted by the mesh apron, which is under negative pressure.

2.2 Statistical Analysis

In this study, all test results were evaluated using one-way ANOVA to detect the significant difference between the means of the properties of yarns spun on the four spinning systems. The difference between yarn properties was examined at 0.05 and 0.01 significance levels. When the analysis of variance (ANOVA) gives a significant result, this indicates that at least one group differs from the other groups. Yet, the omnibus test does not indicate which group differs. In order to analyze the pattern of difference between means, the ANOVA is often followed by the least significant difference (LSD) test. The main idea of the LSD is to compute the smallest significant difference (i.e. the LSD) between two means (i.e. with a t test) and to declare any significant difference larger than the LSD.

The least significant difference (LSD) procedure uses the F statistic for testing $H_0 : \mu_i = \mu_j$

$$t_0 = \frac{y_i - y_j}{\sqrt{MS_E(\frac{1}{n_i} + \frac{1}{n_j}}} \qquad \ldots (1)$$

where MS_E is the mean squares due to error (Within treatments) in ANOVA analysis.

Assuming the two-sided alternative, the pairs of means μ_i and μ_j would be declared significantly different; if

$$\left|\bar{y}_i - \bar{y}_j\right| \geq t_{\alpha/2,N-a}\sqrt{MS_E(\frac{1}{n_i} + \frac{1}{n_j})} \qquad \ldots (2)$$

the quantity $\text{LSD} = t_{\alpha/2,N-a}\sqrt{MS_E(\frac{1}{n_i} + \frac{1}{n_j})}$ is called the least significant difference, where N is the total number of observations; a , the number of treatments; n, the number of observation; α, the level of significance; and N-a, the degree of freedom of the mean square of the error in the ANOVA analysis. If the design is balanced ($n_1 = n_2 = \ldots\ldots = n_a = n$), the least significant difference is equal to

$$\text{LSD} = t_{\alpha/2,N-\alpha}\sqrt{\frac{2MS_E}{n}} \qquad \ldots (3)$$

To use the LSD procedure, we simply compared the observed difference between each pair of averages to the corresponding LSD. If $\left|\bar{y}_i - \bar{y}_j\right| \geq$ LSD, we conclude that the population means μ_i and μ_j differ.

The results of multiple comparison LSD test for yarn tensile properties, yarn hairiness, imperfection and irregularity are introduced in Tables 3 and 4.

3 Results and Discussion

3.1 Breaking Strength

The breaking strength of yarn is an important criterion in assessing yarn quality. The number of yarn breakages in spinning, weaving and knitting processes largely depend on breaking strength. It is

Table 3—Results of multiple comparisons LSD test for yarn tensile properties

Spinning system		Breaking force		Breaking elongation		Work of rupture	
		Absolute mean difference	Significance level	Absolute mean difference	Significance level	Absolute mean difference	Significance level
Ring	K-44	26.5	0.000 ***	0.6	0.003***	39.3	0.001***
	RX-240	12.0	0.055*	0.4	0.053*	21.7	0.069*
	Fiomax	39.9	0.000***	1.1	0.000***	65.9	0.000***
K-44	RX-240	14.6	0.020**	0.2	0.313*	17.6	0.139*
	Fiomax	13.3	0.033**	0.4	0.031**	26.6	0.027**
RX-240	Fiomax	27.9	0.000***	0.7	0.002***	44.2	0.000***

*The mean difference is not significant.
**The mean difference is significant at 0.05 level.
***The mean difference is significant at 0.01 level.

Table 4—Results of multiple comparisons LSD test for yarn hairiness, imperfection and irregularity.

Spinning system		Uster hairiness index		Yarn imperfection index		Irregularity	
		Absolute mean difference	Significance level	Absolute mean difference	Significance level	Absolute mean difference	Significance level
Ring	K-44	1.0	0.000***	277	0.000***	1.0	0.000***
	RX-240	0.3	0.017**	114	0.000***	0.3	0.000***
	Fiomax	0.8	0.000***	185	0.000***	0.8	0.000***
K-44	RX-240	0.7	0.000***	163	0.000***	0.7	0.302*
	Fiomax	0.2	0.096*	92	0.000***	0.2	0.194*
RX-240	Fiomax	0.5	0.000***	71	0.000***	0.5	0.784*

* The mean difference is not significant.
* The mean difference is significant at 0.05 level.
*** The mean difference is significant at 0.01 level.

well known that the breaking force of a spun yarn depends largely on the characteristics and structural arrangements of its constituent fibres. Every spinning technology produces a yarn of unique structure owing to its unique method of fibre integration and nature of twisting. Hence, the geometric configurations of fibres are different in the yarns spun on different spinning systems.

The effect of spinning systems on breaking strength of spun yarns was depicted in Fig. 2. Obviously, the statistical analysis shows that the type of spinning systems has a significant effect on the breaking strength of spun yarns at 0.01 significance level. From this figure it can be observed that all compact spun yarns had a higher breaking strength in comparison with the conventional ring-spun yarn, which is a very important feature from both quality of the yarn and the efficiency of the spinning process points of view. It is also proved that the average values of breaking strength of conventional ring-spun yarn and K-44, RX-240 and Fiomax compact spun yarns are 17.5, 22.0, 19.5 and 24.2 cN/tex respectively.

The difference in yarn breaking strength between conventional ring-spun yarn and the compact-spun yarns may be ascribed to the difference in the structure of spinning triangle in both systems. In ring spinning, the gradual transmission of twists with the traveller along the yarn balloon causes a certain tension in the fibre bundle that forms the spinning triangle, a tension which is not distributed symmetrically in the yarn cross section. It is greatest in fibres that are positioned at the edges of the spinning triangle, and the smallest in fibres lying in the middle of the triangle. This asymmetric distribution is the reason for fibre breakage according to their position in the spinning triangle during subsequent processing [19, 21, 22]. Furthermore, the fibres gradually take over the external axial yarn loading; therefore, they also break one after the other. The consequence is lower yarn strength and poorer utilization of the fibre tenacity (35 - 50%).

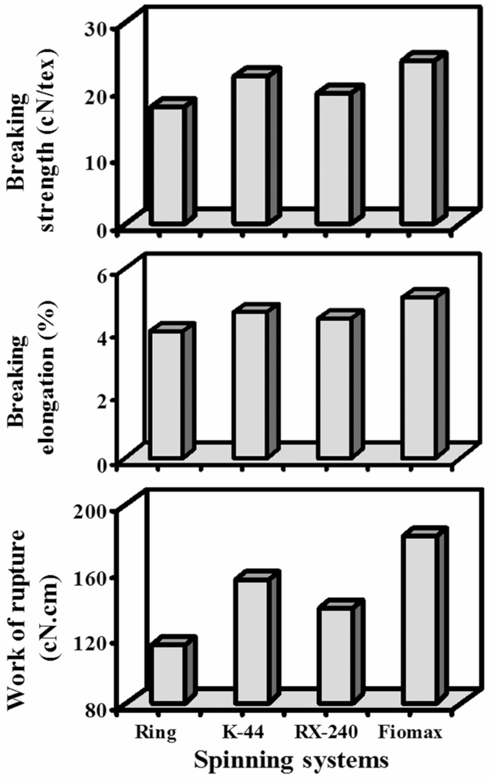


Fig. 2—Effect of spinning systems on the tensile properties of spun yarns

In compact spinning, minimization or even elimination of the spinning triangle enables almost all fibres to be incorporated into the yarn structure with maximum possible length and almost equal pre-tension of the fibres, irrespective of their position in the spinning triangle. The uniform pre-tension of the majority of fibres enables more synchronic breakage of the majority of the fibres, which contributes to higher yarn strength and better utilization of the fibre tenacity (from 65% up to even 80%).

The results of the multiple comparison LSD tests are listed in Table 3. The higher significant difference is found between conventional ring yarn and Fiomax compact-spun yarn and between RX-240 and Fiomax compact-spun yarn. These results are confirmed in Fig. 2 which shows that the yarn spun on Fiomax compact spinning is characterized by the highest breaking force followed by those produced on K-44 and RX-240 compact spinning systems respectively.

The higher breaking force associated with yarns spun on Fiomax compact spinning system may be related to the presence of additional drafting zone, which generates a tension in the longitudinal direction during the condensing process. This tension ensures the straightening of the curved fibres, and therefore supports the condensing effect, which, in turn, increases the tensile properties of the produced yarns. On the other hand, the lower breaking force brought about by RX-240 spinning system might be because of the weak compacting power of this system.

3.2 Breaking Elongation

The elongation percentage is defined as the ratio of elongation of the specimen to the initial length thereof expressed as a percentage. Breaking elongation of a spun yarn is basically related to the fibre extension and the way fibres are arranged in its body. Breaking elongation of spun yarns versus the type of spinning systems is plotted in Fig. 2. From this figure and the statistical analysis it is clear that the breaking elongation of ring-spun yarn and compact-spun yarns differs significantly. Irrespective of the type of compact spinning system, compact-spun yarn exhibits higher breaking elongation in comparison with ring-spun yarn. Breaking elongation of a compact yarn produced on the K-44 spinning machine surpasses the conventional ring yarn by 15% while this value is higher by up to 10% and 26% in the yarns spun on the RX-240 and Fiomax spinning machines respectively.

Compact-spun yarns are characterized by better fibre integration[23,24] and uniform fibre arrangement[25] that probably lead to greater contribution of intrinsic fibre elongation to yarn elongation.

The results of LSD test listed in Table 3 show a significant difference between ring and K-44 and between ring and Fiomax spinning systems in terms of yarn breaking elongation. It is also seen that the difference between ring and RX-240 and between K-44 and RX-240 is not significant. From Fig. 2, it can also be seen that the breaking elongation of yarns spun on ring and compact spinning systems follows the order: Fiomax > K-44 > RX-240 > ring spinning machine. The higher breaking elongation of yarns produced on Fiomax compact spinning machine as compared to the other spinning systems may be due to the higher compacting power of this system.

3.3 Work of Rupture

Meredith[26] reported that the work of rupture is represented by the area enclosed by the stress-strain curve and the strain axis and would be half the product of breaking load and breaking extension if Hooke's law were obeyed. The variation in work of rupture of spun yarns according to the variation in spinning systems is illustrated in Fig. 2. Evidently the spinning system has higher influence on the yarn work of rupture.

As expected, and irrespective of the type of spinning system, compact-spun yarns exhibit considerably higher work of rupture than ring-spun yarn and the difference is statistically significant. The statistical analysis proves that work of rupture of yarns spun on K-44, RX-240 and Fiomax compact spinning machines is more than those produced on conventional ring spinning machine by 34, 19 and 57% respectively.

With regard to the type of compact spinning system and from Table 3, it is shown that there is no significant difference between RX-240 and each of K-44 and ring spinning machines with respect to yarn work of rupture. It is also noticed that the work of rupture of yarns produced on Fiomax compact spinning machine exhibits the highest value, while the work of rupture of those spun on RX-240 compacting system shows the lowest. This is rather anticipated because of the higher breaking strength and elongation of yarns spun on Fiomax compacting system.

3.4 Hairiness Index

Yarn hairiness is one of the essential parameters which influences the performance of yarn in the subsequent processes. Yarn hairiness has a considerable effect on the appearance and handle of fabric, as well as on the formation of pilling.

In present work, hairiness index is measured using Uster tester 3 (UT3) instrument. Hairiness index (HI) can be defined as the total protruding fibre lengths that projects from the yarn body of length 1 cm. Provided that HI is the relationship between two lengths (of hairs and yarn), it is a non-dimensional quantity.

The relationship between yarn hairiness index and the type of spinning system is illustrated in Fig. 3. The statistical analysis proves that spinning system type has a profound effect on the yarn hairiness index at 0.01 significance level. In general, ring-spun yarn exhibits higher hairiness level compared to compact-spun yarns regardless of the type of their compacting system. Regarding the type of compacting system, K-44 compact spinning system is the least hairy yarn type, whilst RX-240 spun yarn is the most hairy. It is also particularly notable that the hairiness index of K-44 compact-spun yarn has hairiness level of 31% lower than the hairiness of ring-spun yarn, while RX-240 and Fiomax compact-spun yarns show hairiness level of up to 9% and 25 % lower than the hairiness of ring-spun yarn.

The higher hairiness values of ring yarn as compared to compact-spun yarns could be associated with the presence of large spinning triangle, which causes a large difference in the path followed by the edge and center fibres. Because of this the edge fibres do not properly integrate into the yarn body. In addition, the reduction in spinning triangle in the compact spinning system brings about less hairiness in the yarn.

The results of multiple comparison LSD test are given in Table 4. It is obvious that there is no significant difference in Uster hairiness index between yarns spun on K-44 and Fiomax compact spinning systems. However, a significant difference is detected between the other spinning systems in relation to hairiness level. Finally, the K-44 compact spinning produces yarns with significantly lower hairiness than the other spinning systems. The lower hairiness levels of yarns spun using K-44 compact spinning system may be attributed to the larger area of its compacting zone in comparison with the other compacting system.

3.5 Imperfection Index

The imperfection index (IPI) of spun yarns can be defined as the sum of yarn thin places, thick places and neps per 1000 meters of yarn length. In the USTER evenness tester, thin and thick places refer to imperfections that are within the measuring sensitivity range (±50% with respect to the mean value of yarn diameter), while neps are classified as the yarn imperfections which may exceed the 200% limit. For ring-spun yarn, imperfections adversely affect yarn and fabric quality. A yarn with more imperfections will exhibit poor appearance grade, lower strength and poor performance in subsequent processes.

The effect of types of spinning systems on the imperfection index of the spun yarns is depicted in Fig. 3. Based on this figure and statistical analysis, it is apparent that spinning system type has a great influence on the imperfection index of spun yarns. Generally, ring-spun yarn has a higher imperfection index compared to compact-spun yarns. The average values of thin places, thick places and neps per kilometer of yarns produced on Ring, K-44, RX-240 and Fiomax spinning machines are recorded in Table 2, from which it is noticed that ring-spun yarn has the higher values of thin places, thick places and neps in comparison with the compact-spun yarns.

From Table 4, a significant difference is observed at 0.01 significance level among all spinning systems in relation to the imperfection index of spun yarns. With respect to the type of compact spinning system, the K-44 spinning system has the lowest value of yarn imperfection, whereas RX-240 spinning system yields the highest imperfection value. The yarns spun by K-44 and Fiomax compact spinning systems has 44% and 13% less IPI respectively as compared to the yarn spun by RX-240. The unsatisfactory values of imperfection index associated with RX-240 spinning system may be related to the lower power of its compacting system.

3.6 Yarn Irregularity

Yarn irregularity is a measure of the level of variation in yarn linear density or mass per unit length of yarn. In other words, it refers to the variation in yarn count along its length. A common method of expressing the irregularity of a yarn is to use the statistical term CV or coefficient of variation. Obviously the higher the CV value, the more irregular is the yarn.

The variation in yarn irregularities versus type of spinning systems are plotted in Fig. 3. The statistical analysis reveals that, irrespective of the type of compacting systems, the differences between the mass irregularity values of ring- and compact-spun yarns are statistically significant at 0.01 significance level; the evenness of compact-spun yarns is better than that of conventional ring yarns. The average values of yarn irregularity for conventional ring-spun yarn, K-44, RX-240 and Fiomax compact-spun yarns amount to 18, 16.8, 16.6 and 16.55% respectively. This result is quite surprising because yarn irregularity is largely governed by the average number of fibres in yarn cross-section[27]. Since the number of fibres in yarn cross-section should remain the same for a given fibre and yarn linear density, the better regularity of the

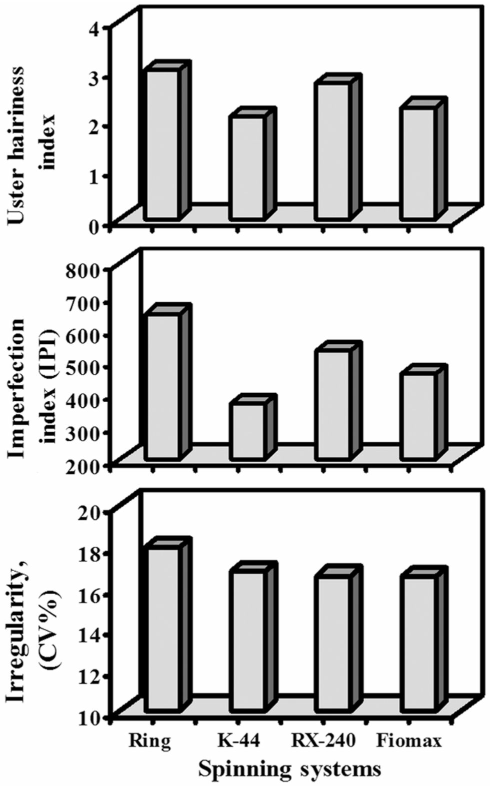


Fig. 3—Effect of spinning systems on hairiness, imperfection and irregularity of spun yarns

compact-spun yarns is the expected consequence of the improved integration of fibres at twisting triangle and the reduction in fibre loss from the yarn body.

The results of multiple comparisons LSD test are given in Table 4. It is clear that there is no significant difference between different compact-spun yarns in relation to its irregularities, and the only significant difference is found between ring yarn and each of compact-spun yarns. It is also noticed that the yarn spun on Fiomax compact spinning system possesses the best irregularity, whereas the K-44 compact spinning system yields the worst yarn irregularity.

4 Conclusion

4.1 By and large, compact-spun yarns are superior to ring-spun yarn in terms of yarn tensile properties, imperfections, hairiness and irregularity.

4.2 Fiomax compact-spun yarn is more effective in terms of breaking strength, breaking elongation and work of rupture as compared to the other spinning systems.

4.3 K-44 compact spinning system is the least hairy yarn type, whilst RX-240 spun yarn is the most hairy. The RX-240 and ring-spun yarns are close to each other with respect to hairiness values.

4.4 K-44 compact-spun yarn is also more effective in terms of imperfection index in comparison with the other compacting systems.

4.5 With respect to the yarn evenness, the compact spinning systems have the order: Fiomax > RX-240 > K-44.

Finally, from the above results it can be concluded that the yarns spun on Fiomax compact spinning machine are the best yarns from the functional point of view. However, the K-44 compact-spun yarn is the most effective from the aesthetic point of view.

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