

Fabric assistance in woven structures made from different spun yarns

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The effect of different spun yarns on fabric assistance has been studied considering the structural parameters, such as yarn-to-yarn friction, strength of ring, rotor, air-jet and OE-friction spun yarns and the strength of fabrics made from these yarns. The ratio of the fabric strip strength per yarn and the corresponding single yarn strength is considered as a measure of quantifying the fabric assistance. Mechanism of yarn failure inside the fabric is different as that of single yarn and the former exhibits more fibre rupture. Fabrics made from weaker yarns have higher ratio of strip strength to single yarn strength than that made from stronger yarns due to larger increase in the percentage of rupture fibres in the former. The fabric assistance also depends, to some extent, on the degree of gripping of the yarns that is influenced by the yarn-to-yarn friction, extent of yarn flattening and yarn diameter.

Keywords: Fabric assistance, Fabric strength, Yarn diameter, Yarn friction, Yarn strength

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1 Introduction

Fabric assistance is generally defined as the percentage rise in the strength of a set of yarns when another set of yarns is inserted to form the fabric. Taylor was the first to introduce the concept of fabric assistance to the fabrics made from ring-spun cotton yarn.¹ Lord and Radhakrishnaiah² examined the tensile strength of fabrics constructed of rotor, friction and ring-spun weft yarns. They explained the difference between yarn strength ratios and fabric strength ratios due to fabric assistance, i.e. the effect of friction at cross-over points in fabrics. A general equation to relate the strength of fabric and the strength of constituting yarns will be a complex one as it is influenced by the raw material characteristics, such as yarn strength, count, yarn irregularity, fabric structure, set, crimp, weave, fabric finish and yarn structure.^{3, 4} The frictional forces between warp and weft, which are mainly dependent on the surface structure of yarns, influence the fabric strength to a greater extent.⁵ It is more practicable to calculate the ratio of strip strength per yarn to the single yarn strength (S-Y ratio) to quantify the fabric assistance, which is generally higher than unity. Ring, rotor, air-jet and OE-friction spun

yarns are commonly used for making fabrics. The internal and external structures of these yarns are quite different⁶. In woven fabrics, cross yarns provide lateral pressure to the longitudinal yarns as the fabric is extended along the longitudinal direction during tensile testing. The presence of cross yarns does the function of reducing the gauge length (in other words, free length of fibres between gripping points) and enhancing the friction forces between the fibres of the longitudinal yarns. Further, the weak places in the individual yarns are supported by the cross-over points between warp and weft in the fabric. These factors cause an increase in S-Y ratio. The improvement in this ratio also depends on the extent of binding/gripping of the cross yarns over the longitudinal yarns that depend on the friction between these yarns and rigidity of the transverse yarns. The friction between the yarns is in the boundary region due to very low relative velocity of the yarns when the fabric is extended during tensile testing. In boundary friction, larger the roughness of the sliding surfaces, higher is the friction.^{7, 8} A yarn with rough surface experiences more friction under sliding at low speeds. In this aspect, the presence of wrapper fibres on yarn surface assumes a significant role. The areas of contact between the yarns also influence the friction, which depends on the extent of flattening of the yarns at cross-over points.

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The effect of various factors, such as weave, construction, yarn irregularity and twist, on fabric assistance has been discussed by a few workers, but the effect of yarn structure on the fabric assistance has not been fully explored. The present work aims at quantifying the effect of different spun yarns on fabric assistance.

2 Materials and Methods

Four different sets of plain woven fabrics were prepared from 20s Ne (nominal count) viscose staple yarns made from ring, rotor, air-jet, and OE-friction spinning systems. Tracer fibres were mixed before opening operation in blow room in such a proportion to have an average of 5 tracers of different colours in the cross-section of every yarn for assessing yarn structure and number of broken fibres after tensile testing. All the fabric samples were made using unsized warp yarns.

In the first three fabrics, the warp and weft yarns were of the same combination (ring/ring; rotor/rotor and air-jet/air-jet). The last set of fabric was prepared using ring and OE-friction spun yarns as warp and weft respectively due to poor strength of the OE-friction yarn. The ends and picks per inch were 44 and 36 respectively for all the fabrics.

For tensile testing of fabrics, specimens of 150×35 mm size were prepared. Vertical yarns were raveled and the width of specimen excluding the raveled portion was 25 mm. These specimens were tested on an Instron tensile tester at a testing speed of 500 mm/min and a gauge length of 75 mm. All the single yarns were also tested at the same gauge length and extension rate. The strip strength of the fabric per yarn in warp direction is the ratio of fabric strength in warp direction to the number of warp yarns in the fabric specimen. The S-Y ratio in warp direction is the ratio of the strip strength per yarn in warp direction to the strength of single yarn representing the warp. Similarly, strip strength per yarn in weft direction could be calculated.

Pairs of broken ends of longitudinal yarns from the broken pieces of the fabric sample were collected in glass slides. This was done by raveling out the transverse yarns carefully from the broken fabric sample. The percentage of rupture fibres in the longitudinal yarns in the fabric was determined using the tracer fibre technique. To determine the proportion of broken and slipped fibres the slide containing the pair of broken ends was covered by another slide and benzyl alcohol solution was

introduced drop by drop in between the slides. The slides were observed under a Projection microscope using a magnification of $\times 50$. As the undyed viscose fibres are optically dissolved in benzyl alcohol solution the tracers of five different colours were clearly visible in the zones of yarn failure. A fibre was classified as broken if the failed ends of yarn contain the same tracer fibre, i.e. the fibre pieces from both the ends have same colour and the sum of lengths of these pieces is equal to the original fibre length. A slipped fibre was classified if only one end of the broken yarn segments contains the tracer of particular colour.⁶ Similarly, the proportion of broken fibres in single yarns was determined from the collected broken pairs of ends after the tensile failure of single yarns.

Yarn-to-yarn friction force in the dynamic condition was measured using a laboratory set-up. A schematic diagram of the measurement of yarn-to-yarn friction force is depicted in Fig.1. The incoming and outgoing yarns were twisted by one turn. Rothschild tensiometer-2000 was used to measure the input (T_1) and out put (T_2) tensions of the yarn. Friction force ($T_2 - T_1$) was measured at 5 cN input tension and a rubbing velocity of 50 mm/min.

Single yarn pull-out force from the fabric specimen was measured using Instron tensile tester at a crosshead speed of 500 mm/min. During the experiment, the upper jaw gripped only the upper portion of the yarn to be pulled, whereas the lower jaw gripped all the yarns of the fabric specimen

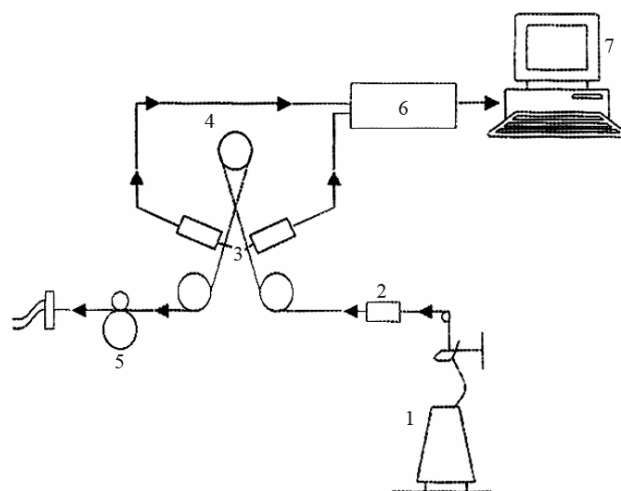


Fig. 1—Schematic diagram of measurement of yarn-to-yarn friction [1—yarn package, 2—tension compensator, 3—tension probes, 4—frictionless pulley, 5—take-up rollers, 6—tensiometer and 7—computer]

except the lower portion of the pulling yarn. The initial distance between the two jaws was 75 mm. Figure 2 illustrates a schematic representation of the experimental set-up for the measurement of the single yarn pull-out force.

3 Results and Discussion

The values of the ratio of fabric strip strength per yarn and the corresponding single yarn strength are given in Table 1. It is observed that these ratios are significantly higher in weft direction compared to that in warp direction. This is ascribed to the more end (cross yarns) density than pick density in the fabric, providing more number of gripping points for the weft yarns, translating higher strengths in weft direction. It is also observed that S-Y ratio is notably higher for fabric made from air-jet yarn followed by rotor and ring yarns, though the constructional parameters of these fabrics are identical. A higher ratio indicates that fibre strengths are exploited to a greater extent in fabrics.

For a given yarn strength, the fabrics made from air-jet and rotor yarns would be stronger by 35% and 21 % respectively compared to ring yarn fabrics. Alternately, it can be stated that the fabrics made from

air-jet, rotor and ring yarns would have the same strength, even if the air-jet and rotor yarns are weaker by 25% and 17% respectively compared to ring yarns. This indicates that the yarn structures also play a vital role in influencing the fabric strength.

The structures of different yarns are shown in Fig. 3. The structural parameters and yarn-to-yarn friction forces are given in Table 2. Under boundary friction, a higher roughness of yarn surface due to the presence of wrapper fibres in air-jet and rotor yarns causes higher friction force between warp and weft yarns. This enhances the radial pressure between the fibres of longitudinal yarns, increasing their friction potential and in the process a better utilization of fibres in the yarn contributing to fabric strength. Furthermore, higher mean fibre extent and a fair degree of fibre alignment in the air-jet spun yarn with the aid of good binding effect at the warp and weft cross-over points increase the load bearing capacity of the fibres, which, in turn, enhance the strength exploitation of the yarn in the fabric. The strength utilization for OE-friction and ring yarn combination is higher than that for the ring and ring yarn combination. The OE-friction spun yarn, having loose

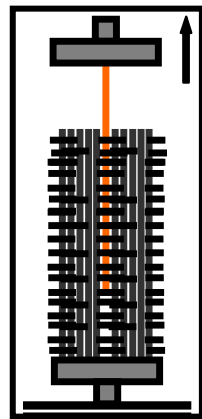


Fig. 2—Schematic diagram of yarn pull-out experiment

Table 1—Ratio of fabric strip strength per yarn and single yarn strength

Fabric made from	Warp direction	Weft direction
Ring yarns	1.08	1.15
Rotor yarns	1.29	1.41
Air-jet yarns	1.43	1.57
Ring-warp/ OE-friction-weft	1.22	1.48

Table 2—Structural parameters of yarns and yarn-to-yarn friction force

Yarn	Mean fibre extent, mm	% Hooked fibres	Yarn diameter, μm	Friction force, cN
Ring	30.2	28	209	7.5
Rotor	20.4	37	220	11.3
Air-jet	33.3	20	182	10.6
OE-friction	13.7	52	245	12.1

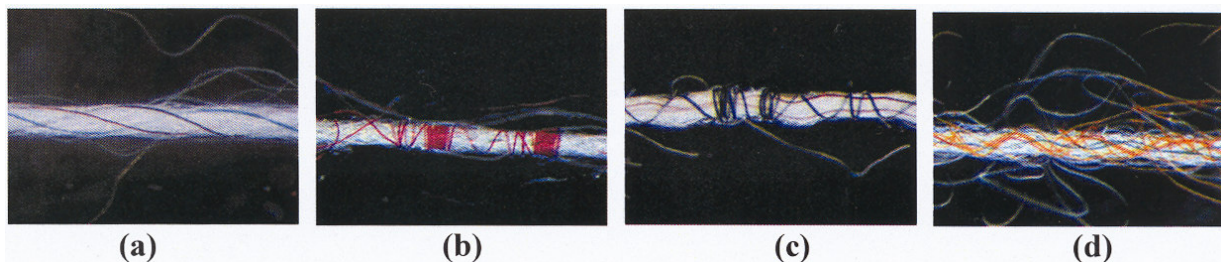


Fig. 3—Structure of yarns [(a) ring, (b) rotor, (c) air-jet, and (d) OE-friction spun yarns]

structures with larger diameter provides larger area of contact between the warp and the weft yarns, increases the frictional assistance of yarns, and hence shows a higher S-Y ratio compared to ring and ring yarn combinations.

It is observed from Table 2 that the yarn-to-yarn friction force is the maximum for OE-friction yarn followed by rotor, air-jet, and ring yarns. Friction in a fibrous assembly mainly depends upon the characteristics of the surfaces which are mutually in contact, in addition to the magnitude of the normal pressure acting between them. Since the surface structure of yarn decides the true area of contact at a given normal pressure, it is expected that the difference in surface structures of these yarns will also be reflected in their frictional behavior.⁹ An OE-friction spun has disorderly arranged helical fibres with inferior degree of orientation and the surface of this yarn contains many loose hairs and loops (Fig. 3). The failure mechanism of single yarn is predominantly by fibre slippage (Table 3). The larger yarn diameter (Table 2) along with its loose structure increases the area of contact between the yarns and hence, the OE-friction spun yarn shows highest inter-yarn friction force than the other yarns. In contrast to this, a lowest friction level for ring-spun yarn is due to the fact that it is characterized by an assembly of helically arranged, well aligned fibres providing relatively a smoother surface to the yarn. The presence of wrapper fibres in the rotor and air-jet spun yarns causes a rougher surface to these yarns. Therefore, the yarn friction forces of rotor and air-jet yarns lie in an intermediate position. A highly compressible yarn will increase the area of contact at the warp and weft cross-over points. Yarn compressibility is expected to be higher for OE-friction spun yarn followed by rotor, ring, and air-jet yarns.

Table 3 shows the values of percentage of broken fibres in the yarns due to the tensile failure of stand-

alone single yarns and the yarns inside the fabric. A higher percentage of fibre ruptures when yarns break inside the fabric indicates that the mechanism of yarn failure inside the fabric is quite different as compared to that of single yarn. This is due to the interactive binding effect between warp and weft yarns inside the fabric under the application of load. The percentage increase in broken fibres of the yarns in fabrics (weft way) from that of single yarns are 28.6, 28.7, 20 and 8.5 respectively for the OE-friction, air-jet, rotor and ring yarns. These values have a high degree of negative correlation (-0.914) with respect to the observed percentage of broken fibres in the corresponding tensile failure of stand-alone single yarns at the same gauge length. This trend indicates that the fabric assistance or S-Y ratio would be higher for weaker yarns than for stronger yarns and the fabric assistance is essentially a phenomenon of reducing the incidence of fibre slippage provided as a result of gripping the longitudinal yarns by the crossing yarns, thus improving the strength contribution of the former to the fabrics.

The thread pull-out tension actually increases during the experiment as the yarn is being pulled, crest at the peak load and then decreases. It is noticed that when the thread pulling tension reaches the peak value of the load, the entire yarn then begins to translate within the fabric and the pull-out force gradually decreases with displacement. The oscillations in the force-displacement curve during yarn translation correspond to the stick-slip phenomenon as the individual cross yarns are passed over by the translating yarns.

Figure 4 depicts the corresponding force-displacement curves for the pull-out of warp thread (by solid line & star) and weft thread (by solid line) from the fabric made of different spun yarns. The maximum values of yarn pull-out forces are given in Table 4. Yarn pull-out force from fabric depends on bending rigidity of that yarn and yarn-to-yarn friction. The former depends on elastic modulus and diameter of the yarn as well the curvature to which it bends in the fabric. The curvature to which a yarn bends in the fabric is influenced by the diameter of the yarn and its compressibility. It is evident from Tables 2 and 4 that the yarn-to-yarn friction forces and maximum thread pull-out forces in the weft direction show the same trend. Further, a close look at the values of maximum pull-out forces in weft direction reveals that the higher pull-out forces are observed when the yarns to

Table 3—Percentage of broken fibres in single yarns and their failure within fabrics

Yarn	Single yarn tenacity cN/tex	Broken fibres in single yarn %	Broken fibres in yarn during failure of fabrics, %	
			Warp direction	Weft direction
Ring	14.9	73.7	75.5	80.2
Rotor	11.2	61.1	64.7	73.3
Air-jet	10.8	55	64.0	70.8
OE-friction	6.2	42.3	-	54.4

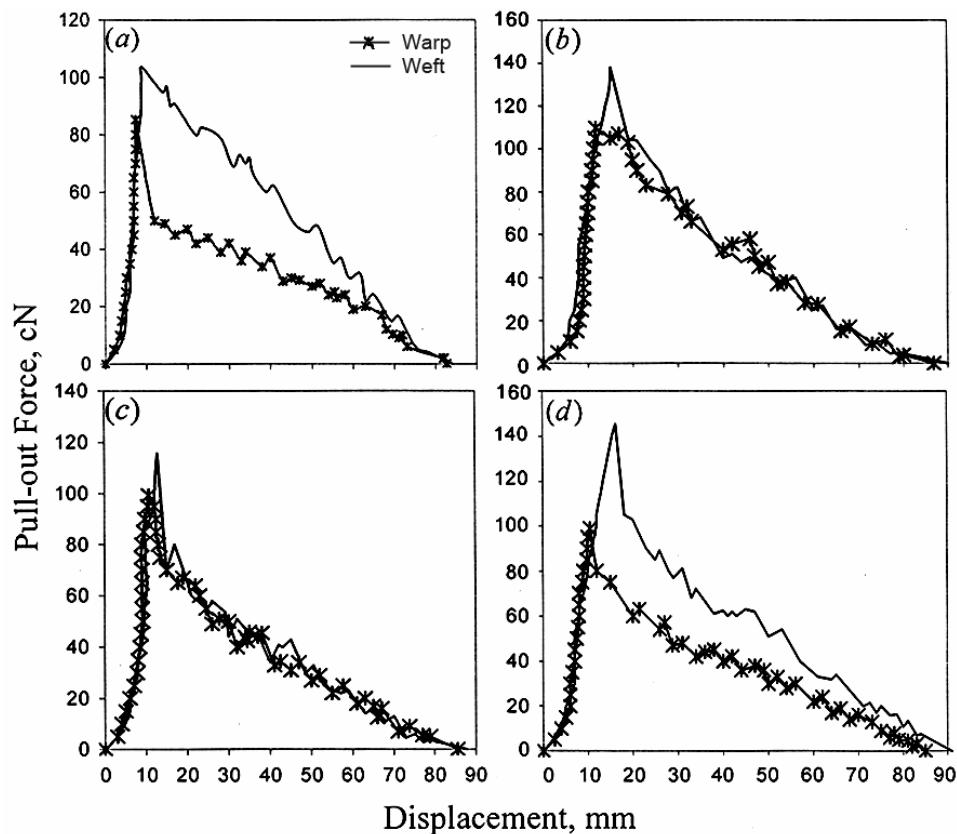


Fig. 4—Force-displacement curves of yarn pulling from the fabric made of (a) ring yarns (b) rotor yarns, (c) air-jet yarns and (d) ring yarns as warp and OE friction yarns as weft

Table 4—Maximum values of yarn pull-out forces

Fabric made from	Maximum yarn pull out force, cN	
	Warp direction	Weft direction
Ring yarns	85.3	103.6
Rotor yarns	109.8	138.1
Air-jet yarns	99.2	115.7
Ring warp & OE friction weft yarns	98.8	145.4

be pulled have larger diameters (rotor and OE-friction yarns). This trend could not be seen clearly in warp direction except for rotor yarn because of the interactive of different yarn combination (ring and OE-friction), elastic modulus, compression and friction effect of yarns.

It is difficult to simulate the friction conditions of the yarns inside the fabric (transverse load between the yarns and their relative sliding speed) during yarn-to-yarn friction testing. The tension of the yarn during friction testing is only 5 cN, quite a lower value and the sliding speed 50 mm/min is much higher compared to that expected inside the fabrics during

tensile testing of fabrics. It is believed that the testing of yarn-to-yarn friction under conditions that exist inside the fabric during tensile testing would give higher friction force value for air-jet and rotor yarns. This also explains the observed higher S-Y ratios for these yarns.

4 Conclusions

The ratio of fabric strip strength per yarn to single yarn strength is the lowest for ring-spun yarn, whereas air-jet spun yarn has the maximum. The value of yarn-to yarn friction force is significantly lower for ring yarn as compared to other yarns. Percentage of broken fibres increases when the yarns break inside the fabric, which indicates a change in the failure mechanism of yarns in fabric. The major cause of the fabric assistance is the gripping effect of yarns at cross-over points that significantly reduces fibre slippage. Hence, the weaker the yarn the higher is the fabric assistance. The factors, viz yarn-to-yarn friction, yarn diameter and extent of flattening of yarns, do influence the extent of gripping of yarns at cross-over points, thus the fabric assistance.

Industrial Importance: This study proves that the weaker yarns produced from rotor, air-jet and OE-friction technologies can be woven into fabrics and these fabrics might be having strengths similar to that of ring yarn fabrics. The structures of these yarns viz looseness and surface fibres have substantial influence on translation of fibre strengths into fabric strength. This phenomenon can be further exploited by manipulating the thread densities in the fabrics.

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