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A study on fatigue behaviour of cotton/lycra core spun yarns

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Article

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ABSTRACT

Core spun yarn gives denim fabrics durability and flexibility, which has increased the focus on these yarns among denim manufacturers in recent years. These yarns undergo tensile fatigue loading, a typical phenomenon that happens on various parts of clothing, during use and wear. The study on the response of yarns during cyclic loading is essential because it leads to a better understanding of the growth characteristics when repeatedly loaded during the use of core spun yarn fabrics. In this study, the impact of various production parameters such as linear density, stretch percentage, twist multiplier, and the number of cyclic loading on the fatigue value of core-spun yarns was investigated. 18 different core spun yarns were manufactured by modified ring spinning to investigate the effect of various production parameters on fatigue value before and after 10, 20, and 30 load cycles. Experimental results showed that there is an increase in fatigue value with an increase in the number of load cycles. Statistical analysis showed that there is a significant effect of linear density, stretch percentage, and twist multiplier on the fatigue value of yarn. There is a reduction in fatigue value with an increase in linear density, stretch percentage, and twist multiplier of yarn. The contribution of the number of cyclic loading was found to be more dominating in comparison to other process parameters like linear density, twist multiplier, and stretch percentage on the fatigue value of core-spun yarns.

KEYWORDS

fatigue value, stretch percentage, twist multiplier, cyclic loading, linear density

INTRODUCTION

The demand for stretch denim is expanding day by day among all genders, age groups, and professionals, due to its higher quality, comfort, tensile strength, and stretch-to-fit properties [1,2]. Stretch yarns are used in the weft during the weaving of stretch denim [3,4]. Stretchable yarns are often manufactured through the core spinning technique, where stretchable fibres/filaments (spandex/lycra) can be used as the core and produced through various available technology like ring spinning, friction spinning, rotor spinning, and air jet/vortex spinning [3,5-8]. Each spinning technique has its features. Out of all mentioned techniques ring spinning is simple, economical, has great strength, outstanding abrasion resistance, and flexibility for the stretch requirements, as well as the ability to generate a wide range of yarn counts [9,10].

Elasticity is a desired attribute in denim fabric because it improves wear comfort, crease resistance, durability, drape, and handle [3,7,11,12]. The stretch encountered during various activities like sitting, bending, or flexing of knees can be used to evaluate the stretch requirements of denim fabric. Consumers, on the other hand, seek low fabric permanent elongation for dimensional stability and long-term flexibility [13]. Long-term and repetitive stresses during use result in growth or permanent elongation [14]. Bagging occurs at the elbows, knees, pockets, hips, and heels as a result of these repetitive stresses [15].

In a variety of applications, yarns are frequently required to support tensile cyclic loads. It is necessary to know the fatigue behaviour of the yarns constituting the fabric after repetitive dynamic loads to understand the permanent elongation developed in the fabric during the use [5]. Fatigue is defined as the failure of material after repeated stress at a level lower than that required to cause failure in a single application of stress. The mechanical characteristics of the yarns are impacted by repeated loading, which may result in degradation or even failure.

Lyons and Prevorsek investigated behaviour of fibres and fibrous materials under various conditions [16-19]. Nylon 6.6, polyester, and polypropylene fatigue characteristics were investigated by Hearle and Wong [20]. Subramaniam et al. investigated the fatigue life of open-end, ring spun, and siro spun yarns using the method of biaxial rotation over a pin. Anandjiwala et al. examined the failure, damage rate, and visual characteristics of the warp yarn's fatigue behaviour under cyclic elongation and abrasion [21]. Nasri and Lallam investigated behaviour of technical polyamide fibres under fatigue [22]. The fatigue behaviour of textured polyester woven fabrics was modeled by Asayesh et al. [23]. Frank and Singleton analysed the variables affecting the tensile fatigue behaviour of yarns [24]. The tensile fatigue behaviour of cotton and cotton-polyester blended yarns at two strains has been studied by Jeddi et al. [25]. The impact of tensile fatigue on the mechanical characteristics of polyester, nylon, and polypropylene filament yarns has been examined by Jamshidi at two strokes and two frequencies [5].

Although a lot of studies have been done on the fatigue behaviour of fibres and yarn, relatively little of it has analysed the fatigue behaviour of core spun yarn and the effects of different process parameters. In the present study, an attempt has been made to study the variation in fatigue value of lycra/cotton spun yarn after several cyclic loading. An attempt has also been made to investigate the effect of various factors like linear density, stretch percentage, twist multiplier of yarn and the number of cycling loading on the fatigue value of lycra/cotton spun.

EXPERIMENTAL

Materials and Methods

Fibre Used

Cotton staple fibre and lycra monofilament filament (70 Denier) were used to prepare yarn samples. Two varieties of cotton J 34 and Sankar 6 were mixed in a 50/50 ratio in the blow room stage.

Yarn Samples Preparation

Three different yarns with a linear density of 73.82 Tex (8's Ne), 59.06 Tex (10's Ne), and 49.21 Tex (12's Ne) were spun each on a modified ring spinning system. The detailed setup arrangement is shown in Figure 1. Each linear density was produced with three different stretch percentages i.e. 3.2, 3.5, 3.8, and two different twist multipliers i.e. 4.2 and 4.5 on the ring spinning system. A full Factorial design was used and from the literature survey, a level of experimental parameters was chosen.

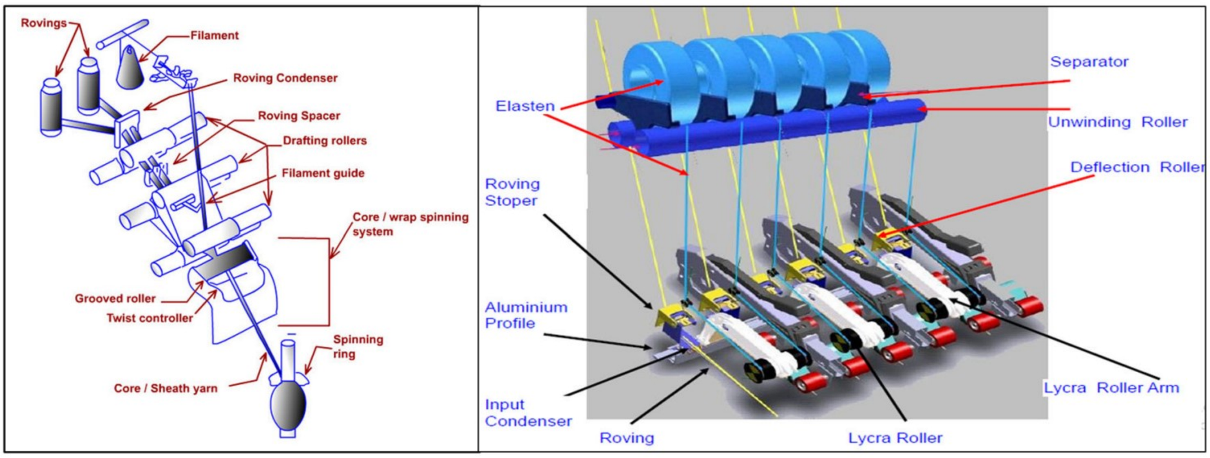

Figure 1. Manufacturing of core spun yarn on modified ring spinning [11]

Testing

Fatigue Test

The number of tensile fatigue cyclic loads was studied at values of 10, 20, and 30 cycles. The sample length was 250 cm. The speed of 85 mm/min was based on the method proposed by Hearl et al. and adopted for testing of fatigue value {FV(%)} [17]. Each sample was loaded up to 30% of its breaking elongation. Breaking load was measured for all the yarns after 10, 20, and 30 numbers of cycles. 30 loading cycles were chosen because many researchers tried to find out FV% near these loading cycles. Regarding the ASTM D2256, the yarn tensile properties were measured before and after applying tensile fatigue cyclic loads using a Zwick tensile tester, based on a constant rate of elongation (CRE) method. Each sample was tested 15 times and the average value was taken. The fatigue value of core spun yarn was determined using Eq. (1) [24].

$$FV\ (\%) = \frac{(Breaking\ load\ before\ cyclic\ load - Breaking\ load\ after\ cyclic\ load) \times 100}{Breaking\ load\ before\ cyclic\ load} \quad (1)$$

RESULTS AND DISCUSSION

Textile products are generally subjected to repetitive type of stress and strain during their end-use. The repetitive action of stress and strain can lead to structural changes through rearrangement and disintegration of fibers. Cyclic loading plays important role in such types of structural changes. FV% of core spun yarn at different cycles is presented in Table 1. To determine the influence of various parameters like linear density, twist multiplier, stretch percentage, and the number of cycles on FV%, data were evaluated using the ANOVA technique on Design Expert software. Table 2 shows the effect of these variables on FV%. It can be observed that the main effect, i.e. (A) linear density, (B) twist multiplier, (C) stretch percentage and (D) a number of cycles are discovered to have a significant impact on FV%. AC, AD, CD, and ACD interactions have a significant effect on the interaction effects.

Table 1. FV (%) value after cyclic loading

Tex	TM	Stretch %	Breaking Load (cN)		Breaking load after cyclic loading (cN)						FV (%)		
					Cycles						Cycles		
			Avg	Std	10		20		30		10	20	30
					Avg	Std	Avg	Std	Avg	Std			
73.8	4.2	3.2	1289	5.99	1047	5.28	943	6.25	848	6.89	18.72	26.83	34.21
		3.5	1224	4.68	997	5.11	898	6.24	807	6.89	18.51	26.58	34.02
		3.8	1154	4.26	944	5.22	851	5.23	763	5.68	18.18	26.23	33.84
	4.5	3.2	1305	5.24	1080	5.78	966	5.89	867	5.99	17.21	25.97	33.53
		3.5	1250	5.89	1036	5.95	928	6.25	834	6.87	17.05	25.72	33.21
		3.8	1170	7.65	973	7.69	871	7.99	783	8.22	16.81	25.51	33.02
59.0	4.2	3.2	1102	5.28	883	5.79	797	5.98	714	6.01	19.79	27.65	35.17
		3.5	980	4.55	788	5.24	711	5.82	637	5.94	19.52	27.38	34.92
		3.8	894	4.58	722	4.98	652	5.69	583	5.88	19.21	27.05	34.73
	4.5	3.2	1138	5.33	923	5.88	833	6.47	744	6.87	18.85	26.78	34.61
		3.5	1018	6.47	828	6.54	748	6.89	668	7.05	18.63	26.49	34.37
		3.8	921	6.98	751	6.36	679	6.57	607	6.86	18.41	26.17	34.02
49.2	4.2	3.2	906	4.57	718	4.89	647	5.25	581	5.69	20.75	28.49	35.84

Tex	TM	Stretch %	Breaking Load (cN)		Breaking load after cyclic loading (cN)						FV (%)		
					Cycles						Cycles		
			Avg	Std	10		20		30		10	20	30
					Avg	Std	Avg	Std	Avg	Std			
49.2	4.2	3.5	824	7.47	655	7.25	591	7.22	530	7.11	20.41	28.23	35.58
		3.8	701	4.28	559	4.39	505	5.26	454	5.69	20.18	27.91	35.13
	4.5	3.2	963	7.11	772	7.22	697	7.29	626	7.97	19.83	27.58	34.98
		3.5	876	6.28	704	7.01	637	7.69	572	7.66	19.58	27.24	34.69
		3.8	772	6.27	623	7.11	564	7.87	507	7.82	19.22	26.85	34.32

Table 2. ANOVA for FV% of core spun yarn at 95% confidence level

Effect	Sum of Square	Degree of Freedom	Mean Square	F	P
Intercept	38705.14	1	38705.14	1233447	0.00
Linear density (A)	28.13	2	14.06	4482	0.00
Stretch % (B)	2.78	2	1.39	443	0.00
TM (C)	11.03	1	11.03	3516	0.00
No. of cycles (D)	2168.00	2	1084.00	345447	0.00
AxB	0.04	4	0.01	3	0.07
AxC	0.11	2	0.06	18	0.00
BxC	0.00	2	0.00	0	1.00
AxD	1.27	4	0.32	101	0.00
BxD	0.01	4	0.00	1	0.62
CxD	0.25	2	0.12	40	0.00
AxBxC	0.01	4	0.00	0	0.74
AxBxD	0.01	8	0.00	1	0.78
AxCxD	0.27	4	0.07	21	0.00
BxCxD	0.01	4	0.00	1	0.52
Error	0.03	8	0.00	-	-

Effect of Number of Cycles on Fatigue Value of Yarn

The statistical analysis of variance (Table 2) shows a significant effect of the number of cycles on the fatigue value of yarn after cyclic loading. It is observed that there is a decrease in the tensile strength of cotton lycra core spun yarn after cyclic loading. After cycling loading there is the damage to fibre structure, the deterioration of the yarn structure, and loss in integrity which may be the reason for the decrease in breaking strength with an increase in the number of load cycles.

The maximum reduction in breaking strength of the core spun yarn is 20.75%, 28.49%, and 35.84% for 10, 20, and 30 load cycles respectively. The effect of the number of load cycles on FV% of yarn and the interaction effect of the number of load cycles, linear density (Tex), and stretch% on FV% of yarn are represented in Figure 2 and Figure 3 respectively. It is observed from Figure 2 that the fatigue value increases with an increase in the number of cycles. When yarn is subjected to cyclic loading it causes a loss in energy primarily from two sources:

- Inherent hysteresis loss of the constituent fibres and
- Friction energy loss between fibres due to slippage, unbending, and straightening action.

There is a loosening of structure and eventual breakage of fibres along with the change in position of the multifilament core within the sheath fibres with an increase in the number of cycles of loading which ultimately leads to an increase in FV%.

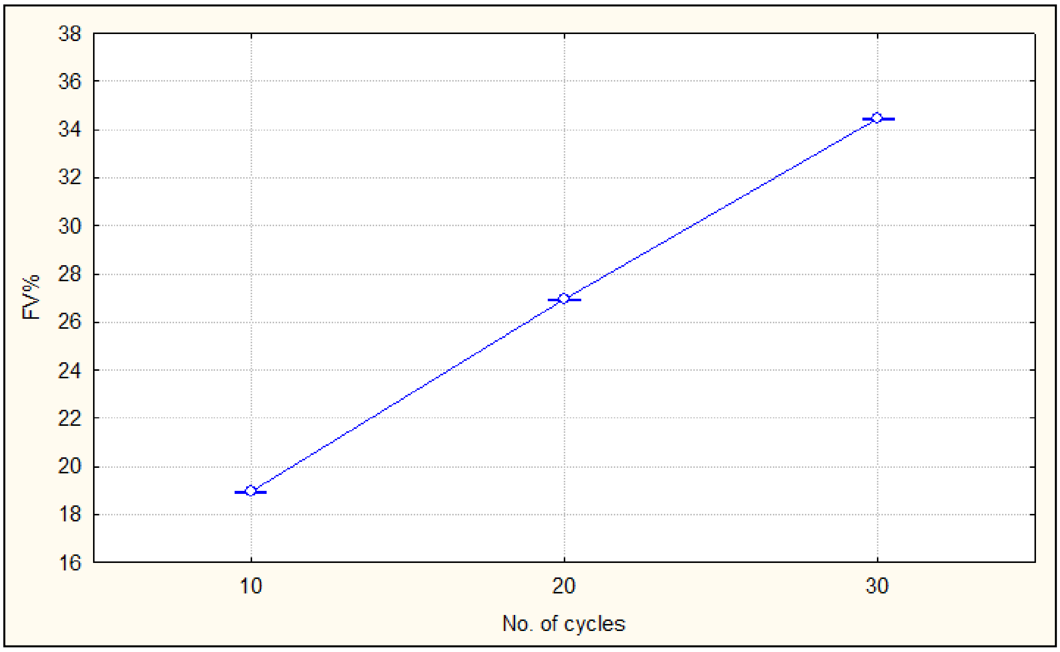

Figure 2. Effect of number of load cycles on FV%

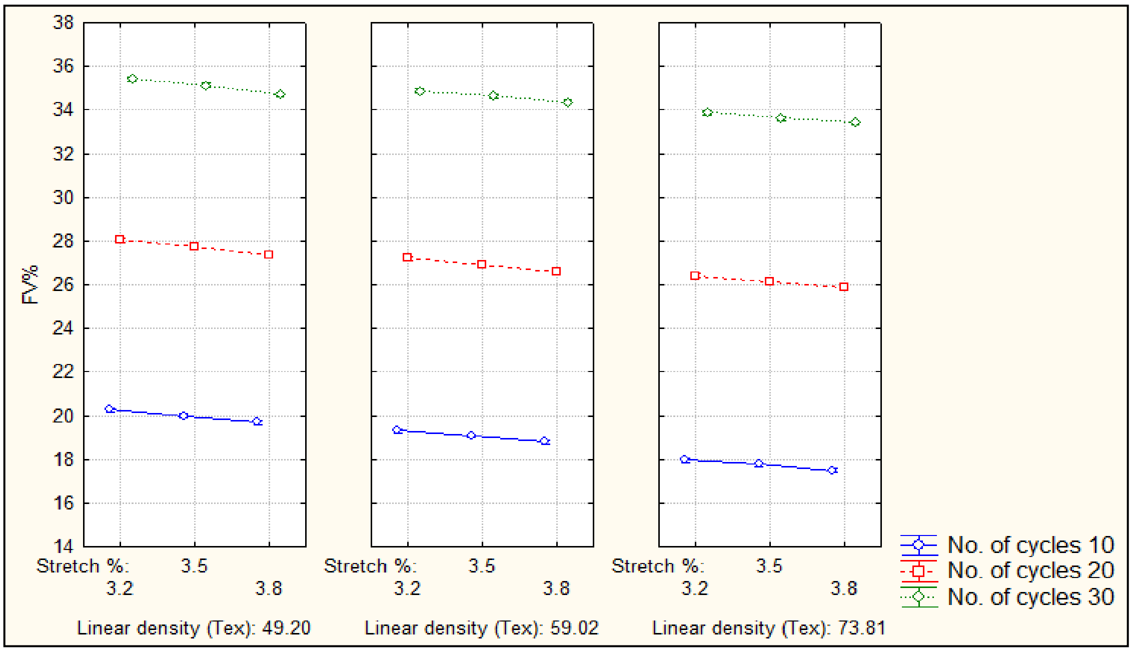

Figure 3. Interaction effect of the number of load cycles, linear density (Tex), and stretch % on FV% of yarn

Effect of Twist Multiplier on Fatigue Value of Yarn

According to the analysis of variance at a 95% confidence interval of fatigue value (Table 2), the twist multiplier shows a significant effect on the breaking strength of yarn after cyclic loading. It is observed from Figure 4 that the fatigue value decreases with an increase in the twist multiplier of yarn. When a load is applied to a compacted structure there is more possibility of disintegration of structure because fibers will not be able to come back to their original position. On the other hand, for a less compacted structure, the degree of disintegration will be less so it will be recovered more. As lycra is used as a core in a multifilament yarn which is highly elastic as compared to the sheath component it creates a more difference in extensibilityof the two components. Yarn spun with a higher twist multiplier increases cohesion between sheath fibers and core filament by increasing packing fraction which makes a compact structure. When yarn with a compact structure is extended, due to the difference in extensibility of the two components, the compacted structure is likely to get more disintegrated and it will not be able to come back to its original position, which may be the reason for the reduction in FV% with the increase in TM of yarn.

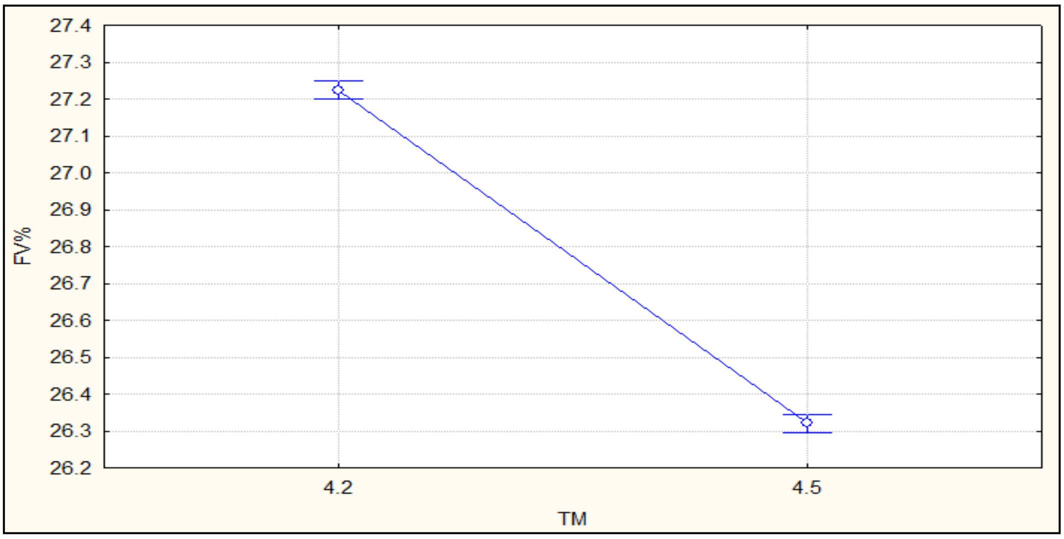

Figure 4. Effect of twist multiplier on FV%

Effect of Linear Density on Fatigue Value of Yarn

According to the analysis of variance at a 95% confidence interval of fatigue value (Table 2), the linear density of yarn showed a significant effect on the FV% of yarn after cyclic loading, but its contribution was less than the contribution of the number of load cycles. It is observed from Figure 5 that the fatigue value increases with an increase in the fineness of the yarn. The combined effect of stretch percentage, twist multiplier, and linear density is represented in Figure 6.

The number of fibres in the yarn cross-section is decided by yarn linear density. Changes in the number of fibres have a direct impact on the number of load-bearing components. The number of load-bearing components increases as the yarn becomes coarser. The larger number of fibres in coarser yarn produces stronger yarns if proper compactness is maintained. When the number of fibres in the cross-section of a coarser yarn is high, the inter fibre cohesion between staple sheath fibres tries to maintain structural integrity. But when the number of fibres in the cross-section of a finer yarn is reduced, the inter fibre cohesion of sheath fibres decreases and fails to maintain structural integrity. So the reduction of FV% is expected with the increase in linear density.

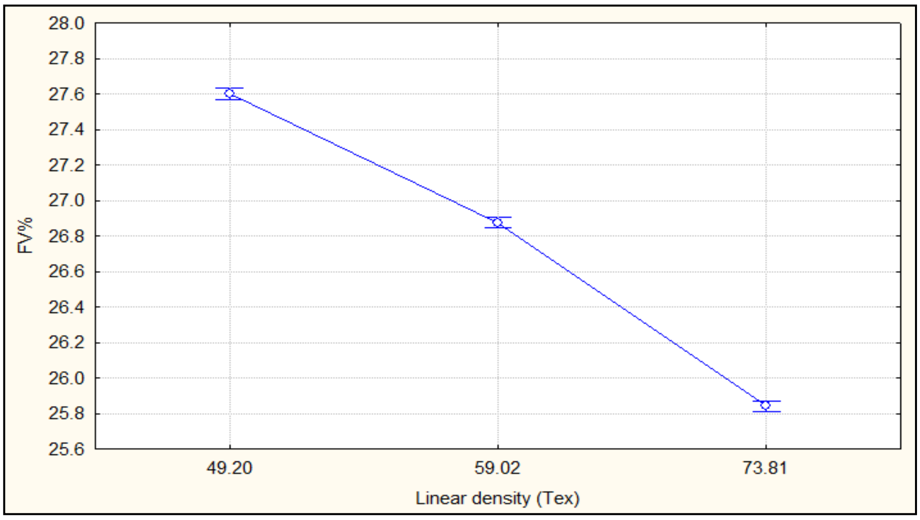

Figure 5. Effect of linear density (Tex) on FV%

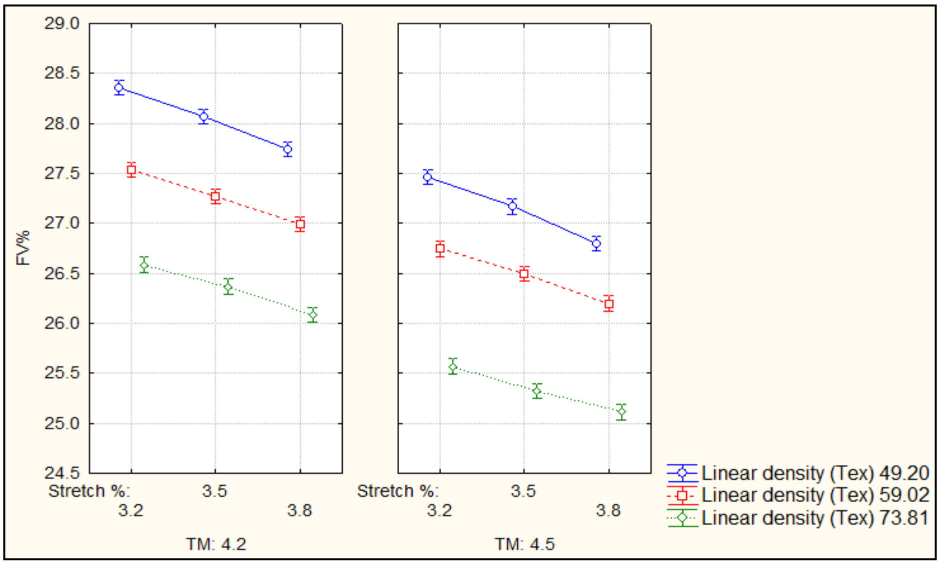

Figure 6. Interaction effect of stretch%, twist multiplier, and linear density (Tex) on FV% ofyarn

Effect of Stretch Percentage of Lycra on Fatigue Value of Yarn

According to the analysis of variance at a 95% confidence interval of fatigue value (Table 2), the stretch percentage of yarn showed a significant effect on FV% of yarn after cyclic loading, but its contribution is less than the contribution of the number of load cycles and twist multiplier. It is observed from Figure 7 and Figure 8 that the fatigue value decreases with an increase in the stretch percentage of yarn. At a higher stretch percentage number of sheath fibres increases, so during cyclic extension, more fibres will be involved in the disintegration and rearrangement process. So when the number of fibres is more in the yarn cross-section there will be more chance of disintegration and rearrangement which leads to a reduction in FV%.

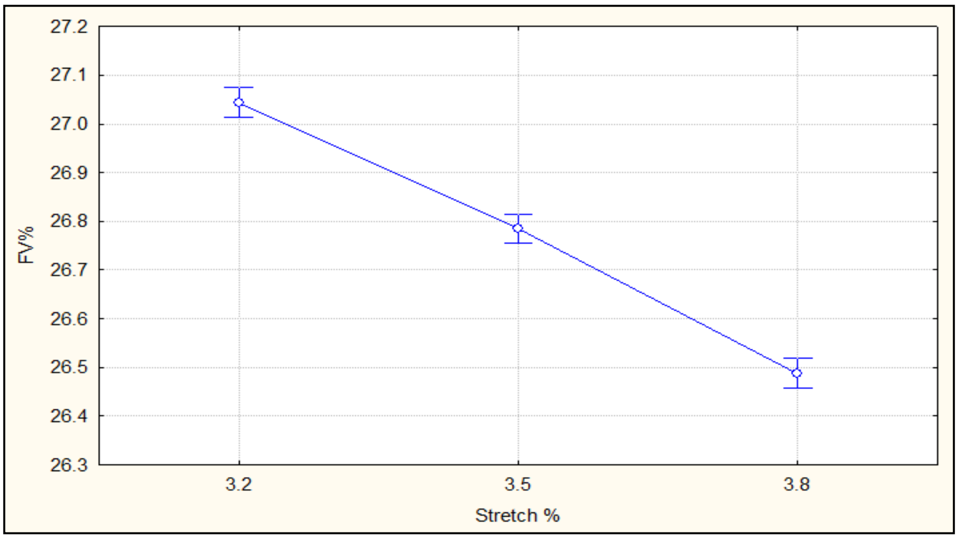

Figure 7. Effect of stretch percentage on FV% of yarn

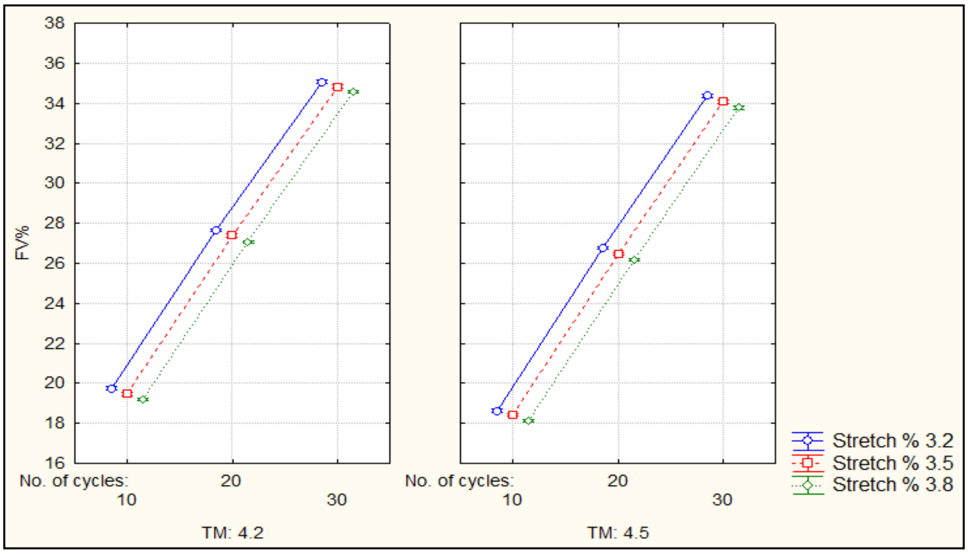

Figure 8. Interaction effect of No. of load cycles, twist multiplier, and stretch% on FV% of yarn

CONCLUSION

The purpose of this study was to investigate the effect of twist multiplier, linear density, stretch percent, and the number of cycling loads on the fatigue value of cotton/lycra core spun yarn. In general, cyclic loading leads to the redistribution of fibers in the structure of yarn because these fibers tend to get the minimum energy state. The coarser yarn has more fibers in yarn cross-section increasing inter-fiber cohesion which maintains structural integrity and leads to more redistribution after cycling loading resulting in a reduction in fatigue value. From the statistical analysis, it was observed that twist multiplier, linear density, stretch percentage, and the number of cycling loads have a significant effect on the fatigue value of cotton/lycra core spun yarn. It is also observed that there is a reduction in fatigue value with an increase in twist multiplier and stretch percentage of yarn due to an increase in compactness of structure. The number of cyclic loading is found to be the key factor for fatigue value after cyclic loading. The optimum value for the best performance of yarn is obtained at the above-mentioned process parameters i.e, 49.2 tex, 4.2 TM, and 3.2 stretch percentage.

Author Contributions

Conceptualization – Sinha SK and Nurussaba K; methodology – Sinha A and Sachdeva A; formal analysis – Nurussaba K; investigation – Nurussaba K; resources – Sinha A; writing-original draft preparation – Bhatia D; writing-review and editing – Bhatia D and Sinha SK; visualization – Sachdeva A; supervision – Sinha SK. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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