NEW METHOD FOR TESTING TENSILE AND TEAR PROPERTIES IN UNI-AXIAL AND BI-AXIAL MODES

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Abstract: Tensile and tear are high stress mechanical properties as characterized for a fabric. In this research a newly developed testing technique of 'Uni-axial' and 'Bi-axial' tensile and tear testing of fabric is studied . A 'textile mechanics model' was implemented and investigated through fabric tensile test results in the two different directions starting with a grey woven suiting fabric Significance of conventional industrial bleaching (regular) with single stage bleaching (advanced) and its effect on fabric comfort is reported. Further, the present research work examined the role of present day chemical processing with respect to combined durable press and soil release finishing. This research report attempts to fill the research gap in comfort evaluation of differently bleached and finished fabrics.

Keywords: Uni - axial and Bi – axial modes, Tensile and Tear testing, Textile mechanics model.

1. Introduction

Fabric is characterized by a wide range of approaches like high stress , low stress subjective and objective methods. Conventionally, tensile and tear are tested in uniaxial condition. The biaxial tensile testing of paintings on canvas was studied under a title the mechanical properties of the complex composite structure by Christina *et.al*., [3] . A new instrument biaxial tensile tester was designed to test the raw linen canvas under uniaxial and biaxial loading. During the same year, Bednar and Garmestani [2] reported biaxial testing of high strength carbon fiber composite cylinders for pulsed magnet reinforcement. They introduced a method to test carbon-fiber-reinforced, hoop-wound composite cylinders for their biaxial mechanical properties under axial compression and hoop tension. Wang [10] *et.al*., considered the tearing analysis of a new kind of coated GQ-6, ultra-high molecular weight polyethylene fiber woven fabric under uniaxial tensile load. Parameters like effects of the stretching rate, the initial crack length, and the initial crack orientation on the material's tearing strength were investigated. Huiqi Shao *et.al*.,[7] in their research studied the Bi-Axial Mechanical Properties of Warp-knitted Meshes with and without Initial Notches. Tearing analysis of PVC coated fabric under uniaxial and biaxial central tearing tests was considered by Han Bao *et.al*., [6]. Recently, Yonglin Chen *et.al*., [9] published their research work in which tear strength of a laminated fabric for stratospheric airship under uniaxial and biaxial tests was reported. In this study, a bi-axial stress & strain tester (BASS), a new type of textile testing instrument was designed to understand the impact on fabric comfort quality evaluation as well as on industry testing practice. Firstly, information on the measurement of tensile and tear by the same instrument is scanty in literature and thus formed the thrust of the present research work. Secondly, combining and demarcating tensile and tear regions of regular tensile testing was the main driving force for the emergence of this new research work.

A theoretical 'textile mechanics model' was proposed to represent resultant tensile force (Kgf) and tensile load (Kg) in warp and weft directions, solely applicable to bi-axial tensile testing condition. Such a mathematical model was not derived in previous research regime and this new objective estimate results in standardizing pattern of loading in either directions. It gave an emphatic solution that load applied in bi-axial condition should be equal in warp and weft directions, else it may result in complication of analysis of tensile test results. Typical factors like 'fabric assistance (compliance)', 'strain hardening' and 'cross-over' of stress-strain curves of warp and weft directions could be investigated in the light of present research work. Such effects cannot be noticed in bi-axial tensile testing conditions as warp and weft are simultaneously/instantaneously loaded. However, distinct advantage of bi-axial tensile testing lies in quantifying the stress strain conditions of warp and weft in a fabric sample, the basis for which is 'fabric assistance (compliance) theory.

'Fabric Geometry' studies and investigations can be better refined and new models can be evolved on the stand point of bi-axial tensile testing. Overall the present research paper aimed and attempted towards new avenues of knowledge by generation of newly designed of Bi-Axial Stress Strain Tester. Further, the objective of the present research work was to make a sharp demarcation of tensile test into three regions, namely, yield, tear and break, unlike the presently considered two regions, namely yield and break.

2. Materials and Methods

100% cotton grey suiting fabric was manufactured at local weaving unit, with 46 x 24 thread sett per cm, of warp and weft count 34 Tex and GSM of 280 and this was the experimental material. Eight fabrics were short-listed for intensive analysis and reduced to form chemical processing set of four which were subsequently analyzed individually as well as collectively by correlation/regression analysis.

Table. 1 Fabric coding of chemically processed fabrics

S.No	Fabric Code	Acronym	Particulars
1	C1	RBDP40	Regular Bleached + Durable Press Finish 40%
2	C2	RBD/DP40	Regular Bleached and Dyed + Durable Press Finish 40%
3	C3	RB/SRDP40	Regular Bleached + Soil Release Finish + Durable Press Finish 40%
4	C5	SSBDP40	Single Stage Bleached + Durable Press Finish 40%
5	C8	SSBD/SRDP40	Single Stage Bleached and Dyed + Soil Release finish + Durable Press Finish 40%
6	C9	RBDP50	Regular Bleached + Durable Press Finish 50%
7	C11	RB/SRDP50	Regular Bleached + Soil Release Finish + Durable Press Finish 50%
8	C12	RBD/SRDP50	Regular Bleached and Dyed + Soil Release finish + Durable Press Finish 50%

2.1 Principle of Testing of fabrics on Instron

Instron is a constant rate of extension and continuous loading type of tensile tester. Load applied on the fabric warp or weft direction in the range from 5 Kgf to 40 Kgf at constant rate of extension in the range from 5 mm to 70 mm. Fabric length engaged in the loading clamps was 200 mm. Thus strain percentage measured as maximum was 35 %. A load – extension/ stress-strain curve was obtained through an auto-graphic pen recorder of the instrument, separately for warp and weft direction. Tear Strength was obtained apart from tensile strength (breaking) and tensile strain (breaking) that was measured conventionally at 28Kgf load. The additional tear strength measurement gave better scope of testing for the instrument and reduced the mechanical power to nearly 50% doubled the measuring capacity of the instrument by making suitable changes in the fabric sample under testing. Conventional Grab test method for recording the tensile properties was used. Six samples were cut to the following dimensions in warp and weft way: Length : 200mm and Width : 50mm.

2.2 Bi-Axial Stress –Strain Test (BASS) – New Method

The instrument Bi-Axial Stress – Strain Tester is shown in Figure 1

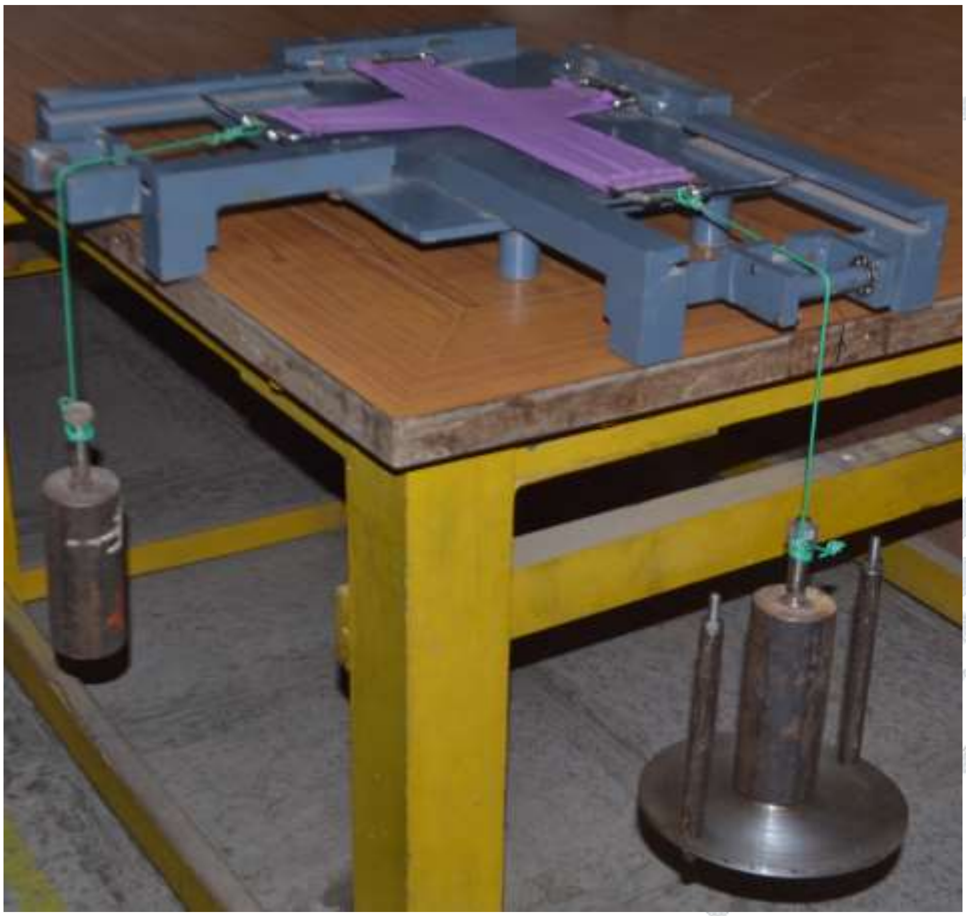

Figure 1. BASS Instrument

BASS has a bi-axial dead weight loading system and fully non-electric power operating instrument. The load range in warp and weft directions equally and simultaneously was from 5 kg to 28 kg. This range gave an effective or resultant load in the 'BIAS' direction of 7 kg to 40 kg (as per textile mechanics model). This range was found sufficient for tear strength measurement of light and medium weight fabrics having GSM in the range of 100g to 350g. For GSM above this range, the instrument required additional weight system or the BASS (Regular) required redesigning to produce a heavy duty testing instrument (HD). The extension range for the BASS (Regular) instrument was from 5mm to 70mm in warp and weft directions. Thus 23% extension (max) on warp and weft can each be measured.

In addition to the stress and strain in yield and tear region, elastic recovery% can be measured by following the de-loading or unloading procedure. However, the tensile properties measured on BASS could be representative measurements of tensile properties, measured on INSTRON and KES-F in corresponding manner.

2.2.1 Working Principle of BASS:

Six pre – measured and template cut fabric samples were prepared for performing the BASS test. In this test, 5cm long reference lines were drawn at right angles to each other and the extension of these reference lines at loads of 5 Kg, 10 Kg, 15 Kg, 20 Kg and 28 Kg were recorded. From these values, the average of combined warp and weft way (W + F) extension % was calculated. The bi-axial extension % was measured in Yield Region and Tear Region for all corresponding discrete or fixed instantaneous loads.

Tensile testing of fabric samples was carried out in 'cruci-form' as shown in Figure 3**.** Fabric **s**amples six in number were cut to the following dimensions: Length in vertical and horizontal ways: Short limb : 100mm; Long limb : 150mm; Width uniformly in both limbs: 50mm. This gave a central square measuring 50mm x 50mm, for conducting actual test, in other words, it was the tensile test area for a fabric specimen.

Table 2 Theoretical load and extn% relation for INSTRON and BASS

INSTRON	Load Kgf	5	10	15	20	25	30	35	40	45	50
	Extension %	10	12	14	16	18	20	22	24	26	28
BASS	Load Kg	7	14	21	28	35	42	49	56	63	70
	Extension %	14	17	20	23	26	29	32	35	38	41

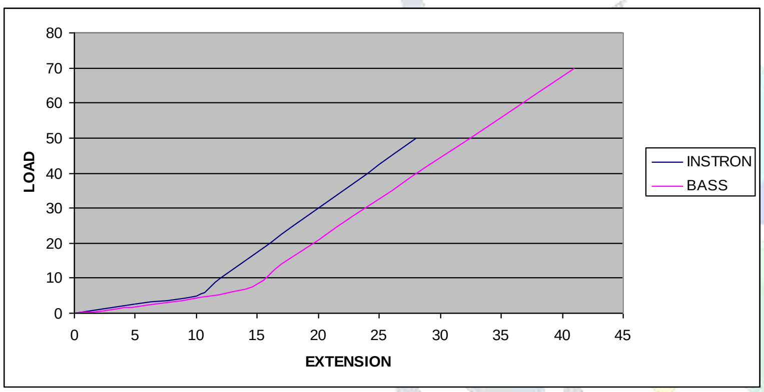

Figure 2. Theoretical illustration of load and extension curve

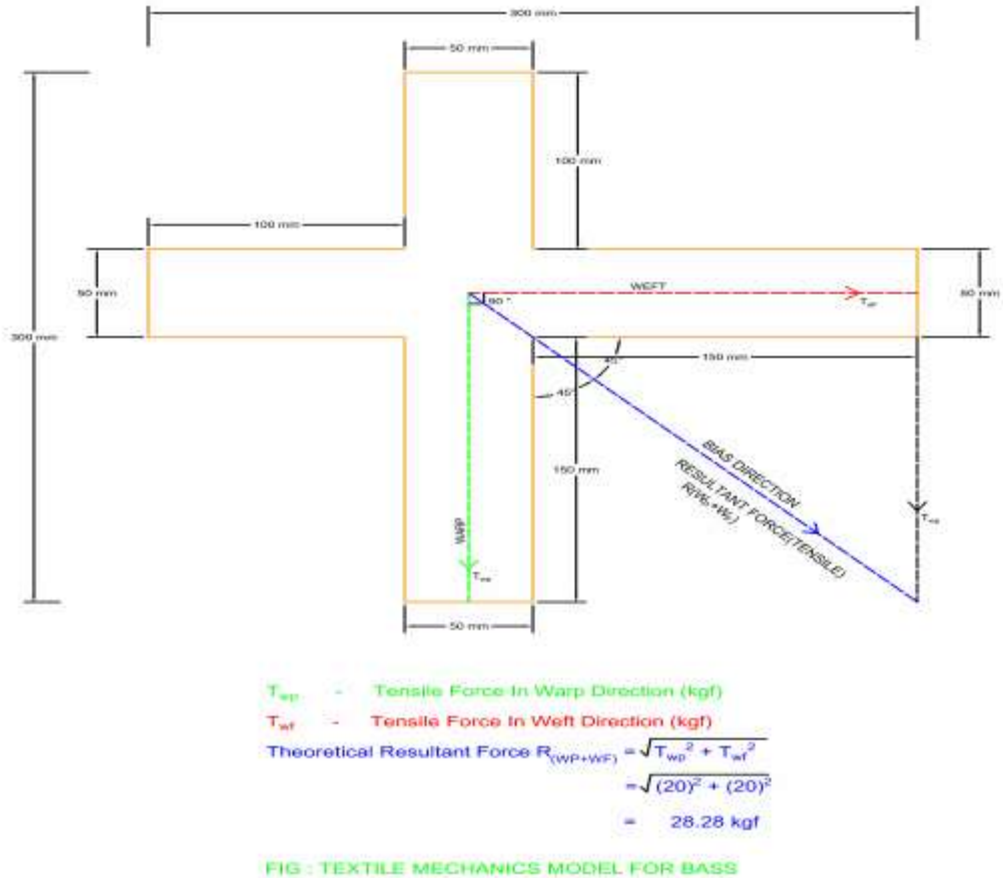

Figure 3. Textile Mechanics Model for BASS

3. Research Methodology

Technical Textiles are occupying large market share and in view of their superior functional properties and daily use, as many popular fibers are being used in their production with high level of technical performance combined with novelty and are also continuously developed for better utility and service. These various products are manufactured predominantly by weaving and are emerging in sports, medical, construction, automotive, marine and geo- applications. In the automobile industry, 'Air Bags' have high potential application due to safety and security that it demands.

All textile products that go into engineering sector have to face stringent quality testing and conformance, as these products are subjected to multi – axial stresses and strains and the test methods devised for this purpose can be cited as planar bi – axial tensile test, cylindrical inflation test and bulge test. These tests cater to multiple states of mechanical behavior to which such products are exposed (Ref.1 to 4).

Fabrics of apparel category and woven products as per industry practice are tested on Instron for their tensile properties in separately warp and weft directions and unfortunately these distinct properties left a yawning gap to the examiner or the observer in terms of their relative influences on overall mechanical properties of the fabric. For example, fabric compliance warp over weft and weft over warp; influence of crimp; contribution of warp and weft to overall fabric strength and influence of yarn count and Thread sett in the two directions. These combined warp and weft related influences are deduced but are not measured as a sum to express as (W+F) or (W+F)/2. Bi – axial tensile testing as per this documented methodology herein given resolved this issue to greatest extent and can be recommended as adoptable and be carried forward as an industry practice.

Four fabrics of chemically processed commercial fabric set have been systematically compared for '3T' values (Tensile + TIV + MT) and FCQ (Fabric comfort quality – It is square root of area of Octogonal Diagram) by using newly evolved geometrical method of 'Octagonal Diagram' (OD3). The sample size was fixed as n= 6.

4. Results and Discussion

Following Table 3 gives the tensile testing results for the eight chemically processed commercial fabrics, both on Instron and BASS in Uni-axial and Bi-axial testing conditions.

Table 3 Tensile properties of chemically processed fabrics

S.No	Fabric Code	A	B	C	C'	D	D'	E	F	G	H
1	C1	20	15.8	44	19.3	15	9.5	20	22	28	30.8
2	C2	20	16	42	18	14	8.4	20	22.4	28	31.4
3	C3	20	13.5	39.5	19.3	15	10.6	20	18.9	28	26.5
4	C5	20	16	42	18.3	14.2	8.5	20	22.3	28	31.2
5	C8	20	10	24.5	11.7	11.5	13.1	20	14	28	19.6
6	C9	20	16	42	18	14	8.4	20	22.3	28	31.2
7	C11	20	13.7	37.5	20.5	16	11.9	20	19.2	28	26.9
8	C12	20	10.3	30.9	12.5	13	11.8	20	14.4	28	20.2

Following are derived from Instron's Stress- strain /Load-Extension graphs obtained from autographic pen recorder.

A. YRST(UA) Kgf ; **B**. YRSN (UA) % (W+F); **C.** TRST (UA) Kgf ;

C'. (W)EXTN. % (derived from Instron graph at 28 Kgf) ; **D.** TRSN (UA) % (W + F) / 2 ;

D'. (F) EXTN. % (derived from Instron graph at 28 Kgf) ; **E.** YRST (BA) Kg ;

F. YRSN (BA) % (W+F) ; **G.**TRST (BA) Kg ; **H.** TRSN (BA) % (W+F).

4.1 Analysis of Tensile Testing Results

Tensile testing results on eight chemically processed commercial fabrics were tabulated in Table 3. From Table 3, it can be seen that uniform loading of 20Kg was maintained for analysing test results on Uni-axial and Bi-axial conditions on the two tensile testing instruments, Instron and BASS. The 20 Kg load and (W+F)EXTN.% referred to 'YEILD REGION' of the stress-strain curves of both the instruments. For comparison of the test results, average of warp and weft way loads were taken into consideration. The 28Kg load and (W+F)EXTN.% referred to 'TEAR REGION' of the stress – strain curves of both the instruments. The stress – strain curve of one of the chemically processed commercial fabric is given in Table 4 and Figure 4. Four Fabrics were only short listed for comparison of stress-strain curves. These four fabrics are chemically processed commercial fabrics C2, C3, C8 and C12.

C2 was Regular Bleached & Dyed - DP40% ; C8 was Single Stage Bleached & Dyed - SRDP 40%; C3 was Regular Bleached – SRDP40% ; C12 was Regular Bleached & dyed – SRDP50%

In the above set of four fabrics C8 and C12 can be compared for the effectiveness of Bleaching and Dyeing process by Regular and Single Stage techniques towards the combined Soil Release Durable Press finish. Fabrics C2 and C3 have to be treated as separate entities, as the pre-processing and finish processing are distinctly different for these fabrics. The objective was to examine the trend of stress and strain curves for differently processed fabrics.

Table 4. Load-Extension for fabric C2

Instron (W)		Instron (F)		BASS (W+F)	
Extn (%)	Load (Kgf)	Extn (%)	Load (Kgf)	Extn (W + F)%	Load (Kg)
0	0	0	0	0	0
7	3	6	5	6	4
20	20	11.5	20	22.4	20
29.5	51	13	32.5	31.4	28

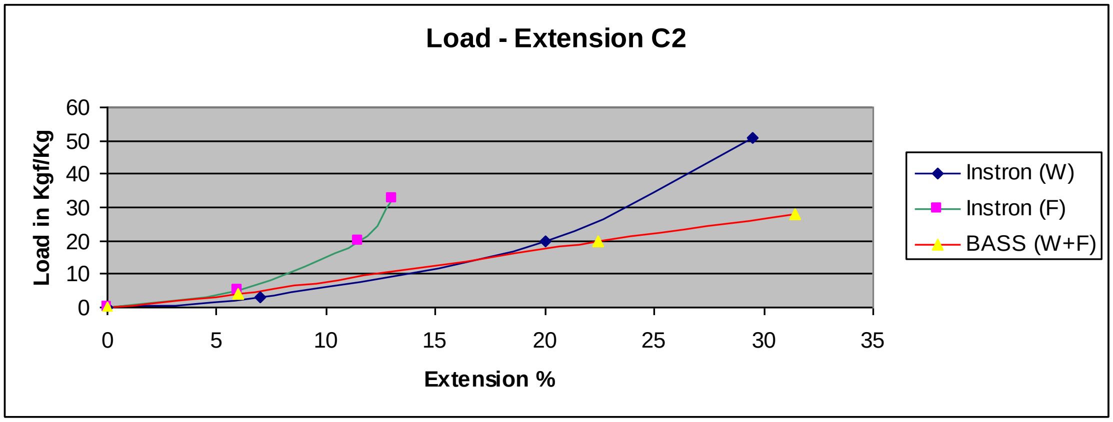

Figure 4. Load-Extension graph for fabric C2

The extension % in BASS against a particular tensile load was found intermediate between warp and weft directions as observed from Instron testing. However it was found lesser than the average extension % obtained from Instron testing of the same fabric. At 20 Kgf: Instron 16% and BASS 11.2% and at 28 Kgf: Instron 18% and BASS 15.7% . This can be explained based on the fabric assistance theory which might have become applicable in BASS testing of the given fabric. There was scope for sharing of stress by the weft in BASS testing, hence less extension% in either of the directions.

According to 'fabric assistance' theory, due to the simultaneous loading of warp and weft in BASS testing, the assistance of weft to warp and vice-versa resulted in reduction in average extension% due to warp and weft of the given fabric at equal tensile loads in both directions. This combined influence was noticed for both Yield and Tear Regions.

Considering fabrics C8 and C12, in which the former was SS-Bleached and Dyed fabric and the latter was Regular Bleached and Dyed fabric, both of them showed a similar load-extension characteristics. 'Strain hardening' was found beyond the yield region in the fabrics. 'Strain hardening' is a peculiar behavior in which above yield region, there is a steep increase in load due to tightened yarn and fabric structure, but corresponding strain% decreases with increase in load. Cross over of the load-extension curves was observed in the two fabrics above the yield region.

In C8 (SSBD) un-conventional trend of warp having more elastic load-extension behavior and weft having less elastic behavior, was found.

In C12 (RBD), unconventional trend was shown by warp in terms of higher elastic behavior below yield region similar to C2, C3 and C8. This was due to higher crimp in weft compared to warp.

It was observed from the tensile test results that fabrics with code numbers C1,C2, C5, C9, exhibited breaking loads in the range of 42 to 44 Kgf. The corresponding tearing loads on BASS tester were 28Kg uniformly for all the four fabrics. The corresponding strain % on BASS for yield and tear regions were respectively ranging from 22.0 to 22.4% and 30.8 to 31.4%. The corresponding strain% on Instron for yield and tear regions were respectively ranging from 15.8 to 16% and 18 to 19.3%. The average (W+F)/2 extension % for all the four fabrics together for Instron and BASS respectively were in the range of 8.4 to 9.5% and 15.4 to 15.7% in the tear region. This was because of higher effective load of 40 Kg in BASS tester.

In view of the asymmetric behavior of strain% in warp and weft directions in a given fabric, stress (Kgf) and strain (%) are separately recorded in Table 5 for Instron and in Table 6 for BASS. This was made to study relative differences in tensile behavior due to the testing instrument as well as effect due to warp and weft directions in a fabric. This tabulation of tensile test results was made for eight chemically processed commercial fabrics.

The asymmetric behavior of warp and weft in the fabrics C1,C2,C5 and C9 in Instron revealed higher extension% in warp than weft in all the three regions namely, at 20 Kgf (Yield Region), 28 Kgf (Tear Region) and Break Region.

Table 5 Tensile Properties of chemically processed commercial fabrics (in Warp and Weft) tested on Instron

S. No	F. Code	20 Kgf - YIELD REGION			28 Kgf - TEAR REGION		BREAK REGION			
		I	II	III	IV	V	VI	VII	VIII	IX
		(W)	(F)	(W+F)	W	F	(W+F) /2	(W+F) /2	W	F
1	C1	20	11.6	15.8	18	12	44	15	19.3	9.5
2	C2	20	11.8	16	24	12.5	42	18	18	8.4
3	C3	16	11.5	13.5	18.5	12.6	39.5	15.5	19.3	10.6
4	C5	20	11.8	16	14.2	14.2	42	14.2	18.3	8.5
5	C8	10	10	10	11.5	11.5	24.5	11.5	11.7	13.1
6	C9	20	11.8	16	14	14	42	14	18	8.4
7	C11	16	11.7	13.7	18.5	12.5	37.5	16	20.5	11.9
8	C12	10.3	10.3	10.3	12	13	30.9	12.5	12.5	11.8

Note: I, II, III, IV, V, VII, VIII, IX were extensions% in different load regions and VI represented Breaking Load.

Table 6 Tensile Properties of chemically processed commercial fabrics(in Warp and Weft) tested on BASS

S. No	F. Code	20 Kg - YIELD REGION			28 Kg - TEAR REGION		
		I (W)	II (F)	III (W +F)	IV (W + F)	V (W)	VI (F)
1	C1	11	11	22	30.8	18.5	12.3
2	C2	11.2	11. 2	22.4	31.4	20.6	10.8
3	C3	9.5	9.5	18.9	26.5	16	10.5
5	C5	11.2	11. 2	22.3	31.2	15.6	15.6
8	C8	7	7	14	19.6	9.8	9.8
9	C9	11.2	11. 2	22.3	31.2	15.6	15.6
11	C11	9.6	9.6	19.2	26.9	16	10.9
12	C12	7.2	7.2	14.4	20.2	9.7	10.5

Note: I, II, III are extensions% for 20 Kg load and IV, V, VI are corresponding extensions % for 28 Kg load.

4.2 Correlation between Instron and BASS

The correlation between strain % values against two loads 20 Kgf and 28 Kgf separately for four short-listed fabrics tested on Instron and BASS Tester is presented in graphs with Figure 5 and Figure 6

Table 7 Correlation of Strain % of Instron and Strain % of Bass at 20 Kgf

Strain% at 20 Kgf	**Instron Strain %**	**BASS Strain %**
C2	16	11.2
C3	13.5	9.5
C8	10	7
C12	10.3	7.2

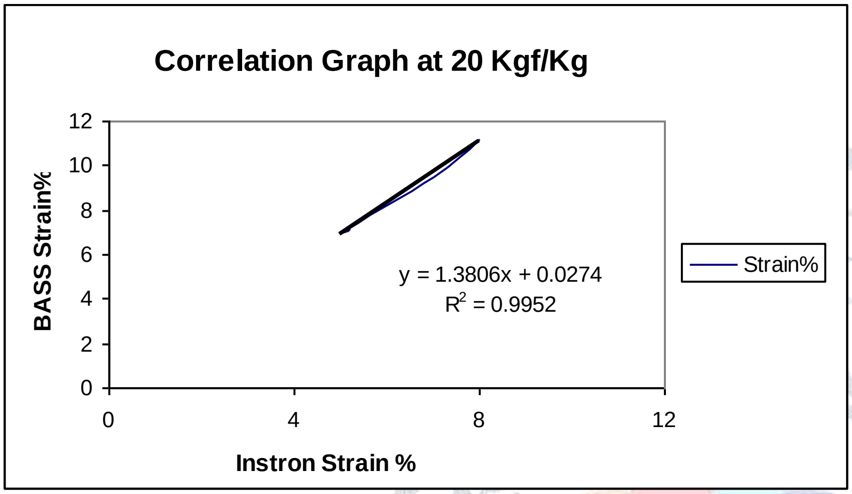

Figure 5. Correlation graph with Strain % of Instron Vs Strain % of BASS at 20Kgf/Kg.

Table 8 Correlation of Strain % of Instron and Strain % of Bass at 28 Kgf

Strain% at 28 Kgf	**INSTRON Strain %**	**BASS Strain %**
C2	18.3	15.7
C3	15.5	13.5
C8	12	9.8
C12	12.5	10

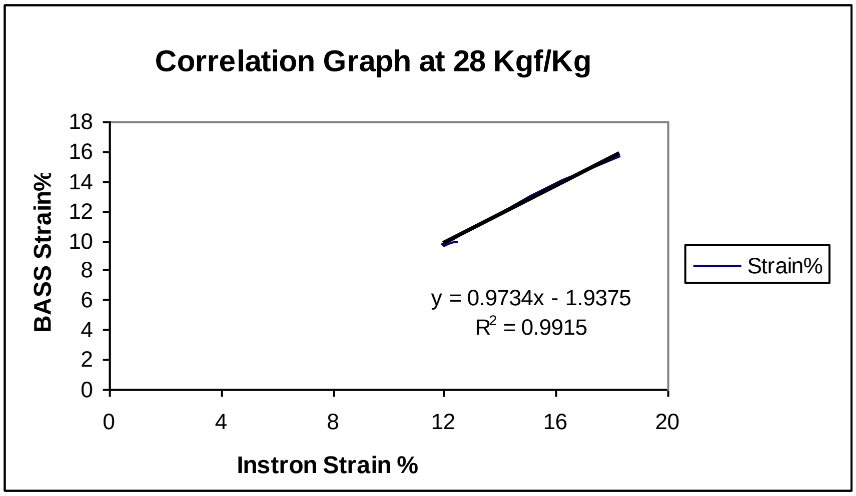

Figure 6. Correlation graph with Strain % of Instron Vs Strain % of BASS at 28 Kgf

4.3 Comprehensive discussion of tensile test results.

- The stress strain curves of the two fabrics C8 & C12 showed 'strain hardening' effect in both. Higher elasticity in warp compared to weft, average extension% lower in BASS tensile testing against Instron tensile testing invariably in yield and tear regions, were observed.
- The reason for higher elasticity in warp may be due to tight yarn and fabric structure in the given fabric setting, in the suiting fabric, and because of higher weft crimp and considerably lower (50% less) warp crimp. Strain hardening effect was also due to tightened fabric structure above the yield region.
- As far as effectiveness of bleaching and dyeing was considered, and their effect on tensile properties concerned, C12 was found better than C8. Regular bleaching can be concluded as better over single stage bleaching. Bleached fabrics were better than bleached and dyed fabrics.
- Fabrics C2 and C3 were viewed as separate entities, due to difference of process conditions, however, C2 was found better than C3 in view of better tensile properties.
- It was observed from the tensile test results that fabrics with code nos C1, C2, C5, C9 have exhibited higher breaking loads compared with the other fabrics and also showed higher strain% invariably in Instron and BASS testing. Hence these were shortlisted for intensive analysis.
- Asymmetric extension% was noticed in warp and weft directions especially on Instron. In that, warp showed higher elasticity invariably in all the fabrics compared to weft irrespective of the type of instrument of testing.
- The correlation coefficient R=1 explains that strain% measured on Instron and BASS correlate absolutely well signifying their accuracy of testing fabrics in the yield region at 20 Kg load or 20 Kgf tensile force.
- The correlation coefficient R=1, explains that strain% measured on Instron and BASS correlate fairly well. However, this cannot be ascertained as tearing extension% fluctuates as per the mechanism of tearing in particular fabric sample.

5.0 Conclusions

Following are the conclusions from the study conducted.

1. Regular bleaching with a durable press finish concentration of 40% showed better strength results than fabric samples treated with combined soil-release and durable press finish.

2. The influence of fabric compliance factors namely thread sett in warp and weft directions, warp and weft crimp%, warp and weft yarn count and weave structure can be studied.

3. Typical aspects like 'fabric assistance (compliance)', 'strain hardening' and 'cross-overs' of stress-strain curves of warp and weft way directions can be investigated in the light of present research work, especially applicable to uni-axial testing conditions.

4. 'Fabric Geometry' studies and investigations can be better refined and new models can be evolved on the stand point of bi-axial tensile testing. Overall the present research paper aimed and attempted towards new avenues of knowledge by generation of research on newly designed Bi-Axial Stress Strain Tester.

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