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Effect of Fiber Friction, Yarn Twist, and Splicing Air Pressure on Yarn Splicing Performance

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Abstract: The impact of fiber friction, yarn twist, and splicing air pressure on mechanical and structural properties of spliced portion have been reported in the present paper. The mechanical properties include the tensile and bending related properties and, in the structural properties, the diameter and packing density of the splices are studied. A three variable three level factorial design approach proposed by Box and Behnken has been used to design the experiment. The results indicate that there is a strong correlation between retained spliced strength (RSS) and retained splice elongation (RSE) with all the experimental variables. It has been observed that RSS increases with the increase in splice air pressure and after certain level it drops, whereas it consistently increases with the increase in yarn twist. The RSE increases with the increase in both fiber friction and yarn twist. It has also been observed that the yarn twist and splicing air pressure have significant influence on splice diameter, percent increase in diameter and retained packing coefficient, but the fiber friction has negligible influence on these parameters. Yarn twist and splicing air pressure has a strong correlation with splice flexural rigidity, where as poor correlation with retained flexural rigidity.

Keywords: Splicing, Retained splice strength, Retained splice elongation, Flexural rigidity, Fiber friction, Yarn twist

Introduction

Knotting is the traditional practice of joining the yarn ends. But knotting, in many occasions, causes serious defects in the fabric appearance due to its width and length of tail ends. Frequent failures of the knots also affect the process efficiency [1]. Several knot free yarn joining methods have been developed like adhesive bonding, wrapping, fusion bonding, electrostatic splicing, mechanical splicing and pneumatic splicing. The splice has replaced the knot, which had detrimental effect on appearance and performance in downstream processing. Among different splicing technique, the pneumatic splicing is most popular because of better processing behavior of spliced yarn in weaving and knitting and also the simplicity of splicing mechanism. The pneumatic splicing has been accepted as a better means of yarn joining and now became indispensable in textile processing of knot free yarn joins. In pneumatic splicing, the yarn ends are overlapped in a turbulent air blast adjustable in duration and consumption to meet the needs of the spliced yarn quality [2-4]. Pneumatic splicing produces splices of adequate strength and appearance with only slight increase in the normal diameter of the yarn. Previous studies [5,6] revealed that splice comprises of three regions viz. wrapping, twisting and intermingling. Bulk of the spliced yarns is from ring spinning technology. Because of the smaller size of ring bobbins as well as the necessity of clearing faults from ring yarns, high-speed winding machines are normally equipped with splicing attachments for making knot free joints. The structure of ring yarn (nearly helical) facilitates the easy removal of the twist and helps in good opening of the yarn.

Even though it was introduced long before, not much research work has yet been reported on the effectiveness of spliced yarn spun from fiber of different properties like fiber to fiber friction, length, fineness, torsional rigidity etc. A number of studies [7-11] were reported on how material and machine variables affect the spliced yarn quality parameters like splice strength, appearance, flexural and other properties. Machine variable like compressed air pressure, its duration and splice length are considered to be significant. It was thought that among all fiber properties, fiber-to-fiber friction plays an important role in splicing performance. According to the basic principle of splicing, the air vortex in the splicing chamber generates torque which rotates the individual fibers of the two yarn ends thus causing fiber-to-fiber intermingling and binding in this zone. During intermingling, as there is interaction between the fibers of two yarns ends then it is expected that frictional properties of fiber have tremendous effect on the spliced yarn qualities.

In this present study, an attempt has been made to correlate the fiber variable (fiber-to-fiber friction), the yarn variable (yarn twist) and the machine variable (splicing air pressure) with tensile properties of splicing performance and also to investigate the combined influence of these parameters on mechanical properties and structure of spliced portion.

Experimental

Raw Material

Medium grade cotton (J-34) was dyed in the different shades with natural dyes to get different level of frictional coefficients. The reason for using natural dyes is that these dyes are mainly surface deposition types resulting significant change only in frictional properties of fiber and the other

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Table 1. Details of properties of grey and dyed cotton

Parameters	Grey cotton	Linen dyed cotton	Blue dyed cotton
2.5 % span length	26.8	26.6	26.7
50 % span length	13.3	13.0	12.9
Uniformity ratio (%)	49.6	48.9	48.3
Short fiber content (%)	10.25	10.38	10.46
Fiber fineness, μg/inch	3.90	3.96	3.88
Bundle strength (g/tex)	21.63	21.64	21.49
Coefficient of friction	0.3	0.4	0.5

properties are least affected. The properties of grey and dyed cotton are given in Table 1.

Experimental Design

A three-variable factorial design technique proposed by Box & Behnken [12] has been used to investigate the influence of three variables, i.e. fiber-to-fiber friction, yarn twist and splicing air pressure. The actual values of the three variables corresponding to coded levels and the experimental combinations of coded levels as per the Box & Behnken model are given in Tables 2 and 3 respectively.

Table 2. Actual values of the three variables along with the coded levels

Factors	Levels		
	−1	0	+1
Fiber to fiber friction (X_1)	0.3	0.4	0.5
Yarn TM (X_2)	3.5	4	4.5
Air pressure during splicing (X_3), bar	4	5	6

Table 3. Experimental combinations of coded levels as per the Box & Behnken model

Sample no.	Coded factor level		
	X_1	X_2	X_3
1	−1	−1	0
2	+1	−1	0
3	−1	+1	0
4	+1	+1	0
5	−1	0	−1
6	+1	0	−1
7	−1	0	+1
8	+1	0	+1
9	0	−1	−1
10	0	+1	−1
11	0	−1	+1
12	0	+1	+1
13	0	0	0
14	0	0	0
15	0	0	0

Sample Preparation

All the cotton fibers were processed through blowroom, card and two passages of draw frames (breaker and finisher) to get the finisher draw frame slivers.

Roving Preparation

The finisher draw frame slivers with three different friction levels were then processed in roving frame (LF 1400A). For all the samples the draft ratio given at roving frame was 7.1, TM (twist multiplier) was 1.3 and the linear density of roving produced was 0.575 ktex.

Yarn Preparation

Sufficient quantities of yarn samples of linear density 29.5 tex were produced in ring frame (LG5/1) from rovings of three different types of cotton with various TM level (Table 3). The optimum processing parameters in the ring frame for all the yarns are as follows:

Back zone setting : 60 mm
Front zone setting : 42.5 mm
Break draft : 1.13
Spindle speed : 13000 rpm
Total draft : 19.10
Traveler count : 2/0
Spacer size : 3.75 mm

Splice Preparation

The three sets of 29.5 tex yarns with various level of fiber friction and yarn twist were processed in Schlafhorst automatic cone winder (Autoconer-338) and deliberately splices were introduced by varying the splicing air pressure (Table 2). The spliced portions were prepared in such a way that the cutter deliberately cut the yarn at particular length interval and the splicer inserted the splice. After that allowing the drum to rotate for few turns so that the distance between two consecutive splice joints were around 1.5-2 meter. The same process was repeated subsequently to get enough splice joints in the wound yarn. About 200 splice joints were prepared for each run. In this way 15 different combination of sample were prepared in a random sequence by varying the splicing air pressure (Tables 2 and 3).

Testing of Materials

Fiber Testing

Cotton fibers were tested for span lengths, uniformity ratio and short fiber content in the Classifiber KCF/LS from Keisokki, Japan. Fiber fineness was measured using air-flow method and the fiber bundle strength was evaluated using Stelometer. Fiber-to-fiber friction was measured by a fiber friction tester using fringe method. The detail test results are given in Table 1.

Yarn and Splice Testing

30 splices for each run were tested for the breaking strength

and elongation at gauge length of 100 mm and traverse speed of 50 mm/min on Statimat-ME tensile tester. The parent yarns were also tested for their tensile properties keeping the same test parameters. Two splice performance indicative parameters have been determined; these are tensile strength and breaking elongation of the spliced yarn in terms of retained splice strength (RSS) and retained splice elongation (RSE). The derivations of these two parameters are as follows,

$$\text{RSS, \%} = \frac{\text{Breaking strength of spliced yarn}}{\text{Breaking strength of parent yarn}} \times 100$$

$$\text{RSE, \%} = \frac{\text{Breaking elongation of spliced yarn}}{\text{Breaking elongation of parent yarn}} \times 100$$

The flexural rigidity of the yarns and the splice portions was measured by the ring loop method [13]. A ring of known circumference (L) was deflected under a constant load (M) and the position of each loop was observed before and after loading. The observations were termed as R_1 and R_2. The yarn deflection D_1, i.e. $(R_1 - R_2)$ was tabulated and respective values of Z i.e. (D_1/L) were read from the supplied table. These values were then used to calculate the corresponding values of flexural rigidity (ML^2/Z). The flexural rigidity results of the spliced portion were compared with the parent yarn. The flexural rigidity of the spliced yarn was expresses as retained bending rigidity (RFR) rather than absolute flexural rigidity and the derivation is as follows;

$$\text{RFR, \%} = \frac{\text{Flexural rigidity of spliced portion}}{\text{Flexural rigidity of parent yarn}} \times 100$$

The diameters of the splice joints were measured at particular interval along the length of the splices using Leica microscope. The average diameters of the spliced portion and the corresponding parent yarns were calculated. Averages of 100 readings per sample were taken. From this diameter the packing coefficient has been calculated as follows.

Yarn specific volume $(V_y) = (\pi D^2/4T) \times 10^5$ cc/g
Fiber specific volume $(V_f) = 1/\rho_f$

where D is yarn diameter in cm, T is yarn linear density in tex and ρ_f is fiber density in g/cc. The packing coefficient

Table 5. Structural properties of parent yarns and spliced portions

Sample no.	Diameter (μm)	Packing coefficient	Increase in diameter (%)	RPC (%)
1	262.6 (330.7)	0.35 (0.22)	25.94	62.71
2	251.8 (312.1)	0.38 (0.25)	23.91	65.10
3	241.2 (301.9)	0.42 (0.27)	25.17	63.72
4	237.6 (295.5)	0.43 (0.28)	24.38	64.81
5	251.4 (322.0)	0.38 (0.23)	28.08	61.03
6	241.0 (311.6)	0.42 (0.25)	29.27	59.76
7	259.5 (323.3)	0.36 (0.23)	24.58	64.36
8	242.3 (304.9)	0.41 (0.26)	25.86	63.13
9	256.0 (331.8)	0.37 (0.22)	29.62	59.43
10	242.4 (309.2)	0.41 (0.25)	27.53	61.59
11	250.4 (312.7)	0.39 (0.25)	24.86	64.17
12	243.4 (308.9)	0.41 (0.25)	26.92	62.04
13	242.5 (307.2)	0.41 (0.26)	26.71	62.31
14	246.9 (310.3)	0.40 (0.25)	25.67	63.40
15	244.1 (306.5)	0.41 (0.26)	25.60	63.32

Note: Values in the parenthesis are the properties of spliced portion.

Table 4. Mechanical properties of parent yarns and spliced portions

Sample no.	Breaking strength (cN/Tex)	Breaking elongation (%)	Flexural rigidity (mg·cm^2)	RSS (%)	RSE (%)	RFR[a] (%)
1	10.73 (9.19)	7.83 (5.91)	2.08 (4.84)	85.64	75.40	232.50
2	13.76 (12.02)	6.31 (3.93)	2.23 (5.10)	87.35	62.28	228.96
3	15.06 (13.86)	5.61 (4.42)	3.00 (7.93)	92.03	78.78	264.17
4	16.18 (14.08)	4.16 (4.07)	3.43 (8.10)	87.02	97.83	236.10
5	13.98 (11.30)	5.58 (4.18)	2.47 (5.46)	80.83	74.90	220.07
6	15.95 (11.60)	6.88 (5.65)	2.88 (5.51)	77.71	82.12	191.41
7	14.11 (10.34)	5.47 (4.51)	2.37 (5.58)	73.34	82.47	235.66
8	15.27 (12.92)	5.11 (4.01)	2.62 (6.13)	84.63	78.47	233.80
9	11.80 (9.38)	6.45 (3.66)	2.09 (5.07)	79.49	56.74	242.30
10	15.40 (14.44)	5.22 (4.25)	3.74 (6.23)	80.12	81.41	166.66
11	12.09 (9.06)	5.48 (4.16)	2.17 (5.90)	74.94	75.91	271.88
12	14.59 (12.03)	5.82 (4.26)	3.52 (8.56)	82.51	73.15	242.90
13	13.67 (11.52)	5.39 (4.55)	2.59 (5.98)	84.27	79.60	230.42
14	14.92 (12.57)	7.06 (5.62)	2.71 (6.14)	84.45	84.41	226.72
15	14.01 (12.01)	6.95 (5.51)	2.83 (6.36)	85.72	79.28	224.65

Note: Values in the parenthesis are the properties of spliced portion, [a]lower the value of RFR means better splicing performance.

Table 6. Response surface equations for mechanical and structural properties of splice

Characteristics	Response surface equation	R^2
Retained splicing strength (RSS), %	$Y = 86.549 + 1.863X_2 - 7.325X_3^2 + 3.602X_1X_3$	0.818
Retained splicing elongation (RSE), %	$Y = 77.517 + 1.863X_2 - 6.857X_2X_3 + 3.602X_1X_2$	0.741
Splice flexural rigidity, mg·cm^2	$Y = 5.882 + 1.239\ X_2 + 0.488X_3 + 0.588X_2^2$	0.856
Retained flexural rigidity (RFR), %	$Y = 229.88 + 20.475X_3 + 12.437X_2^2$	0.438
Splice diameter, μm	$Y = 309.199 - 8.975X_2 + 6.366X_3^2$	0.792
Increase in diameter, %	$Y = 25.336 + 1.535X_3 + 1.754X_3^2 + 1.037X_3X_2$	0.825
Retained packing coefficient (RPC), %	$Y = 63.624 + 1.490X_3 + 1.689X_3^2 + 1.080X_3X_2$	0.800

(Φ) is calculated as follows,

$$\Phi = V_f/V_y$$

The percent increase in diameter (D_i) is measured by using following equation,

$$D_i\,(\%) = \frac{\text{Diameter of spliced portion} - \text{Diameter of parent yarn}}{\text{Diameter of parent yarn}} \times 100$$

Similarly the packing coefficient value was expressed as retained packing coefficient (RPC).

$$\text{RPC, \%} = \frac{\text{Packing coefficient of spliced portion}}{\text{Packing coefficient of parent yarn}} \times 100$$

The details of the test results for all the yarn and splice samples are given in Tables 4, 5 and 6.

Results and Discussions

Mechanical Properties

Effect on Retained Splice Strength

Tensile properties and the response surface equations of parent yarn and the spliced portions are given in Tables 4 and 6 respectively. From the equation of retained spliced strength it is clear that strength retention property is well correlated with fiber friction, yarn twist multiplier (TM) and splicing air pressure, i.e. R^2 value of 0.818. The contour plots (Figures 1 and 2) show the influence of fiber friction, yarn TM and splicing air pressure on retained splice strength (RSS). Figure 1 shows that for a constant fiber friction ($\mu = 0.4$) with the increase in yarn TM the strength retention values go up. The trend is same for other friction level also. This may be due to the fact that after the splice formation there is leaking of twist to the spliced portion takes place from the parent yarns on either side of the joint and hence higher twist level of parent yarn results more twist leaking. As the splice portion contains less twist as compared to the other part of yarn, so it helps in improving the binding of fibers in this region. So higher splice strength is realized as the yarn TM increases. But at the same time parent yarn strength also increases with TM. So the rate at which strength increases due to leaking of twist to the spliced portion may be higher as compared to the rate at which parent yarn strength increases due to increase in yarn TM.

It is clear from Figrue 2 that at constant yarn TM, with the increase in splicing pressure the spliced strength retention increases up to a certain level of air pressure and with further increase in air pressure it deteriorates. This may due to initial increase in splicing air pressure the torque increases which

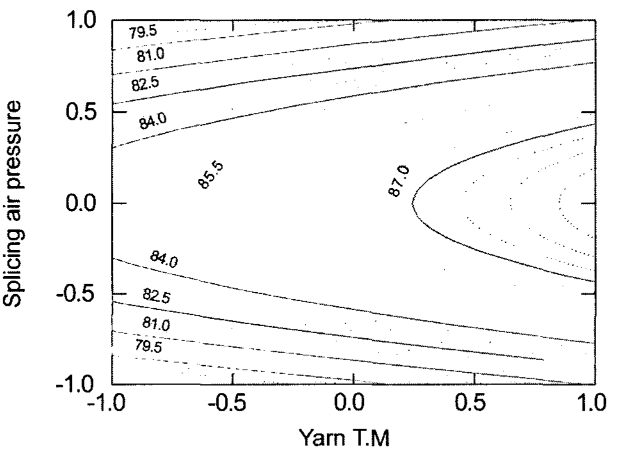

Figure 1. Contour plot showing retained splice strength at different levels of yarn twist and splicing air pressure.

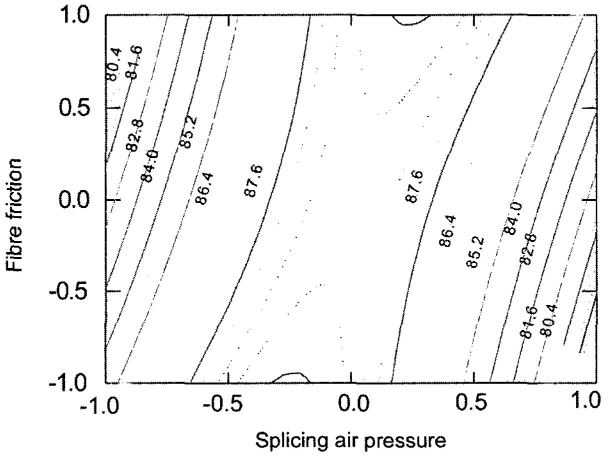

Figure 2. Contour plot showing retained splice strength at different levels of fiber friction and splicing air pressure.

facilitate better intermingling of fibers in the overlapped region and binding gets improved. But after reaching saturation level there is no further improvement in binding of fibers, rather decreases. This may be due to very high splicing torque creates turbulence which has adverse effect on intermingling and binding of fibers, resulting decrease in RSS. And also at lower splicing air pressure, as fiber friction value goes up there is marginal decrement in strength retention, this may due to intermingling is not so effective at low splicing air pressure and ultimately binding of fiber is not good. At the same time parent yarn strength increases as fiber friction increases. So the ratio of splice strength to parent yarn strength decreases. But at higher level of air pressure, the trend is just opposite. This may be due to that at higher level of air pressure, good intermingling takes place and binding is effective.

Effect on Retained Splice Elongation

The results of retained splice elongation (RSE) for different variable combinations and the response surface equation are also given in Tables 4 and 6. The results indicate that the RSE has significant correlation with all the three variables, i.e. R^2 value of 0.741. The contour plots (Figures 3 and 4) show the influence of fiber friction, yarn TM, splicing air pressure on retained splice elongation. It is evident from Figure 3 that at lower level of yarn TM as the splicing air pressure increases the retained elongation value increases, but the trend is just reversed at higher yarn TM. Similar trend is observed for all the experimental frictional coefficients of fibers. Figure 4 shows that at lower level of fiber friction as the splicing air pressure increases the retained splice elongation value increases, but the trend is just reversed at higher fiber friction. This is probably attributed as both yarn TM and fiber friction cause significant reduction of the parent yarn elongation. As fiber itself takes more helical path and in high tension as yarn TM increases. At the same time the effect is getting magnified by higher fiber friction. So the fibers would not get straighten as the tension is applied, in turn causes significant reduction in parent yarn elongation. But in case of splice portion, the structure of spliced portion is different from the parent yarn structure i.e. random arrangement of fibers in that portion. So the retained elongation value improved as both yarn TM and fiber friction increased.

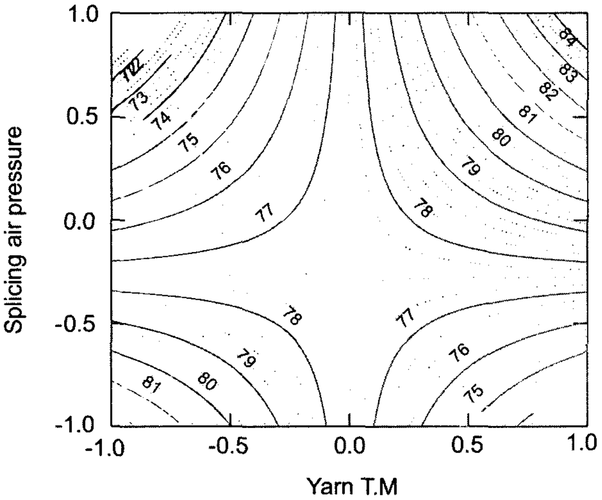

Figure 3. Contour plot showing retained splice elongation at different levels of yarn twist and splicing air pressure.

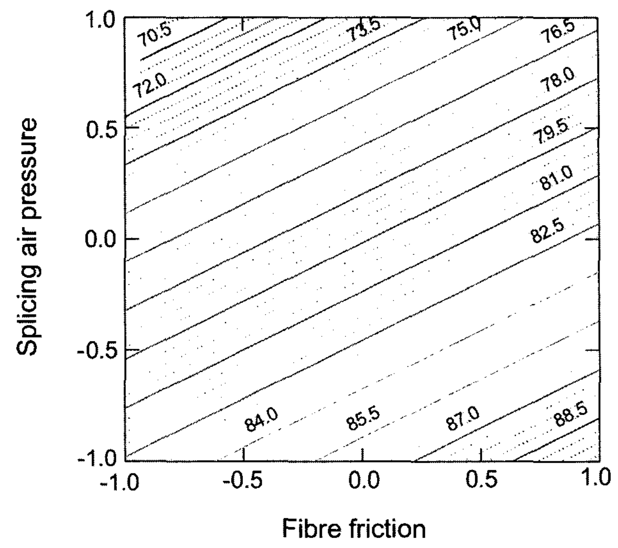

Figure 4. Contour plot showing retained splice elongation at different levels of fiber friction and splicing air pressure.

Effect on Retained Flexural Rigidity

The result of both parent yarn and splice flexural rigidity and retained flexural rigidity (RFR) and the response surface equations for different variable combinations are shown in Tables 4 and Table 6 respectively. The response surface equation indicates that splice flexural rigidity has a good correlation with air pressure and yarn TM, i.e. R^2 value of 0.856, and the fiber friction has little influence on splice flexural rigidity. It is clear from Figures 5 and 6 that with the increase in both

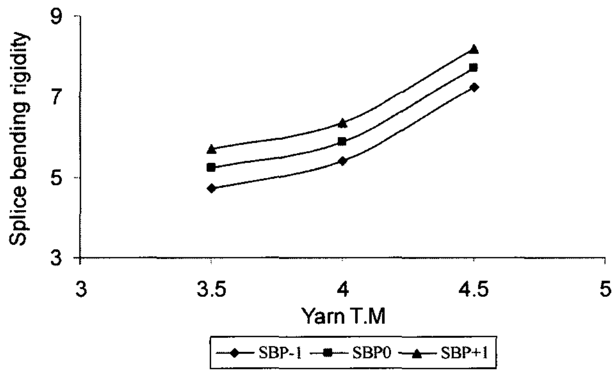

Figure 5. Effect of yarn twist on splice flexural rigidity at different level of air pressure.

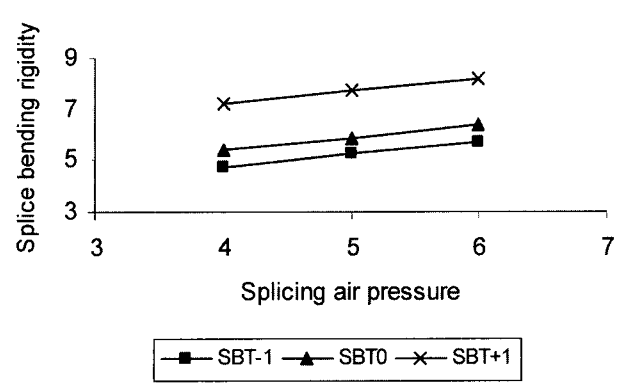

Figure 6. Effect of splicing air pressure on splice bending rigidity at different level of yarn twist.

splicing pressure and yarn TM the splice flexural rigidity increases. As the yarn TM and the splice air pressure increase the compactness of splice increases. In case of higher yarn TM the increase in compactness of splice is due to flow of twist from yarn body to splice portion and in case of higher air pressure it is due to more fiber intermingling. The response surface equation for RFR shows poor correlation with yarn TM and splicing air pressure, i.e. $R^2 = 0.438$.

Structural Properties

Effect on Increment in Diameter

The results of splice and parent yarn diameter and percent increment in diameter for different variable combinations and the response surface equations are given in Tables 5 and 6 respectively. From the results of splice and parent yarn diameter and increase in diameter and response surface equations, it is clear that percent increase in diameter has a good correlation with yarn TM and splicing air pressure i.e. R^2 value of 0.825. Fiber friction has negligible influence on splice diameter and percent increase in diameter. At lower level of splicing air pressure with the increase in yarn TM the percent increase in diameter drops, but at higher level of splicing air pressure the trend is just reverse (Figure 7). This may be due to the fact that at the splice portion the compactness is due to the combined effect of two phenomenon, one is the splicing torque which rotates the yarn ends inside the splicing chamber and another is the leaking of twist from the parent yarn to the joint from either side of splice after the formation of splice. So at reduced level of splicing pressure as we increase the yarn TM the phenomenon of licking of twist dominates over the splicing torque, so compactness achieved and increment in diameter decreases. But at higher pressure and higher TM, it is expected that very high splicing air pressure creating turbulence, causing the extensive opening of the beards causing more open up structure, which neutralizing the effect of leaking of twist due to higher yarn TM. It is also observed from Figure 8 that as the splicing air pressure increases the increment in diameter decreases significantly up to a certain level and with further increase in air pressure cause marginal increase in increase in diameter. This is because of the fact that as the splicing torque increases it helps in better intermingling of fibers, so binding is effective and ultimately compactness achieved. So it was reducing the diameter of spliced joint. But at very high splicing air pressure may be the turbulence has adverse effect on intermingling and so binding. So it is causing the increment in diameter and in turn the percent increase in diameter

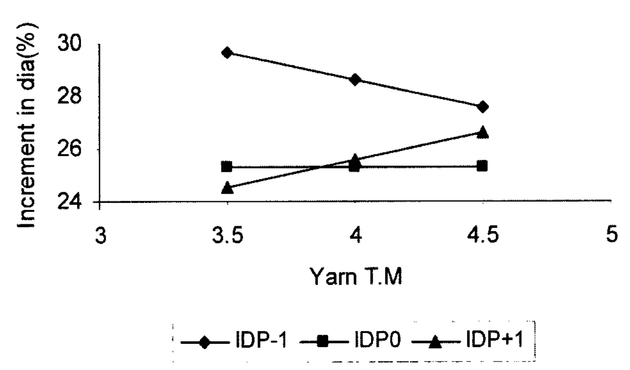

Figure 7. Effect of yarn twist on increment in diameter at different level of splicing air pressure.

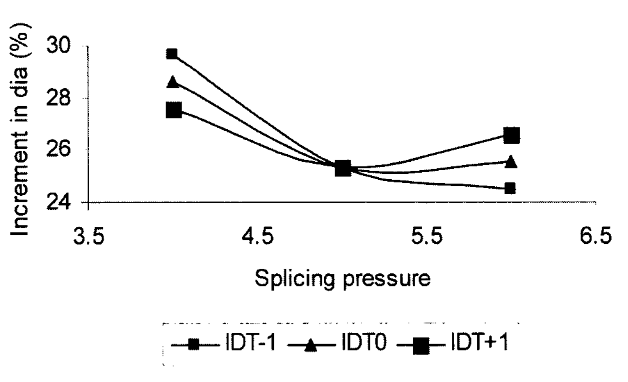

Figure 8. Effect of splicing air pressure on increment in diameter at different level of yarn twist.

Effect on Retained Packing Coefficient

The results of packing coefficients of parent yarn and spliced portion, retained packing coefficient for different variable combination and the response surface equation are shown in Tables 5 and 6 respectively. The response surface equation indicates that the retained packing coefficient has significant correlation with yarn TM and splicing air pressure, i.e. $R^2 = 0.800$, and fiber friction has negligible influence on packing coefficient and ultimately retained packing coefficient. As the packing coefficient is calculated from diameter, so the trend is almost similar to that of diameter.

Conclusions

The correlation coefficient between retained splice strength and retained splice elongation with fiber friction, yarn twist and splicing air pressure is fairly good, i.e. R^2 value is 0.818 and 0.741 respectively. The retained splice strength first increases with the increase in air pressure and after a certain level it deteriorates but it consistently increase with the increase in yarn twist.

Retained splice elongation increases with the increase in both fiber friction and yarn twist.

Yarn twist and splicing air pressure have significant influence on splice diameter, percent increase in diameter and retained packing coefficient, but the fiber friction has negligible influence on these parameters. At lower level of splicing air pressure as the yarn twist increases the percent increase in diameter reduces. But at higher level of air pressure the trend is reversed. Fiber friction has negligible influence on splice diameter and percent increase in diameter.

Yarn twist and splicing air pressure has a strong correlation with splice flexural rigidity, where as poor correlation with retained flexural rigidity.

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