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Investigation on Physical and Mechanical Properties of Denim Woven Fabrics Made from Different Spandex Percentages

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Abstract- **The main topic investigated in this paper is the analysis of the effect of different spandex percentages on physical and mechanical properties of the denim fabric. The results showed that percentage of elastane has a significant effect on the physical and mechanical properties of cotton/elastane woven denim fabric. The influence of various elastane percentages via the above denim fabric performance parameters is investigated by employing a one-way analysis of variance (ANOVA) statistical software package. Tensile strength of denim fabric decreases as the percentage of the elastane increases because of the lower tenacity of spandex fibers compared to cotton fibers. Fabric breaking elongation increases as spandex percentage increases. The tear strength of denim fabric decreases as elastane percentage increases. As spandex percentage increased, the fabric contraction of the woven fabric increased, which made the fabric more compact and bulk, resulting in higher fabric thickness, fabric weight, and deep shade color. In addition, fabric stretchability and fabric elastic recovery increase with spandex percentage since elastane has higher stretch and makes the structure more compact, but fabric growth decreases as spandex percentage increases, due to the rather high recovery properties of spandex. The obtained results showed that Lycra proportion inside fabric has an effect on the fabric tensile strength, breaking extension, tear strength, stretchability, fabric thickness, GSM, and fabric shade color.**

***Keywords*: denim fabric, elastane, woven fabric, tensile, tear, stretch, elongation**

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I. INTRODUCTION

Denim is cotton and twill weave fabric that uses colored warp and white weft yarn and is used for jeans, work clothes, and casual wear [1]. The birth of denim jeans is credited to the Bavarian-born business man, Levi Strauss, who made his way to the Gold Rush in San Francisco nearly 150 years ago. The denim fabric has run the gamut from a basic work wear fabric to a fashion trend setter in the fashion and textile industry today and the original focus was on durability. The evolution of the denim market has led to the development of some unique and creative denim fabrics and opened new worlds of possibility for finishes [2]. Deterioration in the denim fabric of the textile product is often important to the physical properties that the article has reached the end of its using life [3].

Elastane fibers, better known under their trade names such as Lycra, spandex and dorlastan, represent a further high point in the development of man-made fibers. Invented in 1937 in Germany, elastane has properties not found in nature, the most important having an extraordinary elasticity. Spandex is a generic term used to designate elastomeric fibers which have an extension-at-break greater than 200% and also show rapid recovery when tension is released. These fibers exhibit rubber like behavior with high reversible extension as high as 400-800%. The name Spandex is an anagram of the word expands and is known as elastane [2].

A core spun yarn is a compound structure consisting of a spandex core surrounded by staple sheath fibers. The stretch in a core spun yarn is derived from the contraction of the elastomer from the extension to which it is subjected during textile mill spinning. There are many methods for merging spandex with other textile fibers, such as core spinning, rotor spinning, siro spinning, and air entangling. Core spinning is one of these methods, and can be applied by the ring, Murata vortex, friction spinning, and rotor

TABLE I
YARN PROPERTIES

Sample	Breaking strength (cN/tex)	Breaking elongation (%)	U%	Unevenness (CVm%)	Thin places (-50%/km)	Thick places (+50%/km)	Neps (+200%/km)	Hairiness (Uster® H)	Sh
	Warp yarn								
	13.64	7.68	8.95	11.26	0.0	5.0	0.0	5.12	1.06
	Weft yarn								
C1	13.55	8.84	8.85	11.21	0.0	13.8	12.5	8.2	1.95
C2	13.84	9.22	9.76	12.37	0.0	40.0	30.6	8.66	1.99
C3	13.22	9.45	8.66	10.99	1.3	70.0	65	7.47	1.83
C4	12.79	10.32	8.99	10.23	0.5	45	60	8.1	1.92
C5	11.83	10.64	8.52	10.21	2.5	25	40	7.12	1.72

twister techniques (Mourad MM, 2012). Yet, to introduce various elastane's proportions for each yarn, the core's draft is modified as Eq. (1) [3]:

$$D_{Elastane} = \frac{t_{Elastane}}{T_{Yarn} \times P} \tag{1}$$

Where, $D_{Elastane}$, T_{Yarn} (tex), $t_{Elastane}$ (tex), and P (%) are, elastane's draft, yarn's count, elastane count, and fixed percentage of the elastane filament, respectively.

In the present work, an attempt has been made to optimize the elastane percentage to achieve better fabric quality and higher fabric performance with minimum production adjustment time. This helped the commercial stretch denim manufacturer to understand the effect of elastane percentage on fabric properties.

II. EXPERIMENTAL

A. Materials and Methods

A.1. Materials

100% cotton even warp yarns of 10 Ne were manufactured using rotor spinning system while the 10 Ne weft yarns were produced by making 100% cotton roving as sheath material and elastane as a core material for all yarn types. Weft yarn samples were spun in the same yarn count and twist coefficient on a WF 288 spandex covering machine, modified ring spinning frame with special equipment. The percentage variation on weft yarn manufacturing is done by varying the draft ratio of the elastane material but other spinning parameters such as spindle speed were kept constant. The elastane and drafted staple fibers are brought together at the nip point of front rollers of the drafting unit. The elastane thread is stretched between the positive feed roller and the front rollers of the drafting unit. Yarns were tested and evaluated for important mechanical and comfort properties such as, imperfections, tenacity, breaking elongation, hairiness, neps, short fiber, and yarn evenness. Yarn uniformity, thin, thick, IPI values, and yarn hairiness were measured on Uster Tester 5, and tensile properties were measured with premier tensomaxx. Test results are given in Table I.

TABLE II
WARP SPECIFICATIONS

Parameters	Specifications
Yarn count	10 Ne
Yarn type	100% Cotton (rotor)
Yarn appearance	Even/normal
Yarn status	Dyed
Dye type	Vat (sulfur)
Ends per width	4608

A.1.1. Yarn Specification

Weft yarns were produced from modified ring spinning system using elastane fibers of 70 Dtex at five spandex percentage levels of 1.5, 2.5, 3.5, 4.5, and 5.5 as a filament and sheath consists of staple cotton fibers. The warp specification, weft yarn production specification and yarn properties result are shown, respectively, in Tables I to III.

A.2. Methods

In this study, five different cotton denim fabric samples with 3/1 twill pattern having different amounts of spandex

TABLE III
WEFT YARN PRODUCTION SPECIFICATIONS

Parameters	Specification
Lycra yarn count	70 Dtex
Lycra draft	2.15-6.2
Yarn appearance	Normal/even
Yarn status	White
Yarn type	Core spun yarn

percentage were woven to investigate their mechanical and comfort properties. The fabric samples were woven on an air jet weaving machine with a specific insertion rate. Sample fabrics were produced using weft yarn of cotton elastane combination with different spandex percentages. The fabric samples were coded as C1, C2, C3, C4, and C5 with different Lycra percentage of 1.5, 2.5, 3.5, 4.5, and 5.5%, respectively. The specifications of denim fabrics were also described. Regarding the test results, the effects of varying spandex percentage on the physical and mechanical properties were assessed and analyzed for significant difference through SPSS statistical package.

Warp yarns were processed in conventional denim process, which includes rope dyeing, rope opening (LCB), sizing, etc. Core-spun yarns were used as weft yarns in weaving. The weaving process was performed in Toyota air jet loom with five different elastane percentage values and the other production parameters were kept constant. Z Twill 3/1 woven fabrics were treated according to standard denim finishing procedures.

A.2.1. Conditioning

Denim fabric sample tests were performed after conditioning the samples in the standard testing atmosphere of 65% relative humidity and temperature 20±2 ºC for each fabric property.

A.2.2. Tensile Strength and Extension

The fabric tensile strength and extension values were measured according to ASTM D5035-11 standard strip for denim woven fabrics. The experiments were performed with a Tenso lab tensile strength tester. The distance between the jaws was 3 in, and the speed of the universal tensile strength tester was 300 mm/min. Tests were performed in warp and weft directions and five samples were taken from both directions of each type of fabric. The length of test sample (specimen) was 4 in width by 6 in length with pretension of 1% and the clamp speed of test of 300 mm/min.

A.2.3. Fabric Tear Strength

The tearing strength of the fabric was measured according to ASTM D1424-9 standard test method used for tearing strength. It uses a pendulum to apply enough energy to tear through the fixed length of the fabric. In this experiment the tear strength of the cotton denim twill fabric was determined by using a pendulum Elmendorf tearing strength apparatus (Origin Germany) and the sample size used was 7.5 cm×10 cm. A sharp knife was used to begin the tear of the test specimen by cutting a slit of 20 mm mid-way between two jaws. The mean tear force across warp and weft was calculated. The load applied during testing the tearing properties of samples was adjusted to test load D (6400 N).

A.2.4. Stretchable Properties

Fabric stretchability properties are related with fabric stretching percentage, fabric growth percentage, and elastic recovery percentage. Fabric stretchability properties are tested as per ASTM D3107-07. The sample of 65 mm × 560 mm was cut from fabric. Elastic performance is the ability of a material to exhibit its original properties after repeated use under cyclic loading and unloading, so fabric stretchable properties after cycling loading were also measured. Cyclic loading was done at three different target loads, i.e. 35% Breaking Load, 55% Breaking Load and 75% Breaking Load, and then fabric stretching (Eq. (1)), fabric growth (Eq. (2)) and elastic recovery (Eq. (3)) values were calculated:

$$\text{Fabric stretching } (\%) = 100 \times \frac{B - A}{A} \quad (1)$$

$$\text{Fabric growth } (\%) = 100 \times \frac{C - A}{A} \quad (2)$$

$$\text{Elastic recovery } (\%) = 100 \times \frac{B - C}{B - A} \quad (3)$$

Where, A is the distance marked between the upper and bottom parts of the fabric (250 mm), B is the distance between the marked points after 10 cycles of loading (in mm), and C is the distance between the marked points after 1 h relaxation.

A.2.5. Fabric Weight and Thickness

The thickness of stretchable denim fabric was measured using a thickness tester (Karl Schroder KG) under 100 kPa pressure following BS EN ISO 9073-2: 1997 standard. The weight per unit area (g/m^2) was measured by using an electronic fabric GSM weight scale balance from a circular specimen of 100 cm^2 area following ISO 3801-1977 standard test method.

A.2.6. Fabric Color

The color value of the samples was measured by taking photograph and comparisons are made between them.

A.2.7. Statistical Analysis

In this study to determine the relationship between independent variables (elastane percentage) and the response variables (tensile strength, breaking extension, tear strength, fabric stretchability, GSM, fabric thickness,

TABLE IV
FABRIC THICKNESS AND FABRIC WEIGHT TEST RESULT

Sample	Type of weave	Thickness (mm)	GSM
C1	Twill	0.69	309.5
C2	Twill	0.715	318.5
C3	Twill	0.73	334.0
C4	Twill	0.79	341.5
C5	Twill	0.80	356.5

and fabric color) the one-way Analysis of Variance (ANOVA) statistical software package was used to analyze the tested results of all the samples by comparison the significance value of fabric properties.

III. RESULTS AND DISCUSSION

Assessments of the produced fabrics for physical and mechanical properties were carried out in both the warp and weft directions for each of selected fabric characteristics.

A. Physical Properties

A.1. Fabric Thickness and GSM

As observed in Table IV, the fabric thickness and the fabric weights were increased as the elastane proportion was increased because the elastane yarn was used. This is because the elastane makes the fabric more compact, bulky, and tighter. As a result, the fabric thickness measured between the two plates increased as well as fabric weight per unit area became more.

A.2. Fabric Color

As observed from the photographic image in Fig. 1, the color shade for sample C1 is light shade and for C5 is deep shade and the remaining samples were between them. Since elastane yarns make the fabric tighter, the fabric shade becomes a deep shade for samples with high elastane percentage.

Fig. 1. Photographic image of color shade.

B. Mechanical Properties

In this study mechanical properties include tensile strength (N), tear strength (N), and breaking extension (%) were analyzed for denim fabric made from different spandex percentages. The test results for mechanical properties of denim samples are given in Table V.

B.1. Fabric Tensile Strength

The tensile strength of a fabric is a measure of its performance during use. The fabric used for the construction of particular clothing should be able to withstand the fatigue applied to it. A garment with insufficient tensile strength may fail during use, which can lead to the rejection of the garment. The effect of spandex percentage on tensile strength in the direction of both warp and weft is shown in Fig. 2.

According to the statistical analysis from the ANOVA Table V, the fabric tensile strength was affected significantly at significance level 0.00 by the percentage of spandex in both warp and weft directions but change in the warp direction is not such much significant as compared to the weft direction.

Fig. 2 shows the values of woven fabric tensile strength

TABLE V
ANOVA TABLE FOR TENSILE STRENGTH

	Direction	Sum of squares	Df	Mean square	F	Sig.
Between groups	Warp	82327.840	4	20581.960	14.222	0.000
	Weft	80093.360	4	66.158	66.158	0.000
Within groups	Warp	28943.600	20	1447.180		
	Weft	6053.200	20	302.660		

TABLE VI
ANOVA TABLE FOR BREAKING ELONGATION

	Direction	Sum of squares	Df	Mean square	F	Sig.
Between groups	Warp	12.762	4	3.190	1.512	0.237
	Weft	3208.455	4	802.114	48.870	0.000
Within groups	Warp	42.213	20	2.111		
	Weft	328.266	20	16.413		

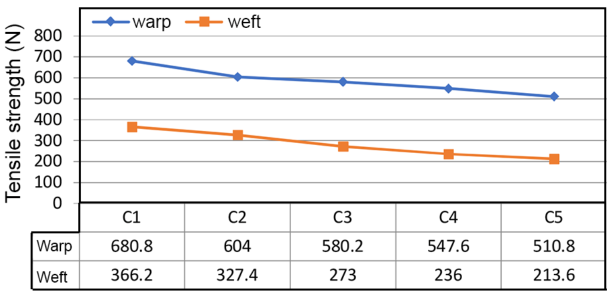

Fig. 2. Tensile strength of denim fabrics at different spandex percentage.

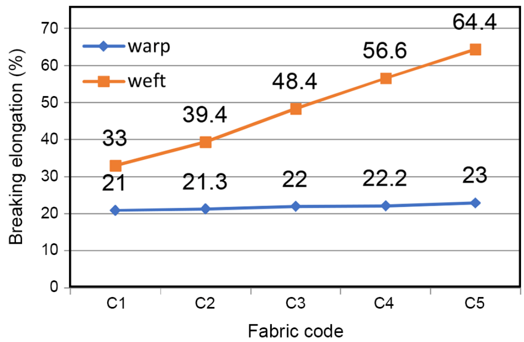

Fig. 3. Breaking elongation of denim fabrics at different spandex percentage.

versus spandex percentage and reveals that as the amount of spandex increases, the tensile strength of the woven fabrics decreases in warp as wheel as weft direction. This is due to the lower tenacity of spandex fibers compared to cotton fibers.

The statistical analysis showed that the maximum tensile strength was associated with the fabric sample C1 and the minimum value of tensile strength was observed for sample C5. From statistical analysis (one-way ANOVA) it was observed that there is a significant difference in the tensile strength of the five experimental fabrics having different spandex percentages in both warp ($F=14.222$, $p=0.000$) and weft ($F=66.158$, $p=0.000$).

B.2. Breaking Elongation

Breaking elongation of different fabric samples was investigated via different spandex percentages. The statistical analysis proved that the breaking elongations of fabric samples were significantly affected by the percentage of spandex at significance level $P=0.000$ in weft direction but in the warp direction breaking elongation was not influenced by spandex percentage since the significance level was $P=0.237$ (Table VI). As seen from Fig. 3, the fabric breaking elongation increases with the increase in spandex content along the weft but the change in the warp direction is not such significant. This is because the breaking elongation of spandex fibers (500%) was higher than that of cotton fibers (7%). That maximum breaking elongation of 64.4% was observed for fabric sample C5 and the minimum value of breaking elongation of 33% was also observed for fabric sample C1.

B.3. Tearing Strength

Tear strength of woven fabrics is mainly related to their serviceability. From the statistical analysis of tear strength (Table VII), it is clearly seen that fabric tear strength is significantly affected by the percentage of spandex in the weft yarns.

In this study, spandex percentage versus tear strength was plotted (Fig. 4) and observed that there is a negative

TABLE VII
ANOVA TABLE FOR TEAR STRENGTH

	Direction	Sum of squares	Df	Mean square	F	Sig.
Between groups	Warp	30.030	4	7.507	1.915	0.147
	Weft	215.034	4	53.759	9.015	0.000
Within groups	Warp	78.423	20	3.921		
	Weft	119.271	20	5.964		

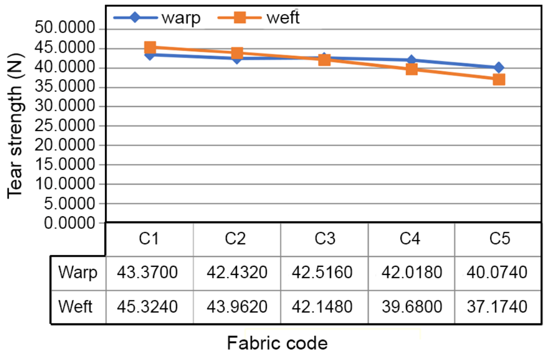

Fig. 4. Tear strength of denim fabrics at different spandex percentage.

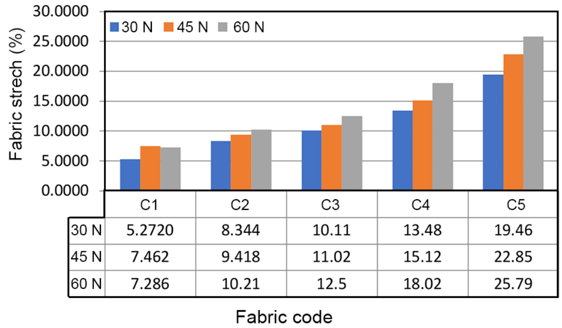

Fig. 5. Stretchability of denim fabrics at different spandex percentage.

relationship between the tearing strength and the spandex percentage. As the spandex percentage increases the fabric tearing strength decreases. This is because the lower fabric weight and relatively loose fabrics are always accompanied by lower spandex rate.

C. Influences on Fabric Stretchability Properties

The test results for fabric stretch, fabric growth, and elastic recovery of denim samples are given in Table VIII. The effect on stretchable properties is analyzed under different loading (30, 45, and 60 N) of each sample fabric. Fabric stretch (%), fabric growth (%), and elastic recovery (%) were calculated and the results are given in Table VIII.

C.1. Fabric Stretch

Fabric stretchability indicates that the property of the fabric facilitates the body part movements. A fabric with higher stretch may follow the body movement easily. However once the force is being removed, the fabric should return to its original dimensions. The fabrics containing Lycra are well known for their good stretchability and stretch recovery characteristics. The interactive relation between the spandex percentage and the fabric stretchability of denim fabrics is shown in Fig. 5. It can be observed that the stretchability was increased with the Lycra percentage since elastane makes the structure more compact. From Fig. 5, it can be noticed that as the applied load increases the percentage of stretchability also increases. From ANOVA analysis in Table IX it was observed that there is a significant difference in fabric stretch properties of the five denim fabrics having different Lycra percentages (F=194.333, p=0.000).

C.2. Fabric Growth

According to ANOVA statistical analyses in Table X, the significant effect of spandex percentage on fabric growth was studied and a negative relation between the

TABLE VIII
FABRIC STRETCH, FABRIC GROWTH, AND ELASTIC RECOVERY PROPERTIES OF FABRIC SAMPLES

Fabric code	Breaking load (N)								
	30	45	60	30	45	60	30	45	60
	Fabric stretch			Fabric growth			Elastic recovery		
C1	5.272	7.462	7.286	3.51	3.84	4.73	75.49	73.43	73.40
C2	8.344	9.481	10.21	2.98	3.59	3.90	78.72	74.42	72.88
C3	10.11	11.02	12.50	2.44	2.73	2.87	83.73	82.08	79.61
C4	13.48	15.12	18.02	2.06	2.58	2.87	88.63	83.84	80.49
C5	19.46	22.85	25.79	1.52	1.95	2.28	96.84	95.15	91.34

TABLE IX
ANOVA TABLE FOR FABRIC STRETCH PROPERTY

	Sum of squares	Df	Mean square	F	Sig.
Between groups	2360.046	4	590.012	194.333	0.000
Within groups	212.526	70	3.036		
Total	2572.572	74			

TABLE X
ANOVA TABLE OF FABRIC GROWTH

	Sum of squares	Df	Mean square	F	Sig.
Between groups	41.278	4	10.320	43.546	0.000
Within groups	16.589	70	0.237		
Total	57.867	74			

TABLE XI
ANOVA TABLE OF FABRIC ELASTIC RECOVERY

	Sum of squares	Df	Mean square	F	Sig.
Between groups	4006.822	4	1001.706	144.523	0.000
Within groups	485.177	70	6.931		
Total	4491.999	74			

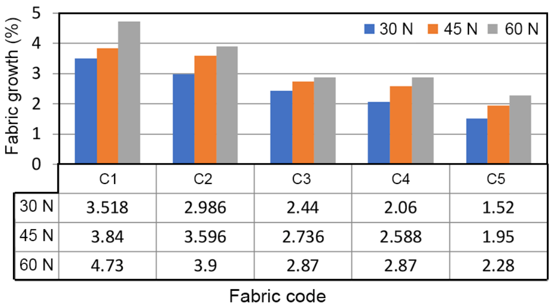

Fig. 6. Fabric growth of denim fabrics at different spandex percentage.

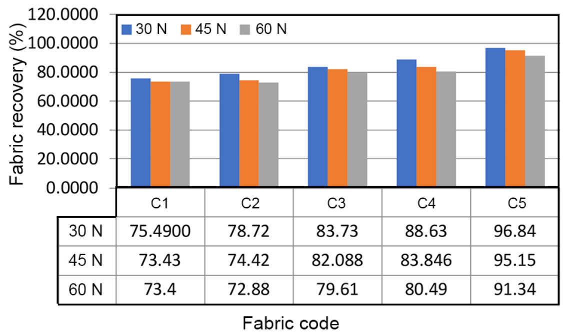

Fig. 7. Fabric recovery of denim fabrics at different spandex percentage.

spandex percentage and the fabric growth was detected at significance level of F=43.54 and p=0.000.

Fig. 6 ensures that as the spandex percentage increases, the fabric growth decreases due to the rather high recovery properties of elastane. The inversely effect of spandex percentage on fabric growth can be attributed to the higher extensibility ranges of the elastic complex yarn, which is associated with higher spandex amount. The reduction of fabric growth can be shown in a good fit of fabrics containing spandex.

C.3. Elastic Recovery

According to the results given in Fig. 7, it can be said that there is a positive relation between the spandex percentage and the elastic recovery. It can be observed that there is a tendency of increasing in elastic recovery values for all fabric samples in proportion to the increase of spandex percentage. These results were expected because the spandex in the yarn behaves like a spring, which tends to return to its original length after stretching.

From ANOVA analysis in Table X1 it was observed that there is a significant difference in fabric recovery properties of the five denim fabrics having different Lycra percentages (F=144.523, p=0.000).

IV. CONCLUSION

In this study, an attempt has been made to investigate the effect of elastane percentage on performance of physical and mechanical properties of woven denim fabric. The result obtained in the study indicates that percentage of elastane has a significant effect on the physical and mechanical properties of cotton/elastane woven denim fabric. It is observed that tensile strength of denim fabric decreases as the percentage of the elastane increases since the lower tenacity of spandex fibers compared to cotton fibers. Fabric breaking elongation increases as spandex percentage increases; this is because the breaking elongation of spandex fibers was higher than that of cotton fibers. The tear strength of denim fabric decreases as elastane percentage increases. As spandex percentage increased, the fabric contraction of the woven fabric increased, which made the fabric more compact and bulk, resulting in higher fabric thickness, fabric weight, and deep shade color. Fabric stretchability and fabric elastic recovery increased with spandex percentage since elastane had higher stretch and made the structure more compact but fabric growth decreases as spandex percentage increases due to the rather high recovery properties of spandex. Statistical analysis proved that the difference between the results for the five fabrics were significant for all the properties. Comparing the fabrics analyzed, it can be concluded that they have a wider field of variation in the performance characteristics (physical and mechanical) of denim fabric as the percentage of elastane content in the yarn starts to change. Research towards improvement in the elasticity of fiber, yarn and fabrics and development in testing methods for elastic garments are the current requirements for the industrial product development.

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