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Effect of spinning variables on packing density of cotton yarn

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In this study, fibre distribution through the cross-sections of ring-spun yarns and their packing density values has been investigated to provide a better understanding of the internal structures of ring-spun yarns manufactured by changing different spinning variables. After the yarn manufacturing process, diameter, IPI index, uniformity index, single yarn strength, density and hairiness are tested and then evaluation of tests is done on the Minitab and Microsoft Excel. The impact of TPI, spindle speed, count, hairiness and diameter has been analyzed using yarn packing density as a response variable. The aim of present study is to produce a yarn with improved packing density so that the yarn properties could be predetermined. The study shows that the increase in yarn count, TPI and spindle speed increase the yarn packing density

Keywords: Cotton yarn, Packing density, Spinning variables, Yarn compactness

In recent years, much attention has been paid to create more comfortable living conditions. Packing density is a very important parameter of a yarn as it determines the bulkiness, warmth, feel, moisture management and dyeing characteristics of a yarn. Packing Density is greatly influenced by the raw material as well as yarn manufacturing technique and the spinning variables. Awareness on the effects of the spinning variables on packing density could help us in predetermining of dynamometric and comfort properties of yarn in the final fabric stage. The mechanical properties of staple yarns depend not only on the physical properties of the constituent fibres, but also on the yarn structure characterized by the arrangement of individual fibres in yarn cross-section. The structure of the yarn consists of two main constituents, i.e. fibres and the air. Fibres represent the main component while the other component is the air pockets created by the spinning technique, both of them are related using the term yarn packing density. It is the main cross-section structure parameter and gives the information about the radial distribution of the fibres.

Different scientists studied yarn structure using direct method[1] which involves coating of a yarn with substance like polyvinyl acetate to prevent disturbance of fibres during cross-sectioning. After drying the yarn is embedded in the medium of 25.5 mm sections. The embedding media could be a substance including Perspex in chloroform, nitrocellulose in ether/ethanol (later covered with wax), molten wax and paraffin. Secant method[1] is used for the yarn containing fibres of irregular cross-section like viscose and 3 lobe polyester. In this method, centre of gravity of yarn is found and the fibre cross-sections are constructed around after determining the equivalent fibre diameter. Equivalent fibres diameter is estimated from the linear density and the mass density assuming the cross-section to be circular. Jaoudi *et al.*[2] found that yarn density increases with twist and asymptotically approaches a value. Twist and count have the maximum influence on packing coefficient. Hearle and Merchant[3] also found that with the increase in twist, specific volume of yarn (inverse of density) reduces and asymptotically approaches to a value of 1.25 3cm/g, which is still higher than fibre specific volume 0.88 3cm/g, in nylon staple fibre yarns. This is because of the reason that the entrapped air is not fully expelled with increase in twist. Initial fall in specific volume with twist is greater for finer yarns than in coarser yarns. He found that with polypropylene, packing density increases slowly with twist and reaches a limiting value of 0.7-0.8. For cotton, the increase in packing density with twist is more rapid. Barella[4] found that yarn density approaches fibre density at the time of break during loading in tensile load tester. The study of packing fibres in a yarn cross-section was started by Schwarz[5], and Hamilton[6] suggested a direct method of measuring yarn diameters and bulk densities under conditions of thread flattening. He showed how the denier and the major & minor diameters vary with twist. Later on, Hearle *et al.*[7] gave some formulae to calculate specific volume of yarn based on yarn twist, twist angle and yarn linear density. The formula given by Hearle *et al.*[7] is only

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valid in the case of an idealized ring yarn structure, and is not applicable for other structures of yarns manufactured on different spinning technologies, such as rotor and air-jet techniques. In this regard, Ishtiaque[8] derived a formula to calculate the packing density of the yarn, the formula is applicable for the yarns manufactured on different technologies. This formula is based on the actual values of yarn diameter, helix twist and number of fibres in the yarn cross-section, as obtained by the study of fibre migration behavior[9]. Despite this massive research, no work has been carried out to control packing density by controlling spinning variables. This study therefore focuses on controlling packing density by finding its relation with these variable.

Experimental

Materials

100% Cotton was used as a raw material for this research. Three different types of yarn counts were produced using Toyoda RY-5 ring-frame. These counts include Ne 8, 16 and 24. To perform the study, 9 different samples of each count were produced. Variables within a count were TPI (twist per inch) and spindle speed. Three different levels of each variable within a count were used. Hence each count results in a combination of 9 different samples. Then TPI was checked to verify the calculation made on the RY5 ring-frame. After the production, samples were tested for different parameters of yarn, i.e. U%, index, CVm, thin places, thick places, neps, hairiness, 2 dimensional diameter, shape, density, count were tested on Uster Tester 5. TPI of each sample was checked on digital Zewigller tester. All results were compiled and each flow set was averaged on the basis of count, so that the total no. of samples was shrined to only 27. Testing results of 27 samples are shown in Table 1. Then yarn packing density[10] was calculated using the following formula:

$$\text{Packing density} = \frac{\text{Specific volume offibre}}{\text{Specific volume of yarn}}$$

where

$$\text{Specific volume} = \frac{250\,\pi\,(\text{diameter})^2}{\text{tex}}\,\text{cm}^3/\text{g}$$

Taking cotton density as 1.52g/cm^3, we get

$$\text{Packing density} = \frac{\text{tex}}{380\,\pi\,(\text{diameter})^2}$$

Results and Discussion

Effect of Count

Study shows that packing density is affected by count (Table 1). There is a direct relation between count and packing density. This has been concluded by conducting correlation analysis on Minitab. The positive correlation is found between count and packing density. The Pearson correlation value of both the variables is 0.693 which depicts that there is a moderate correlation between them.

Effect of Spindle Speed

Spindle speed during production of yarn has great effect on packing density (Table 1). The phenomenon behind this relation is the effect of spindle speed on yarn tension during the spin process. More the yarn is under tension the shorter is the spinning triangle and hence the angle of binding of fibres in the yarn cross-section is decreased and fibres come closer to each other, thus increasing the packing density. The Pearson

Table 1— Yarn packing density values against selected spinning parameters

Sample no.	Packing density, g/cm^3	Count Ne	Spindle speed, rpm	TPI	Hairiness
1	0.22	7.94	9500	9.718	12.32
2	0.21	8.03	10500	9.786	12.53
3	0.22	8.09	11500	9.704	11.34
4	0.26	7.81	9500	10.602	10.08
5	0.25	7.81	10500	10.796	10.36
6	0.25	7.89	11500	10.698	10.85
7	0.25	7.85	9500	11.68	11.65
8	0.27	7.83	10500	11.456	9.9
9	0.27	7.80	11500	11.66	9.87
10	0.24	15.79	10000	15.072	8.68
11	0.24	15.84	13000	15.622	8.74
12	0.27	16.12	15800	14.816	7.38
13	0.29	15.63	10000	16.706	7.53
14	0.29	15.83	13000	16.484	7.32
15	0.27	16.11	15800	16.77	8.11
16	0.30	15.41	10000	18.392	7.42
17	0.31	15.62	13000	18.452	7.08
18	0.30	15.99	15800	18.358	7.2
19	0.27	23.67	10000	21.064	7.33
20	0.27	24.06	13000	20.748	6.92
21	0.29	24.04	15800	20.646	6.64
22	0.29	23.7	10000	21.14	6.63
23	0.31	24.07	13000	22.592	6.18
24	0.31	24.67	15800	22.496	6.03
25	0.32	23.36	10000	24.086	6.17
26	0.34	23.82	13000	24.77	5.88
27	0.32	24.70	15800	24.1	6.03

correlation has been conducted and correlation coefficient is found to be 0.413. This shows slight moderate correlation between both the variables.

Effect of TPI

It is observed that as the TPI increases, packing density of yarn also increases (Table 1). This shows positive correlation between TPI and yarn packing density. As TPI increases the angular tension of the fibre increases and due to increase in tension the force on fibre increases. This force brings the fibres closer to each other, resulting in an increase in yarn packing density. Pearson correlation coefficient for these variables is found to be 0.833, representing the strong positive correlation.

Effect of Yarn Diameter

Yarn diameter highly affects the packing (Table 1). The decrease in diameter represents the decrease in inter fibre distance within yarn and vice versa. The Pearson correlation coefficient of these variables is -0.797, that depicts strong negative correlation.

Effect of Yarn hairiness

Yarn hairiness has major effect on packing density of a yarn (Table 1). The increase in hairiness represents the increase in fibre-to-fibre distance. As the hairiness increases yarn diameter also increases which decreases the packing density of yarn. Study reveals strong negative correlation (-0.874) between these two variables. Following regression equations could be used to find the packing density of yarn:

$$\text{Packing density} = 0.210 - 0.000293\ \text{count} - 0.00000013\ \text{spindle speed} + 0.00633\ \text{TPI} + 0.645\ \text{diameter} - 0.0316\ \text{hairiness}$$

S = 0.0112862, R-Sq = 90.2%, R-Sq (adj) = 87.9%.

Study shows that there is large effect of count, TPI and spindle speed on yarn packing density. Adjusting these properties can help us to attain desired dynamometric and comfort properties of yarn. The increase in count results in increased yarn packing density and vice versa. The increase in TPI results in increased yarn packing density and vice versa. The increase in spindle speed also results in increased yarn packing density and vice versa.

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