CHAPTER IV
RESULTS AND DISCUSSION

Textiles have their wide application for apparel products. The geometry of the fabrics and types of yarns used in manufacture could also define the end use of textiles. Apart from pure yarns, elastic blended yarns made a large amount of choice in various fields like casuals, sports, medical textiles and so on. In the present study the effect of fabric parameters on performance characteristics were studied. The influence of Elastane with cotton and the effects of the wear performance properties were analyzed under study.

The present research "Performance Characteristics of Elastane Incorporated Woven and Knitted Fabrics for Garments" has been categorized under three phases. Phase I consisting of preliminary testing of fabrics of various geometry. In Phase II an experimental work of physical testing was carried out for performance and serviceability of fabrics and Phase III was carried out for production of garments and their visual assessment for overall appearance and aesthetics.

The results of the study were given and discussed under the following subsections:

4.1 Phase I: Preliminary data of the fabric under study

4.1.1 Fibre content of the fabrics

4.1.2 Thread count of fabrics

4.1.3 Cloth cover and tightness factor of the fabrics

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4.2.1.1 Pilling resistance

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4.2.2 Growth and Elastic Recovery properties of fabrics

4.2.3 Strength and elongation properties

4.2.3.1 Comparison between woven fabrics A and B for their strength and elongation behavior

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4.3.3 Assessment of garments stretch and recovery property on wear trials

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4.1 Phase I: Preliminary data of the fabric under study

The fabrics for research were provided by Arvind Mills, Ahmedabad. Four fabrics with content of elastane constant i.e., 3% with 97% of cotton, two in each woven and knitted category in different geometry were selected to study performance of Elastane with different fabric construction patterns. Woven fabric category had two fabrics having 2 x 2 basket weave and 2 x 2 twill weave construction respectively. Knitted fabric category had single jersey and rib knit i.e. double jersey construction. All four fabrics under study were mill finished and ready for use.

The details of fabrics used for the study have been given with codes in Table 4.1.

Table 4.1: Details of Cotton / Lycra fabric (97 x 3 %) for the study

Fabric code	Structure Pattern
A	Plain Basket weave(2x2)
B	Twill Weave(2x2)
C	Single Jersey knit
D	Rib knit

Preliminary data for fibre content, tread count, cloth cover, tightness factor, thickness and weight per unit area of fabric were determined as per standard testing methods (Table : 4.2) The results obtained were as follows:

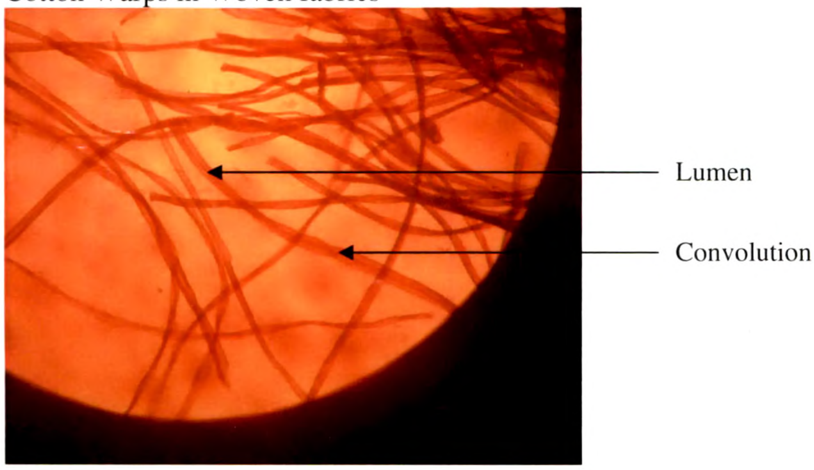
Table 4.2: Preliminary data of fabrics

Fabric Code / Preliminary Data	A	B	C	D
Fabric count / 2.5 cm^2	168 x 96	168 x 92	46 x 64	33 x 60
Cloth cover	26.2	26.6	-	-
Tightness factor	-	-	0.67	0.85
Thickness (mm)	0.26	0.26	0.69	0.78
Weight per unit area (gm/m^2)	141.31	140.92	202.49	299.39

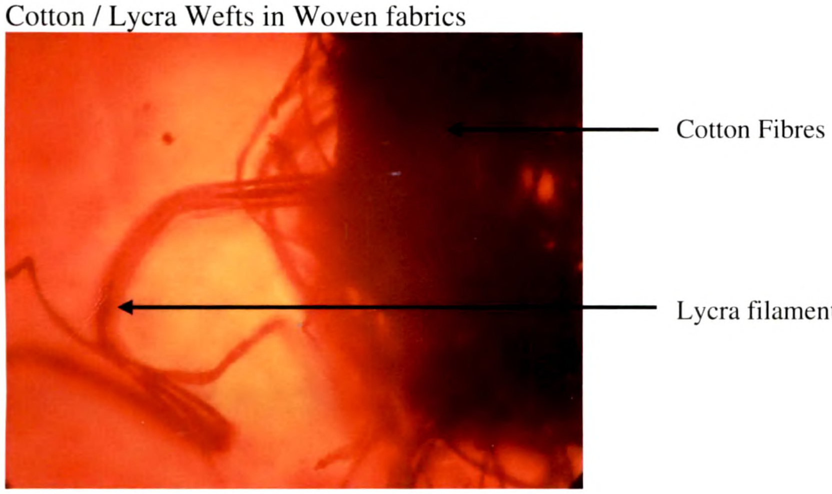
4.1.1 Fibre content of the fabrics

To confirm the content of Lycra in the fabric identification through microscopic observation and solubility test were carried out. It was observed that Lycra filament had been used in core spun form in the weft direction of woven fabrics. Warp direction did not have Lycra incorporated. In knitted fabrics, single jersey and rib knitted fabric had Lycra in half plating form.

Cotton Warps in Woven fabrics



Cotton / Lycra Wefts in Woven fabrics



Appearance of Lycra filament

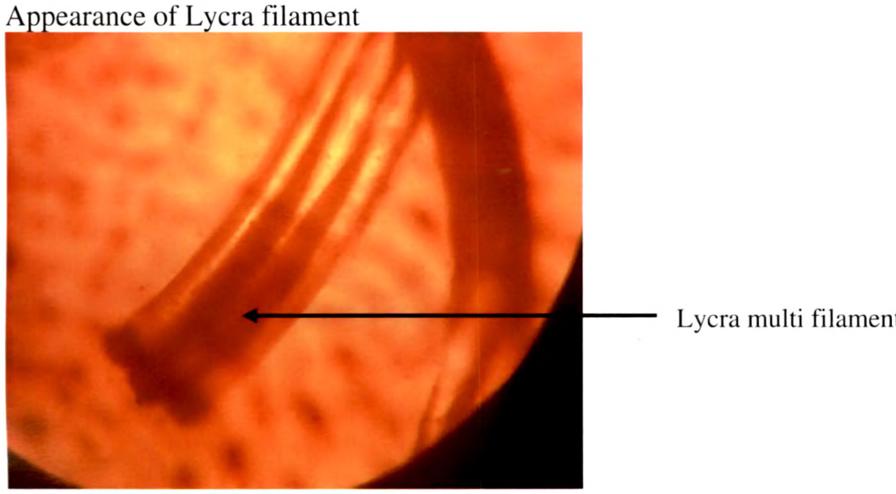
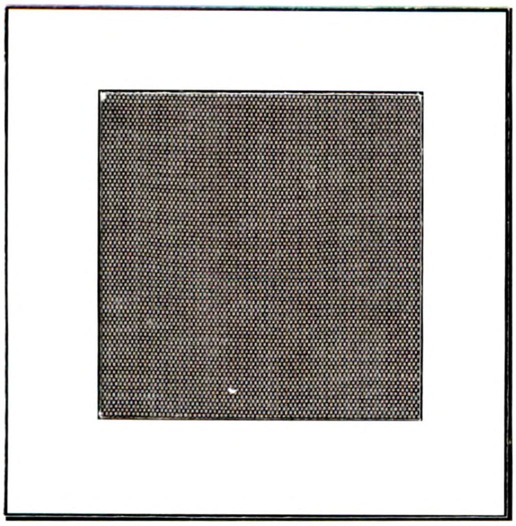
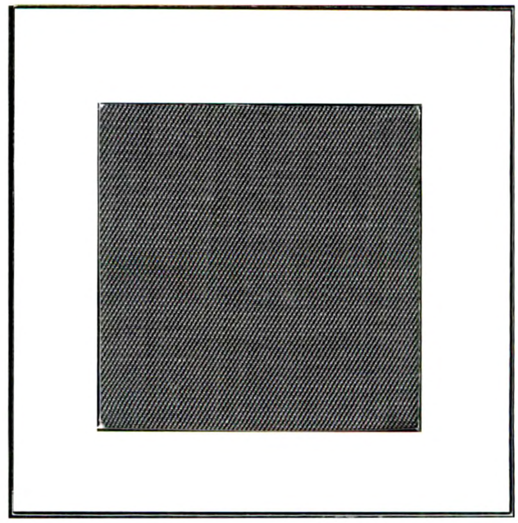


Plate 4.1: Microscopic view of fibre content of fabrics (under 100 x)

WOVEN FABRICS



A – Plain (2x2 basket) Weave



B – Twill (2x2) Weave

KNITTED FABRICS

C – Single Jersey Knit

D – Rib Knit

Plate 4.1: Fabrics used for the study
(a)

The warp yarns of woven fabrics showed twisted longitudinal structure with lumen in the center. The weft yarn showed a transparent cylindrical longitudinal structure of Lycra and cotton with a twisted longitudinal structure with lumen in the center, core spun Lycra yarn. Knitted fabrics showed core spun yarn in the course direction, in half plating for single jersey and rib knitted fabric structures.

All the four fabric samples showed that the percent Lycra was about almost 3% in all four fabrics (Table 4.3). [31]

Table 4.3: Percent Lycra content in fabric samples under study

Fabric Samples	Weight before DMF treatment (gm)	Weight after DMF treatment (gm)	% weight loss
A	7.05	6.83	3.1
B	7.00	6.78	3.1
C	10.12	9.79	3.2
D	14.97	14.52	3.01

The fabrics selected for study were having different geometry but content of Lycra was constant so as to study the performance of Lycra incorporated fabric with different geometry for elongation, elastic recovery and growth and recovery properties while making garments out of these fabrics.

4.1.2 Thread count of fabrics

(i) Woven samples

Thread count (number of warps and wefts) were determined using pick glass. Fabric A with plain 2 x 2 basket weave structure had thread count 160 x 98 per square centimeter. Fabric B with 2 x 2 twill weave structure had thread count 164 x 92 per square centimeter. Both fabrics had almost similar thread count, though their weave pattern was different. Fabric B appeared to have more compact being twill structure than fabric A, but actually the thread count was same for both.

(ii) Knitted samples

Knitted samples in Fabric C (single jersey knit) and Fabric D (double jersey/rib knit) had number of wales and courses as follows: Fabric C had 46 x 64 and Fabric D had 33 x 60 thread count. Fabric C due to single jersey knit pattern showed higher thread count than Fabric D. Fabric D also showed more compact structure due to double jersey knit construction.[30]

4.1.3 Cloth cover and tightness factor of the fabrics

Woven fabrics A and B were studied for cloth cover and knitted fabrics C and D for tightness factor. Both woven fabrics A and B had almost similar values for cloth cover as their thread count was also almost similar. Knitted fabrics C and D had different values for tightness factor as 0.67 and 0.85 respectively. Fabric C had lower value for tightness due to single knit construction. Though single jersey knit fabric C seem to have compact structure with tiny and higher number loops per centimeter. Fabric D had higher value due to double knit construction (Table 4.2).

Cover factors do not necessarily indicate textile merit because differences in count, twist factor, fibre, etc. all play their part.(6)

4.1.4 Thickness of the fabrics

Thickness values of both woven fabrics A and B were similar i.e., 0.26 mm as the thread count was same. Fabrics C and D showed different thickness values, 0.69 mm and 0.78 mm respectively. Fabric C with single jersey knit construction. Fabric D appeared to be thicker than fabric C, A and B.

4.1.5 Weight per unit area of fabrics

The mass units (gm/m^2) for woven fabrics A & B were similar as the thread count and thickness of both the fabrics were same. Knitted fabrics C and D had 202.49 and 299.39 gm/m^2 value respectively. Fabric D showed highest value due to double knit construction, and was heaviest amongst all four fabrics. (Table 4.2)

4.2 Phase II: Physical testing for performance and serviceability of fabrics

Results of physical testing for performance and serviceability for all four fabrics gave comparative idea for fabrics as how woven or knitted fabrics perform for their behavior with Lycra incorporated with them.

4.2.1 Results of pilling and abrasion resistance properties

4.2.1.1 Pilling resistance

Fabrics during wearwereconsiderably affected by conditions like use of garments by actual wearing and laundering. To produce pills most closely resembling those produced in wear, conditions of low pressure are required. From a pilling point of view, shirts, blouses, lingerie, and dresses are considered to be critical end-uses. These garments would be frequently laundered between wearing, while medium and heavy weight garments will not normally be washed or cleaned with similar frequency, so the fabrics were subjected to pilling test up to 400 cycles under load of

290 grams to observe any surface fibre appears which could further entangle during wash and wear. As all the fabrics were made of cotton, pilling was not expected on the fabric surface. The impact of Lycra was the only concern for pill formation.

Table 4.3(a) Pilling resistance of fabrics under study

Fabric Code	No. of Cycles			
A	100	200	300	400
B	100	200	300	400
C	100	200	300	400
D	100	200	300	400
Observation	**Protruding fibres or pilling effect was not observed**			

Woven fabrics A and B were with their geometry so compactly constructed that irregularities of any protruding fibres were not observed. Similarly knitted fabrics C and D showed no effect of pilling on the surface. Any effect of fussiness, fading or change in colour was also not observed. (Table 4.3(a))

4.2.1.2 Abrasion resistance

The results of woven fabrics A and B showed very good resistance because of compact weave structure. As number of abrasion cycles progressed, after 680 cycles there was single yarn breakage in the fabric. The thickness of the fabrics reduced up to 0.02 mm.

Table 4.3(b) Abrasion resistance of fabrics under study

Fabric Code	No. of Cycles	Observation	Loss in Thickness (in mm)
A	680	Single yarn breakage	0.02
B	685	Single yarn breakage	0.02
C	850	Single yarn breakage	0.03
D	1000	No yarn breakage	0.03

Knitted fabrics showed loss of luster due to abrasion effect, colour of the fabric surface became dull. Single jersey knit fabric C showed yarn breakage after 850 cycles with reduction of fabric thickness from 0.69 mm to 0.66 mm. Rib knit fabric D also showed similar thickness results but there was no yarn breakage observed even at 1000 cycles. Rib knit i.e., double jersey knit construction was responsible for such result.

The fabrics with their close woven and knitted structure were quite resistance to abrasion. (Table 4.3(b))

4.2.2 Effect of growth and elastic recovery properties on fabrics under study

Textiles used for apparel purpose need to have certain properties for their satisfactory performance. Apart from strength, elastic behavior is very important for ease of movement and comfort property.

Woven fabrics are quite rigid with their elastic property due to firm, compact structure. Knitted fabrics overcome this problem and make the wearer comfortable. The deformation of shape and size after regular wash and wear is very obvious with cotton knitted fabrics and so Lycra is incorporated to overcome this problem.

The fabrics for this research had 3% Lycra with 97% of cotton constructed with weaving and knitting techniques. Their performance for shape retention was studied by conducting growth and elastic recovery to size and fit of the garment made out of these fabrics.

Results of fabrics for growth and recovery property have been presented in Table 4.4. Perfectly elastic materials will have an elastic recovery of 1.0, while materials without any power of recovery will have recovery of zero. [6]

Fabrics A and B did not show recovery in warp direction presenting elastic recovery value 0. Weft direction exhibited better recovery for fabric A (0.8) and fabric B (0.9).

Table 4.4: Growth and elastic recovery value of fabrics in warp and weft directions

	Original length (cm)	Extended length	Immediate Recovery	Recovery after 24 hrs	Elastic recovery value
A warp	20.0	20.4	20.1	20.0	0.0
A weft	20.0	20.7	20.2	20.1	0.8
B warp	20.0	20.4	20.1	20.0	0.0
B weft	20.0	21.1	20.3	20.1	0.9
C wale	20.0	28.6	21.2	20.3	0.9
C coarse	20.0	28.4	20.8	20.3	0.9
D wale	20.0	22.3	20.5	20.2	0.9
D coarse	20.0	26.2	20.5	20.3	0.9

Knitted fabrics C and D both had very good extension and recovery. Knitted looped structure and presence of Lycra were responsible for such behavior. Though Lycra was present only in course direction, wale direction also exhibited good recovery due to knit structure. Fabric C and D both had recovery value of 0.9 in wale as well in course direction indicated that these fabrics recovered better. [19][22]

4.2.3 Load and elongation characteristics of fabrics under study

Lycra alone exhibits about 600% elongation, and when incorporated in fabrics even in small amount of 2 to 5% gives improved results.[20] Data of fabrics with 97% x 3% cotton/Lycra in different woven geometry for strength and elongation property had been represented in Table 4.5.

In warp wise direction fabric A (2x2 basket weave) showed highest load i.e., 61.98 kgf with minimum elongation value of 10.16 mm. As the warp yarns could be under stress while manufacture of fabric and also being pure cotton elongation value obtained was low. The fabric had decreased load value of 43.28 kgf in weft with increased elongation value of 26.33 mm. This was due to presence of Lycra in the weft direction and also the relaxed, corrugated path that weft yarn followed while weaving. Bias exhibited maximum elongation of 46.34 mm with lowest load value of 37.66 kgf. This result was due to no support of warp or weft yarns in bias direction.

Table 4.5: Load and elongation properties of woven fabrics

Direction of Sample	Fabric A (Plain weave)		Fabric B (Twill weave)	
	Load (kgf)	Elongation (mm)	Load (kgf)	Elongation (mm)
Warpwise	61.98	10.16	65.12	9.64
Weftwise	43.28	26.33	39.96	24.38
Bias	37.66	46.34	28.46	36.78

Fabric B (2x2 twill weave) exhibited load elongation property expressed in Table 4.5. Twill weave pattern showed highest load i.e., 65.12 kgf in the warpwise direction with minimum elongation value of 9.64 mm. Weftwise direction with Lycra exhibited decreased load of 39.96 kgf, as elastic property of Lycra contributed higher elongation in this direction. Bias direction elongated maximum 36.78 mm with minimum load of

28.46 kgf. As usual behaviour of woven fabrics, bias direction showed maximum stretch.[16]

Fabric C and D were also tested for their elongation property. The data was expressed in Table 4.6.

Table 4.6: Load and elongation properties of knitted fabrics

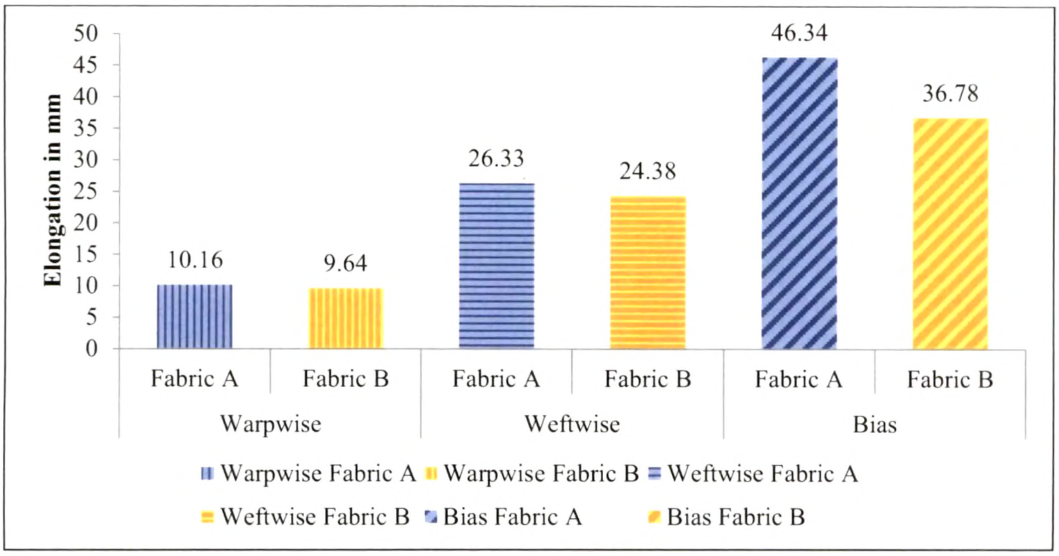
Direction of Sample	Fabric C (Single jersey)		Fabric D (Rib knit)	
	Load (kgf)	Elongation (mm)	Load (kgf)	Elongation (mm)
Walewise	26.16	149.30	48.16	83.93
Course wise	18.24	185.80	24.66	206.22
Bias	26.72	105.67	33.30	96.69

Single jersey fabric C exhibited higher elongation value of 149.30 mm at 26.16 kgf load. The interlooped weft knit construction in single jersey knit allowed the fabric to undergo higher stretching. Coursewise direction showed maximum elongation value with Lycra in alternate plating allowed the fabric to extend so high up to 185.80 mm at 18.24 kgf load. Unlike woven fabrics bias direction showed elongation value which was lower (105.67 mm) than walewise or coursewise direction value though the amount of load required was same as walewise direction load. Slippage of knitted loops was the reason for lower elongation value.

Fabric D with double jersey weft knit construction showed higher strength value of 48.16 kgf with 83.93 mm elongation value. Coursewise direction with 24.66 kgf load showed highest elongation value of 206.22 mm. Lycra in double jersey knit construction in single plating was responsible for higher elongation value. Bias direction showed elongation value of 96.69 mm which was slightly higher than walewise elongation value but quite lower than coursewise value at the load value of 33.30 kgf.

4.2.3.1 Comparison of load and elongation behaviour of woven fabrics under study

A comparative behaviour of elongation against applied load had been expressed in Graph 4.1.

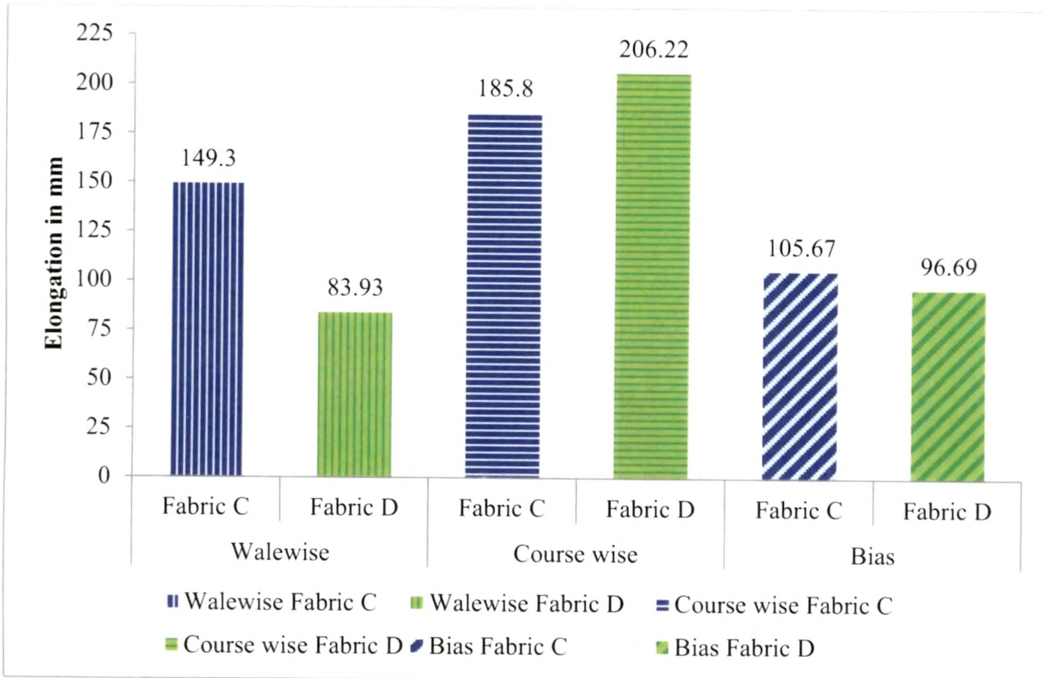


Graph 4.1: Elongation property of woven fabrics

Plain weave fabric A showed higher elongation value in both warp and weft direction compare to twill weave fabric B. Compact twill weave and rigid structure expressed low elongation value. Similarly weft direction for fabric A showed higher elongation value than twill weave fabric B for the same reason. Compare to warp direction, weft direction showed more elongation that was contribution of stretch property of Lycra in weft direction for these fabrics. Bias direction of plain weave showed higher elongation value exhibiting quite flexible behaviour than compact twill weave construction. Though the fabric count and weight per unit area was same for both the fabrics, only geometry of fabric was responsible for this result.

4.2.3.2 Comparison of load and elongation behaviour between knitted fabrics

Fabric C showed higher elongation value in walewise direction than fabric D because Fabric C had more number of single loops which straightened up with applied load. Fabric D had double jersey structure, but numbers of loops were less compare to single jersey knit fabric C, hence showed lower elongation value. In bias direction, the loops for both the fabrics behaved independently, showing lower elongation value than coursewise direction. Fabric D had support of loops in double knit pattern making it compact resulting in lower elongation than single knit pattern of fabric C (Graph 4.2).



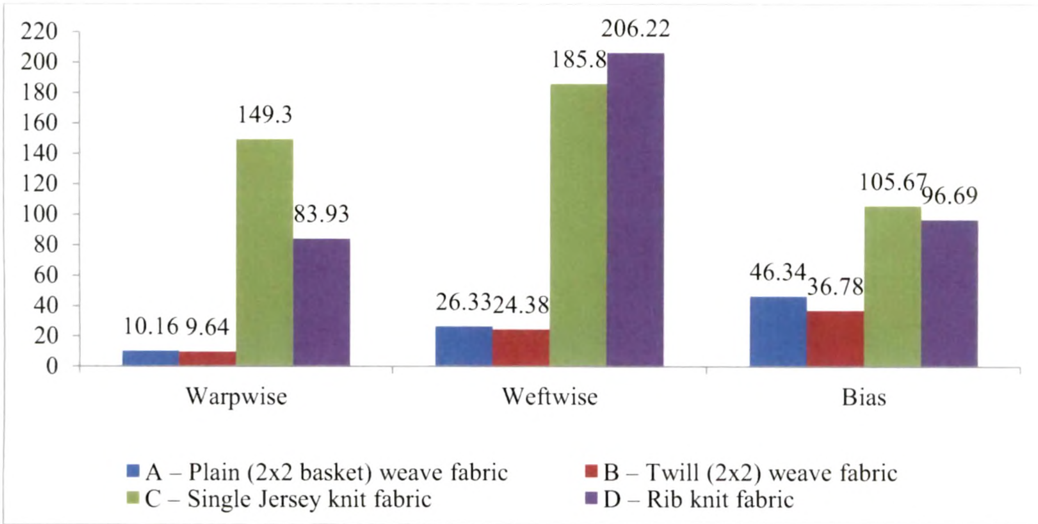
Graph 4.2: Elongation property of knit fabrics

Both the knitted fabrics C and D showed higher values for elongation in course wise direction with presence of Lycra and straightening of weft knitted loops in the fabrics. Fabric D showed higher elongation than Fabric C as it had Lycra in double jersey knit construction contributing to this property.

4.2.3.3 Comparison between woven and knitted fabrics for load and elongation behavior

The overall elongation behaviour of woven and knitted fabrics had been represented in Graph 4.3. Both the woven fabrics A and B showed lower elongation value than knitted fabrics. Woven fabrics being compact with interlaced structure did not show flexible behaviour. Though weft direction had shown higher values due to stretch behaviour of Lycra in it, twill weave fabric B had impact of geometry resulting in lower elongation than plain weave.

Single jersey fabric C and Rib knit fabric D showed highest course wise elongation being weft knitted fabric and Lycra incorporated in this direction. Unlike woven fabrics, knitted fabrics did not show good stretch ability in bias direction.[37]



Graph 4.3: Comparison of elongation property of fabrics under study

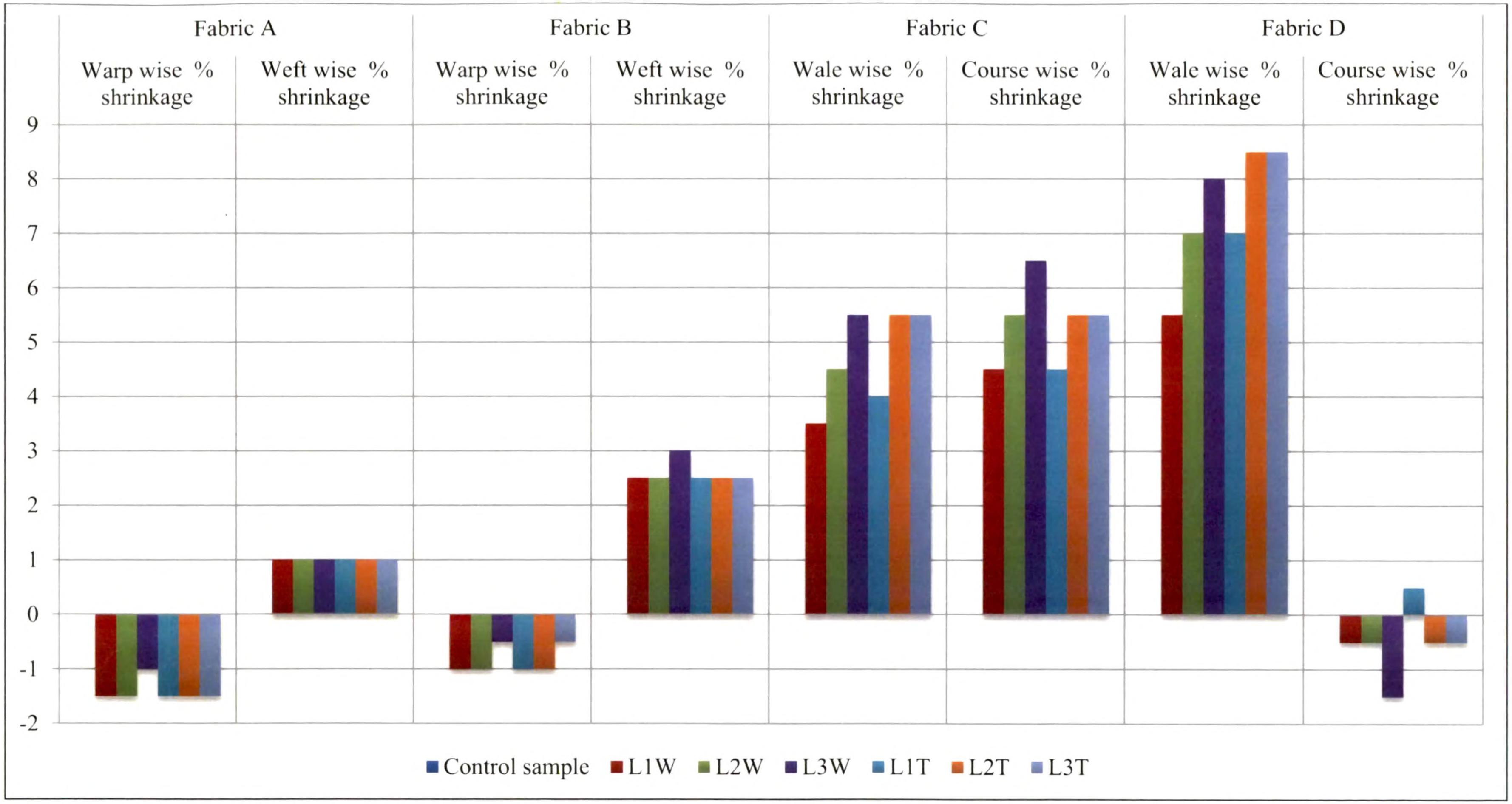
4.2.4 Shrinkage behavior of fabrics

The test samples of all four fabrics were subjected to three laundry washes. Two sets, one washed with only water and another with 5% detergent solution were measured for shrinkage behavior to study effect of non-ionic detergent on fabrics. The results of percent shrinkage were expressed in Table 4.7.[38][46]

Table 4.7: Shrinkage behavior of fabrics under study

Fabrics	A		B		C		D	
Laundry washes	Warp wise % shrinkage	Weft wise % shrinkage	Warp wise % shrinkage	Weft wise % shrinkage	Wale wise % shrinkage	Course wise % shrinkage	Wale wise % shrinkage	Course wise % shrinkage
Control sample	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
L1W	-1.5	1.0	-1.0	2.5	3.5	4.5	5.5	-0.5
L2W	-1.5	1.0	-1.0	2.5	4.5	5.5	7.0	-0.5
L3W	-1.0	1.0	-0.5	3.0	5.5	6.5	8.0	-1.5
L1T	-1.5	1.0	-1.0	2.5	4.0	4.5	7.0	0.5
L2T	-1.5	1.0	-1.0	2.5	5.5	5.5	8.5	-0.5
L3T	-1.5	1.0	-0.5	2.5	5.5	5.5	8.5	-0.5

Key: **L1W** – Wash cycle I – treatment with only water, **L2W** – Wash cycle II- treatment with only water, **L3W** - Wash cycle III -treatment with only water, **L1T** –Wash cycle I- treatment with 5% detergent solution, **L2T**–Wash cycle II- treatment with 5% detergent solution, **L3T** –Wash cycle III- treatment with 5% detergent solution



Graph 4.4: Shrinkage behaviour of fabrics treated with and without detergent solution

Shrinkage values for woven and knitted fabrics indicated that all fabrics behaved differently as per their geometry.

Fabric A exhibited extension of -1.0 to -1.5 percent in warp direction when washed with water as well as with 5% detergent solution. Weft direction showed shrinkage of 1.0 percent due to presence of Lycra in the weft.

Fabric B exhibited extension of -0.5 to -1.0 percent in warp direction. Weft direction exhibited shrinkage of 2.5 percent. Only third wash cycle with water resulted in shrinkage of 3 percent in weft direction. Compact twill weave pattern was responsible for lesser values in warp direction shrinkage than fabric A. Similarly weft shrinkage values were more for fabric B than fabric A.

Fabric C exhibited progressive shrinkage when washed with water in wale as well as in course direction ranging from 3.5 to 5.5 percent and 4.5 to 6.5 percent respectively. When washed with detergent, first two wash cycles in wale direction showed progressive shrinkage from 4.0 to 5.5 percent and then it became steady at the third wash cycle. The course direction shrinkage was also progressive from 4.5 to 5.5 percent and became steady at the third wash cycle. The contraction of loop structure and presence of Lycra resulted in such changes. The sample edges also curled after washing. This showed the dimensional set of fabric with detergent solution. The garments made out of the fabrics could be easily washed with detergent solution without much of damage in the dimension.[25]

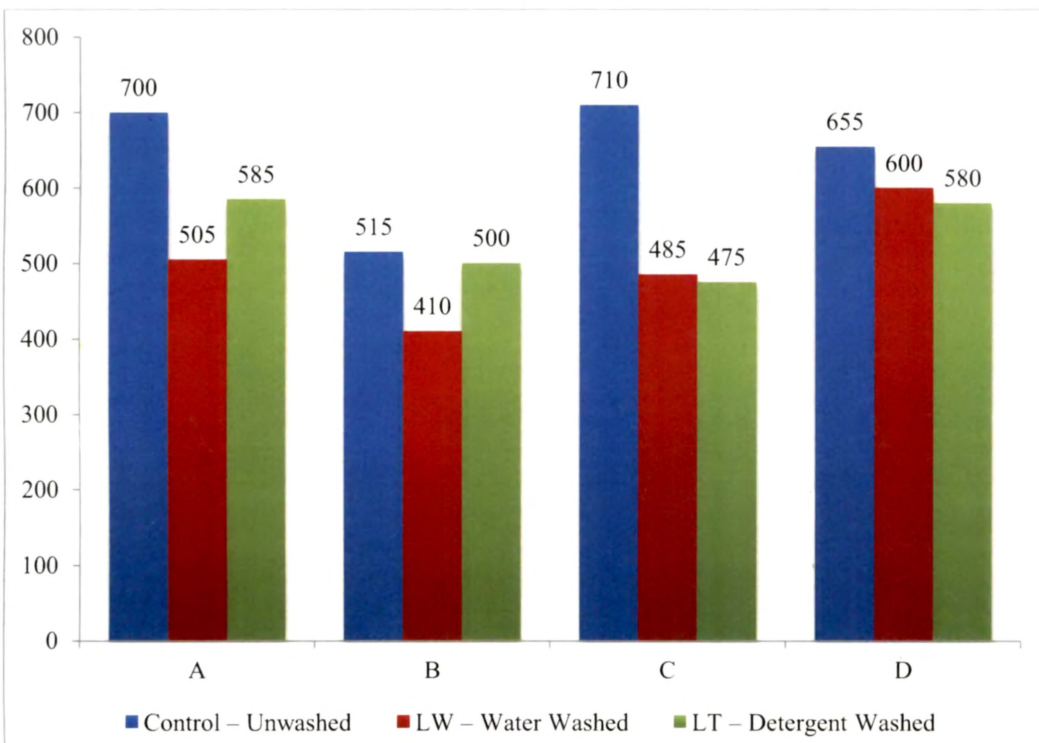
Fabric D being double knitted showed progressive shrinkage in wale direction from 5.5 to 8.0 percent with water and 7.0 to 8.5 percent with detergent solution. Unlike the behaviour of single jersey fabric in course direction, fabric D showed extension from -0.5 to -1.5 percent with water wash and 0.5 to -0.5 percent with detergent in course direction. The third wash with detergent showed steady shrinkage value. Compact double knit construction might not have allowed the fabric to contract in this direction. Though the fabric construction was weft knitting structure with Lycra in course, rib knit structure exhibited more shrinkage in wale direction slightly higher than warp shrinkage value for fabric C. Rib knit structure unlike single knit structure did not curl from the edges and maintain firm shape due to double knit construction pattern and bulkiness of the fabric.

4.2.5 Air permeability of fabrics

The fabrics in their control state and after each laundry cycle of water and detergent wash were subjected to air permeability test. The results obtained have been presented in Table 4.8 and they have been compared in graph 4.5.

Table 4.8: Air permeability of treated and untreated fabrics

Treatments	Fabrics			
	A Air permeability $m^3/m^2/hr$	B Air permeability $m^3/m^2/hr$	C Air permeability $m^3/m^2/hr$	D Air permeability $m^3/m^2/hr$
Control	700	515	710	655
LW	505	410	485	600
LT	585	500	475	580



Graph 4.5: Air permeability of treated and untreated fabrics under study

The amount of air passing through the fabric depends on the geometry of fabrics. The fabrics showed higher readings of permeable air for control fabrics. Plain basket weave fabrics though being close compact woven had more permeability to air(700 $m^2/m^3/hr$) than fabric B(515 $m^2/m^3/hr$). Fabric C having single jersey knit pattern showed more of air (710 $m^2/m^3/hr$) passing through than fabric D (655 $m^2/m^3/hr$) with double knit construction.

When these fabrics were washed with water, due to swelling and contraction of the yarn in the fabrics A and B showed decreased permeability of air(505 and 410 $m^2/m^3/hr$) respectively. This was supported by results of fabric shrinkage. With detergent wash there could be removal of surface finish from the fabrics and hence the permeability of fabrics A (585 $m^2/m^3/hr$) and B (500 $m^2/m^3/hr$) increased than the samples washed with water.

Knitted fabrics C and D with their looped structure showed more air permeability readings. Fabric D with double jersey knit construction showed lesser permeability to air than fabric D. The treatment with water made the fabric structure swollen and compact and more resistant to air showing decreased value for fabric C(485 $m^2/m^3/hr$) and 600 $m^2/m^3/hr$ for fabric D. Further the treatment with detergent showed lower readings of air permeability for fabric C (475 $m^2/m^3/hr$) indicating closeness of the fabric structure supported by progressive shrinkage in the wale and course direction of with presence of Lycra. Fabric D showed shrinkage resulted in resistant to air with less amount of air passing through (580 $m^2/m^3/hr$) after detergent wash. (Graph 4.5)

4.2.6 Elastic recovery property of fabrics under cyclic loading

The fabrics when put to end use as apparel product, would undergo various stresses in all directions many times with various movements. To study further the use of recovery parameter in garment fit, this test was carried out. Fabrics A, B, C and D were first tested for their tensile strength in lengthwise, widthwise and bias direction.[20][26] On the basis of the tensile graph obtained yield point for maximum recovery at stress was found and the samples in each direction were worked to study recovery below yield point, at yield point and above yield point.[3][29] The results obtained were as follows.

The elastic recovery property of fabrics had been discussed here. Table 4.9 showed tensile property of plain weave fabric A in warp, weft and bias direction.

Table 4.9: Tensile strength of woven fabric A

Sr. No.	Sample	Gauge length (mm)	Batch reference	Maximum load (gf)	Percent strain at Maximum load	Load at Break (kgf)	Percent strain at Break
1	A1 warp wise	50.00	Plain woven (2x2 basket)	58940	16.90	29.47	17.46
2	A2 weft wise	50.00	Plain woven (2x2 basket)	41440	39.86	20.71	42.32
3	A3 Bias	50.00	Plain woven (2x2 basket)	17710	63.30	8.85	69.82

Fabric A showed minimum load of 8.85 kgf with highest elongation of 63.30% in bias direction, followed by 20.71 kgf load and 39.86% elongation for weft direction and 29.47 kgf load with 16.90% elongation for warp direction. Bias showed maximum stretch of the fabric. Weft direction with Lycra in the yarn showed better elongation property. From the graphs (Graph 4.6, pg. 88) of tensile strength in each direction, yield points at which maximum recovery value for each direction was obtained. The sample recovery values at yield point, below yield point and above yield point were studied and have been represented in tables 4.10, 4.11 and 4.12 for the warp, weft and bias direction respectively. (Graph 3.1, pg. 60; 4.6)

Table 4.10: Elastic recovery behaviour of plain weave fabric in warp direction

Sr. No.	Sample reference	First cycle Extension (cm)
1	Warp a below yield point	0.139
2	Warp b at yield point	0.241
3	Warp c above yield point	0.341

From the above table it can be inferred that the warp direction can be worked within limitations of 0.24 cm to 0.13 cm which is very low recovery value and fabric does not behave like a stretch fabric. The weft direction with Lycra showed recovery value presented in Table 4.11.

Table 4.11: Elastic recovery behaviour of plain weave fabric in weft direction

Sr. No.	Sample reference	First cycle Extension (cm)
1	Weft a below yield point	0.79
2	Weft b at yield point	0.89
3	Weft c above yield point	0.99

The weft direction showed better results as it exhibited higher stretch ability and recovery value due to Lycra present in the weft direction. 0.79 to almost 1.0 cm recovery could give very good result when garments would be constructed out of it specially to get better fit in the girth of the body.

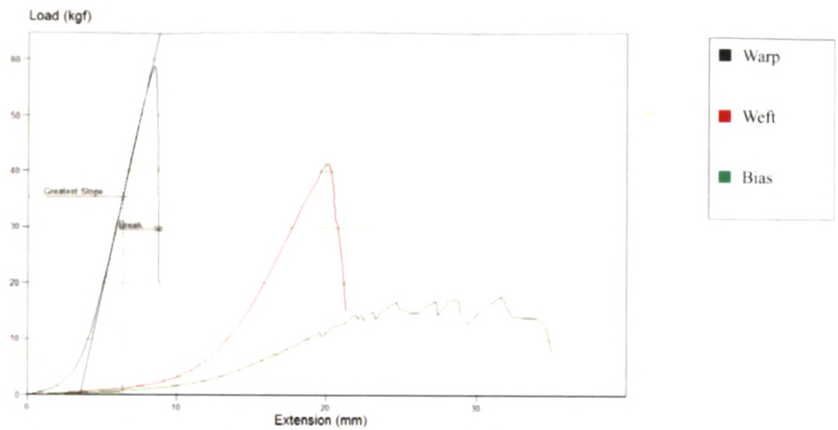
Bias also had similar but slightly lower recovery value as the weft direction (Table 4.12).

Table 4.12: Elastic recovery value of plain weave fabric in bias direction

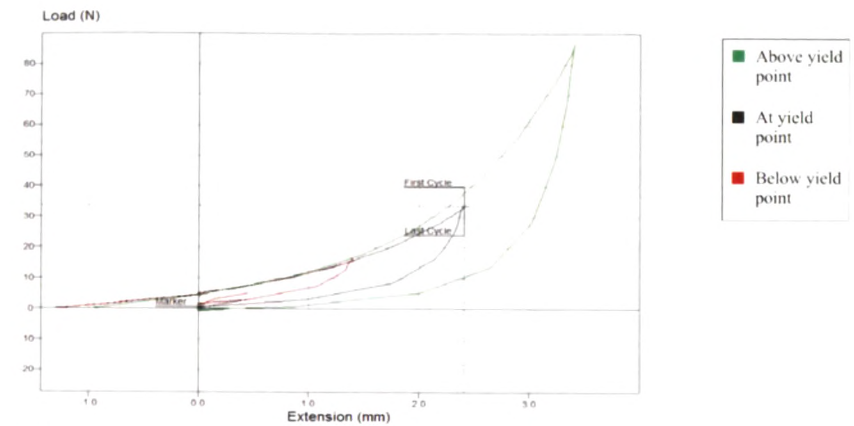
Sr. No.	Sample reference	First cycle Extension (cm)
1	Bias a below yield point	0.79
2	Bias b at yield point	0.81
3	Bias c above yield point	0.91

Plain weave fabrics showed maximum stretch ability in bias direction. The values presented in table 4.12 supported this property as the extension at maximum recovery was 0.81 cm at yield point and 0.79 cm below yield point.

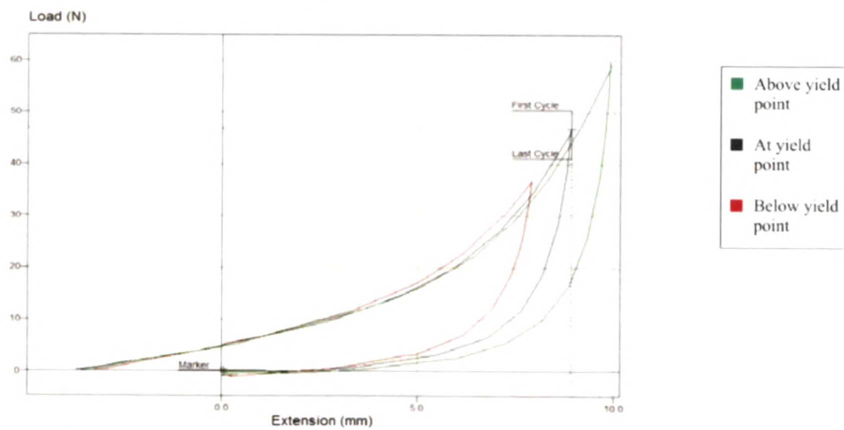
Bias and weft direction both showed similar values showing very good strength and recovery property of fabric in the weft direction with presence of Lycra yarn.



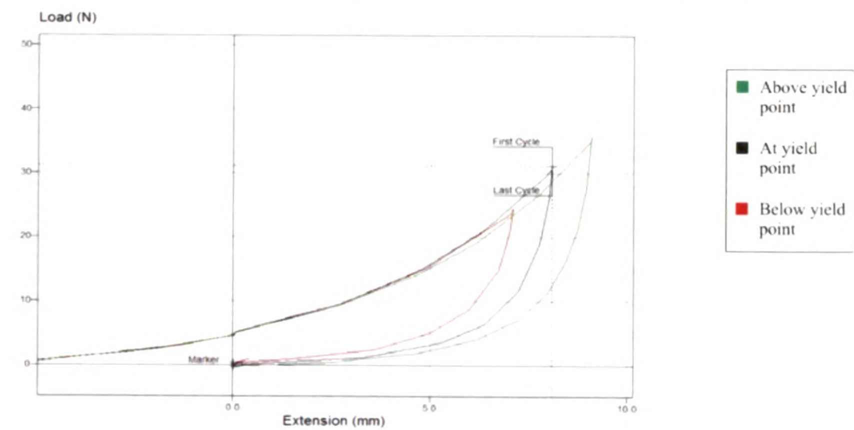
4.6a: Tensile properties of plain weave fabric



4.6b: Recovery behaviour of plain weave fabric in warp direction



4.6c: Recovery behaviour of plain weave fabric in weft direction



4.6d: Recovery behaviour of plain weave fabric in bias direction

Graph 4.6: Recovery behaviour of plain weave fabric under cyclic loading

The tensile strength of twill weave fabric B has been exhibited in Table 4.3.

Table 4.13: Tensile strength of twill weave fabric B

Sr.No.	Sample	Gauge length (mm)	Batch reference	Maximum load (gf)	Percent strain at Maximum load	Load at Break (kgf)	Percent strain at Break
1	B1 warp wise	50.00	Twill woven (2x2)	59300	16.40	29.65	17.26
2	B2 weft wise	50.00	Twill woven (2x2)	36810	48.98	18.40	52.12
3	B3 bias	50.00	Twill woven (2x2)	17350	41.77	8.67	63.81

As seen in plain weave fabric, twill weave also shows highest load of 29.56 kgf for warp wise direction with elongation of 16.40%. Weftwise direction and bias showed 8.67 kgf load and maximum elongation of 41.77%.

On the basis of these tensile strength values, the elastic recovery values at yield point, below yield point and above yield point were studied and have been presented in Table 4.14, 4.15 and 4.16 for the warp, weft and bias direction respectively. (Graph 4.7)

Table 4.14: Elastic recovery value of twill weave fabric in warpwise direction

Sr. No.	Sample reference	First cycle Extension (cm)
1	Warpwise a below yield point	0.19
2	Warpwise b at yield point	0.29
3	Warpwise c above yield point	0.39

Like plain weave fabric, twill weave also showed lower recovery value range from 0.29 to 0.19 cm.

Table 4.15: Elastic recovery value of twill weave fabric in weftwise direction

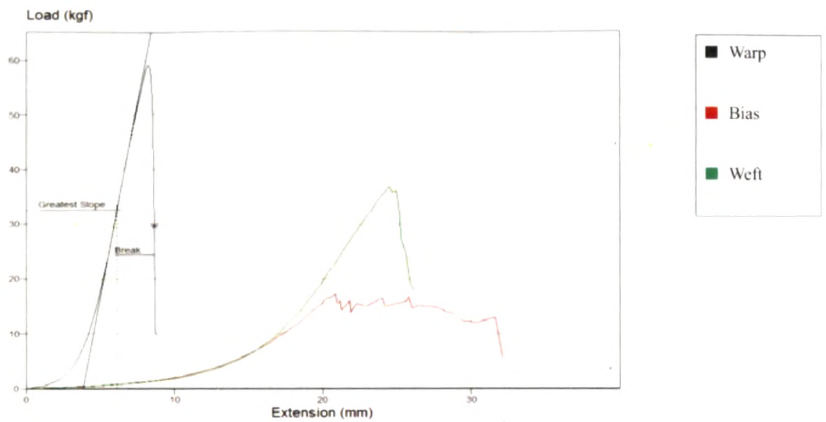
Sr. No.	Sample reference	First cycle Extension (cm)
1	Weftwise a below yield point	1.02
2	Weftwise b at yield point	1.12
3	Weftwise c above yield point	1.22

The weftwise direction with compact weave structure of twill pattern and Lycra showed recovery value of 1.12 cm at yield point at 1.02 cm below yield point, which is expected to give better result for garment fit and comfort.

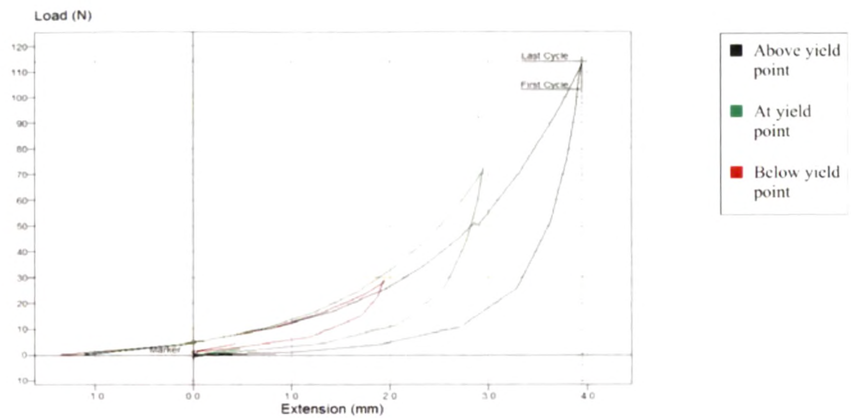
Table 4.16: Elastic recovery value of twill weave fabric in bias direction

Sr. No.	Sample reference	First cycle Extension (cm)
1	Bias a below yield point	0.75
2	Bias b at yield point	0.85
3	Bias c above yield point	0.95

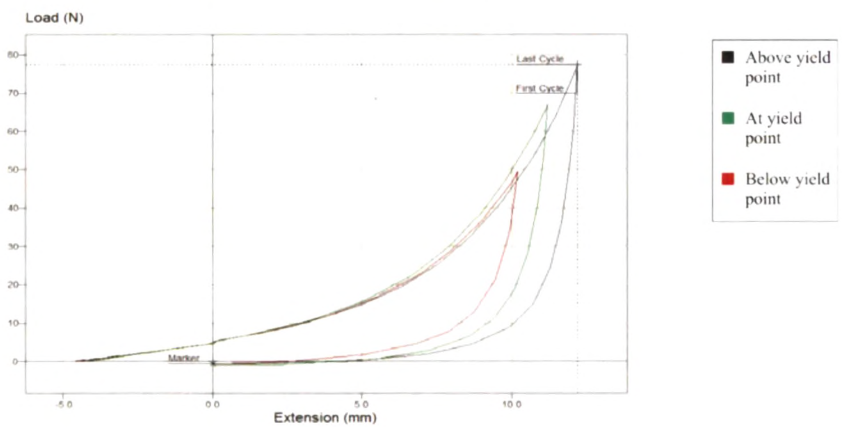
Elongation in bias direction was expected to show maximum recovery value due to higher strength property. However twill fabric in the bias direction did not show the expected values of high elongation as seen in the plain woven fabric A.



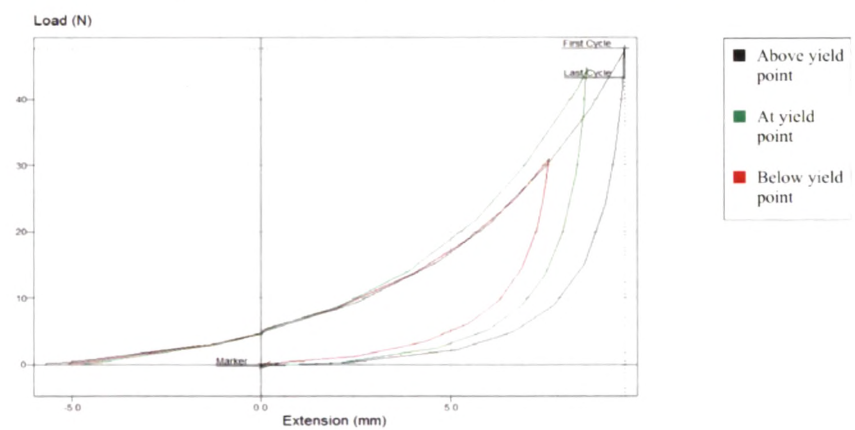
4.7a: Tensile properties of twill woven fabric



4.7b: Recovery behaviour of twill weave fabric in warp direction



4.7c: Recovery behaviour of twill weave fabric in weft direction



4.7d: Recovery behaviour of twill weave fabric in bias direction

Graph 4.7: Recovery behaviour of twill weave fabric under cyclic loading

The tensile behaviour of single jersey knit fabric C has been presented in Table 4.17.

Table 4.17: Tensile strength of single jersey knit fabric

Sr.No.	Sample	Gauge length (mm)	Batch reference	Maximum load (gf)	Percent strain at Maximum load	Load at Break (kgf)	Percent strain at Break
1	C1 Walewise	50.00	Single Jersey	21770	263.1	10.88	266.29
2	C2 Coursewise	50.00	Single Jersey	16970	365.0	8.48	372.86
3	C3 Bias	50.00	Single Jersey	15330	189.6	7.66	208.13

It was observed that the course direction with Lycra in weft knitting construction technique exhibited maximum elongation value of 365.0% with load of 8.48 kgf, followed by 263.1 % for walewise direction with load of 10.88 kgf and 189.6% with load of 7.66 kgf in bias direction. Unlike woven fabric, knitted fabric showed lower elongation value in bias direction as individual loop structure did not support each other in bias direction.

On the basis of these tensile strength values, the elastic recovery values at yield point, below yield point and above yield point were studied and have been presented in Table 4.18, 4.19 and 4.20 for the warp, weft and bias direction respectively. (Graph 4.8)

Table 4.18: Elastic recovery value of single jersey knit fabric in walewise direction

Sr. No.	Sample reference	First cycle Extension (cm)
1	Walewise a below yield point	4.67
2	Walewise b at yield point	4.78
3	Walewise c above yield point	4.87

The looped structure in single jersey knit construction contributed to very good recovery value range from 4.78 cm to 4.67 cm. This recovery value could be useful to produce the garments which could at least be worn by two people with two sizes bigger.

Table 4.19: Elastic recovery value of single jersey knit fabric in coursewise direction

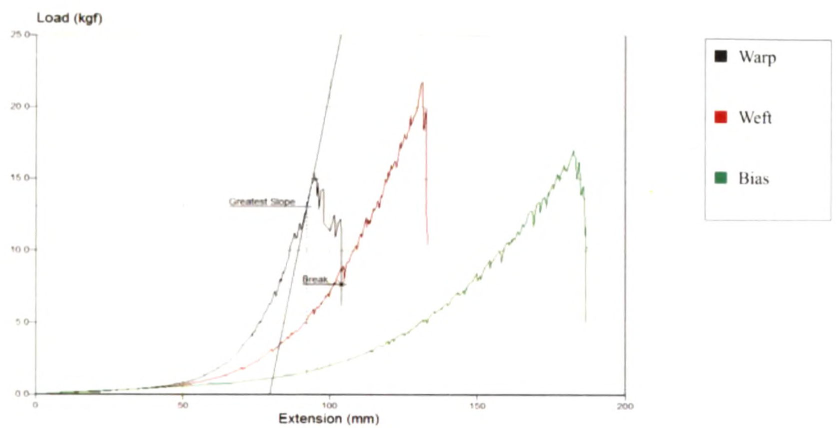
Sr. No.	Sample reference	First cycle Extension (cm)
1	Coursewise a below yield point	7.09
2	Coursewise b at yield point	7.20
3	Coursewise c above yield point	7.30

The recovery value from 7.20 cm to 7.09 cm could be considered very high. Weft knitted structure with Lycra was responsible for such an excellent property.

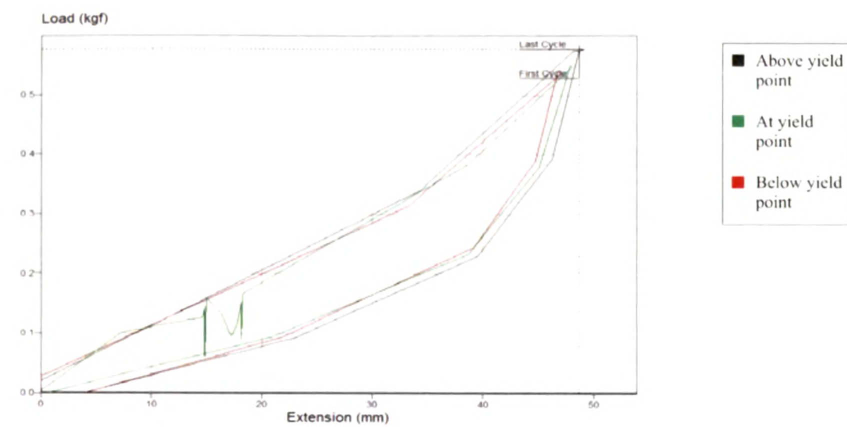
Table 4.20: Elastic recovery value of single jersey knit fabric in bias direction

Sr. No.	Sample Information	First cycle Extension (cm)
1	Bias a below yield point	3.08
2	Bias b at yield point	3.12
3	Bias c above yield point	3.19

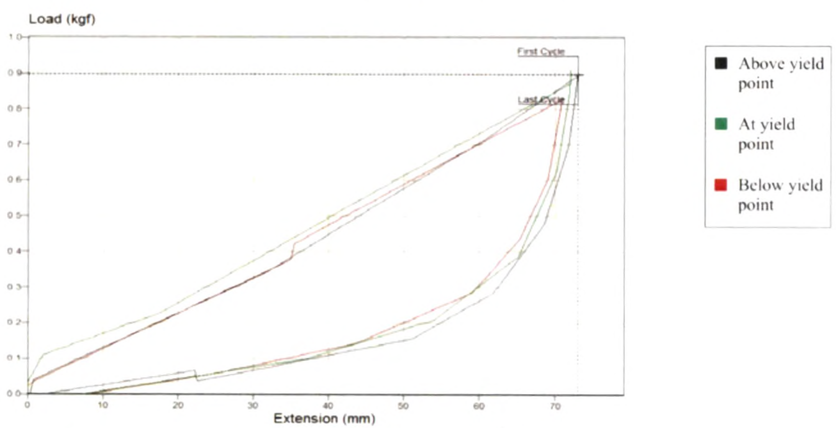
From the table it was observed that bias direction showed minimum elastic reçovery value from 3.12 cm to 3.08 cm at and below yield points respectively. This values were lowest than walewise and coursewise direction recovery values. Interlooped structure of knitted fabric when undergoes stretching, slippage of looped stitches cause this result.



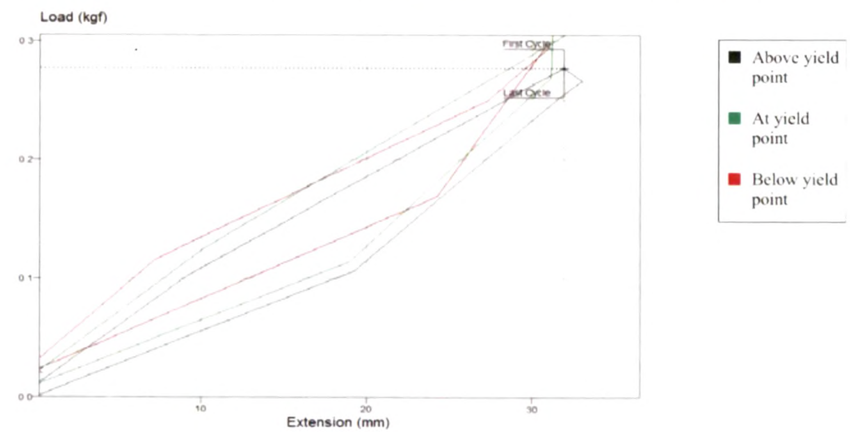
4.8a: Tensile properties of single jersey knit fabric



4.8b: Recovery behaviour of single jersey fabric in wale direction



4.8c: Recovery behaviour of single jersey fabric in course direction



4.8d: Recovery behaviour of single jersey fabric in bias direction

Graph 4.8: Recovery behaviour of single jersey fabric under cyclic loading

Rib knitted fabric D showed tensile property presented in Table 4.21.

Table 4.21: Tensile strength of rib knit fabric in wale, course and bias direction

Sr.No.	Sample	Gauge length (mm)	Batch reference	Maximum load (gf)	Percent strain at Maximum load	Load at Break (kgf)	Percent strain at Break
1	D1walewise	50.00	Rib knit	46010	140.1	23.00	266.29
2	D2 coursewise	50.00	Rib knit	20450	398.4	10.22	372.86
3	D3 bias	50.00	Rib knit	27530	166.0	13.76	208.13

Fabrics D showed minimum elongation of 140.1 percent at 23.0 kgf load in wale wise direction. Double knit construction was responsible for compactness of knitted loops showing lower elongation value. Course wise it exhibited highest percent elongation of 398.4 with load of 10.22 kgf. This was due to Lycra yarn and double jersey weft knitted structure. Bias direction showed lower elongation value than course wise direction but it was higher than wale wise direction, i.e., 166.0 percent at load of 13.76 kgf.

Elastic recovery values at yield point, below yield point and above yield point were studied on the basis of tensile strength values and have been represented in Table 4.22, 4.23 and 4.24 for the wale, course and bias direction respectively. (Graph 4.9)

Table 4.22: Elastic recovery of rib knit fabric in wale direction

Sr. No.	Sample	First cycle Extension (cm)
1	Wale wise a below yield point	2.3
2	Wale wise b at yield point	2.4
3	Wale wise c above yield point	2.5

The wale direction did not show much elasticity as double knit compact structure did not loosen so easily, showing 2.4 and 2.3 cm extension at yield point and below yield point respectively.

Table 4.23: Elastic recovery of rib knit fabric in course direction

Sr. No.	Sample	First cycle Extension (cm)
1	Course wise a below yield point	7.69
2	Course wise b at yield point	7.79
3	Course wise c above yield point	7.89

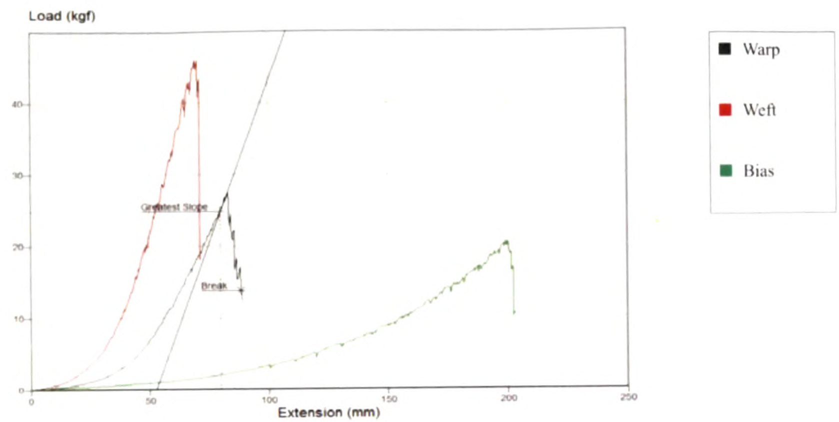
The course wise direction due to Lycra and opening of double knitted loops exhibited very good elastic property of 7.79 to 7.69 cm. This was observed as highest amongst all three direction of the rib knitted fabric.

Table 4.24: Elastic recovery of rib knit fabric in bias direction

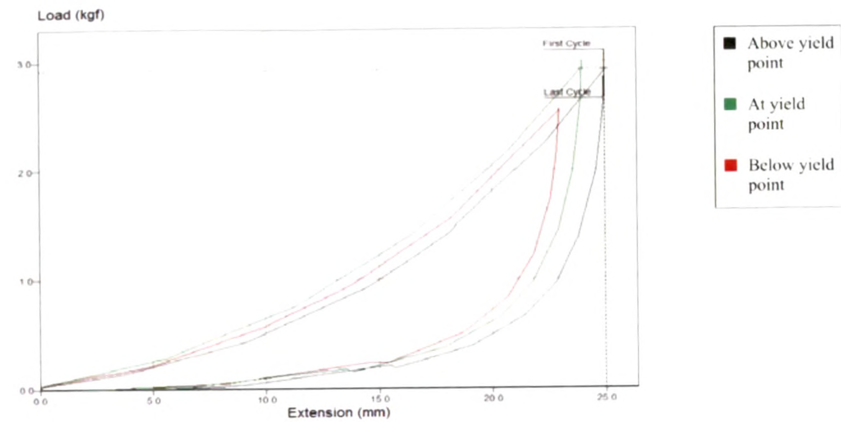
Sr. No.	Sample Information	First cycle Extension (cm)
1	Bias a below yield point	2.64
2	Bias b at yield point	2.73
3	Bias c above yield point	2.84

Bias direction showed slightly higher values than wale wise direction i.e., 2.73 and 2.64 cm at yield point and below yield point respectively. Though the fabric was double jersey knitted, the loops did not support the behaviour of wale or course direction getting better recovery.

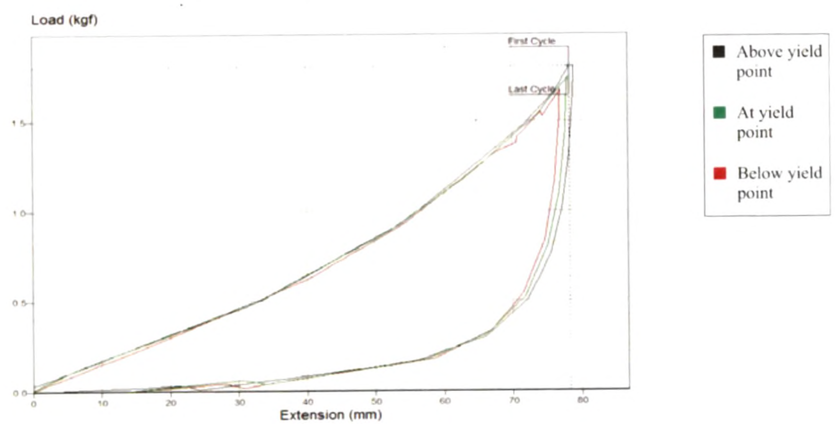
Overall it could be viewed that Lycra had its impact on improving stretch and recovery property of fabrics (Graph 4.10). Woven fabrics with their firm geometry had low recovery as compared to elastic property of knitted fabrics.



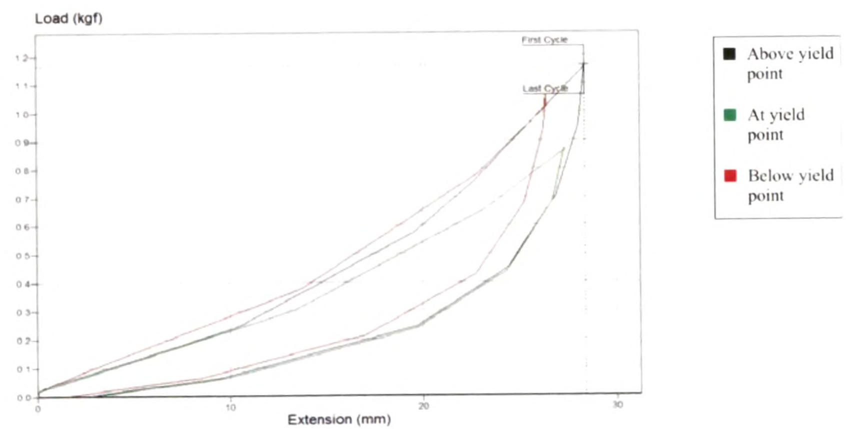
4.9a: Tensile properties of rib knit fabric



4.9b: Recovery behaviour of rib knit fabric in wale direction

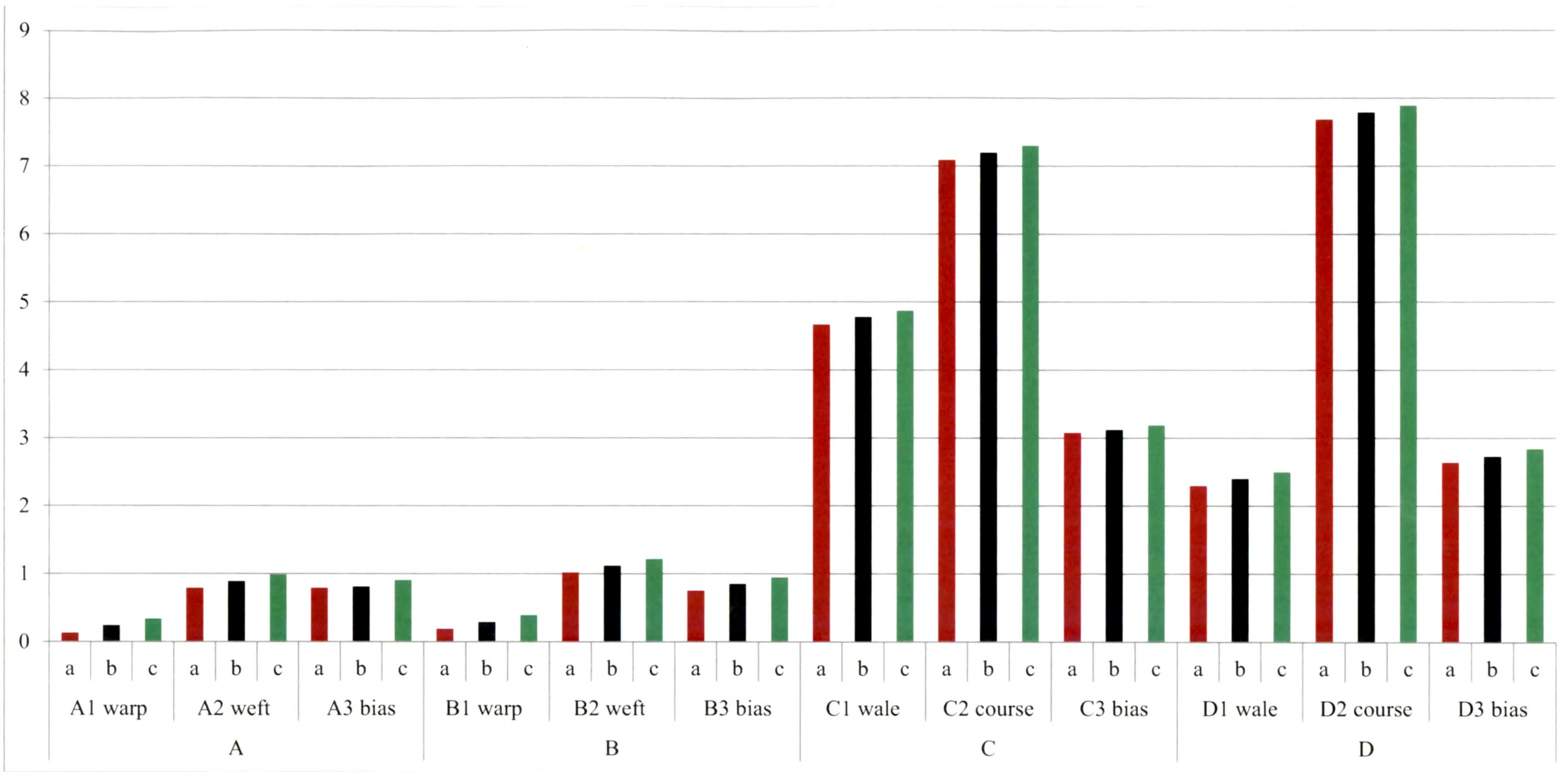


4.9c: Recovery behaviour of rib knit fabric in course direction



4.9d: Recovery behaviour of rib knit fabric in bias direction

Graph 4.9: Recovery behaviour of rib knit fabric under cycling loading



Key: A – Plain weave; B – Twill weave; C – Single jersey knit; D – Rib knit
1 – Warp / Wale; 2 – Weft / Course; 3 – Bias
a – Recovery below yield point; b – Recovery at yield point; c – Recovery above yield point

Graph 4.10: Comparison of elastic recovery of fabrics under study

4.2.7 Seam strength of fabrics

Any fabric put in use as an apparel product would be subjected to sewing and stress while in actual use. So, seam strength was important to study.

The selection of thread, needle and stitch type would perform well or not was found from the results of seam strength. As the materials for research contained 3% Lycra, textured polyester thread was selected which had elastic property.

The tensile behaviour of seam was studied with extension load curves. The results had been described with visual analysis also as followed.

4.2.7.1 Seam strength in woven fabrics

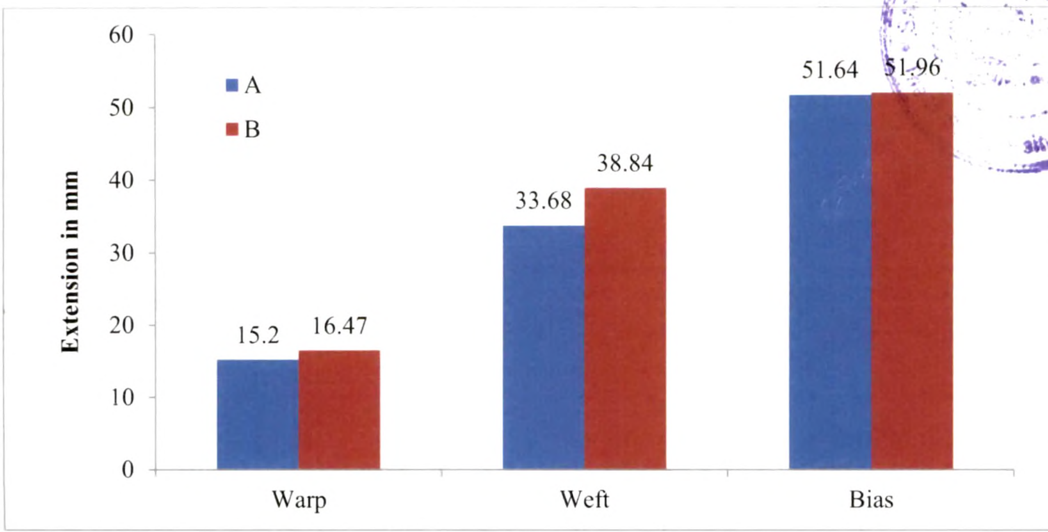
Plain weave fabric A in warp direction showed the extension of 15.20 mm under load of 19.65 kgf (Table 4.25). The seam caused pulling of yarns in fabric structure leaving holes due to yarn slippage followed by rupture of sewing thread.

In weft direction the value for extension obtained was 33.68 mm with load of 20.93 kgf. The weft showed higher value of r extension with presence of Lycra yarn in this direction. The series of stitches broke at a time caused shifting of warp yarns creating a gap in the fabric.

In bias direction with higher extensibility of fabric the textured polyester thread showed very good compatibility. The highest extension of 51.64 mm at 20.06 kgf load showed hole formation in the fabric followed by stitch breakage. Some fabric samples remain intact with seam but the fabric ruptured the edge of the jaw.

Table 4.25: Seam strength of woven fabrics under study

	A		B	
	Load (kgf)	**Extension (mm)**	**Load (kgf)**	**Extension (mm)**
Warp	19.65	15.20	21.95	16.47
Weft	20.93	33.68	21.49	38.84
Bias	20.06	51.64	21.34	51.96



Graph 4.11: Comparison of seam strength of woven fabrics

Twill weave fabric B showed similar behaviour as plain weave fabric A in warp direction seam. The extension 16.47 mm with load 21.95 kgf was observed causing seam slippage. The hole formation followed by sewing thread rupture was observed. Weft direction showed 38.84 mm extension at 21.49 kgf load. This direction with presence of Lycra showed higher extension than warp direction causing series of stitch break at a time creating a gap of shifting of yarn in the fabric. (Table 4.25)

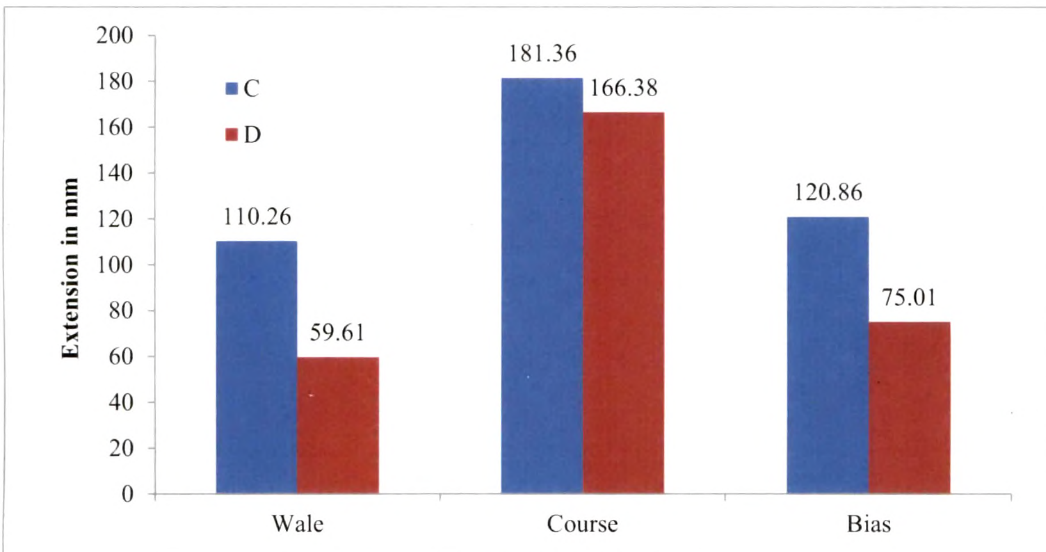
Bias direction seam showed highest extension of 51.96 mm at 21.34 kgf load showing hole formation in the fabric and breakage of stitches. Few samples showed fabric rupture at the edge of the jaw. (Graph 4.11)[41]

4.2.7.2 Seam strength in knitted fabrics

The seam strength of single jersey knit fabric C showed higher extension value of 110.26 mm for wale direction at 16.66 kgf load (Table 4.26). The seam held the fabric firmly and the loops of fabric in wale direction broke causing the fabric rupture. The seam remained intact in the fabric. Course direction showed highest extension of 181.36 mm at 20.11 kgf load for seam strength. This was due to Lycra yarn and weft knit structure of fabric. Finer yarn and loops extended more with applied load finally resulting in breakage of knitted loops and fabric rupture. The seam did not undergo any damage. The bias direction showed extension of 120.86 mm at 18.64 kgf load which was lower than course direction seam strength value. Seam in this direction also behaved similar like course direction, higher extension and fabric rupture without any damage to the seam.

Table 4.26: Seam strength of knit fabrics under study

	C		D	
	Load (kgf)	**Extension (mm)**	**Load (kgf)**	**Extension (mm)**
Wale	16.66	110.26	23.29	59.61
Course	20.11	181.36	20.96	166.38
Bias	18.64	120.86	17.64	75.01

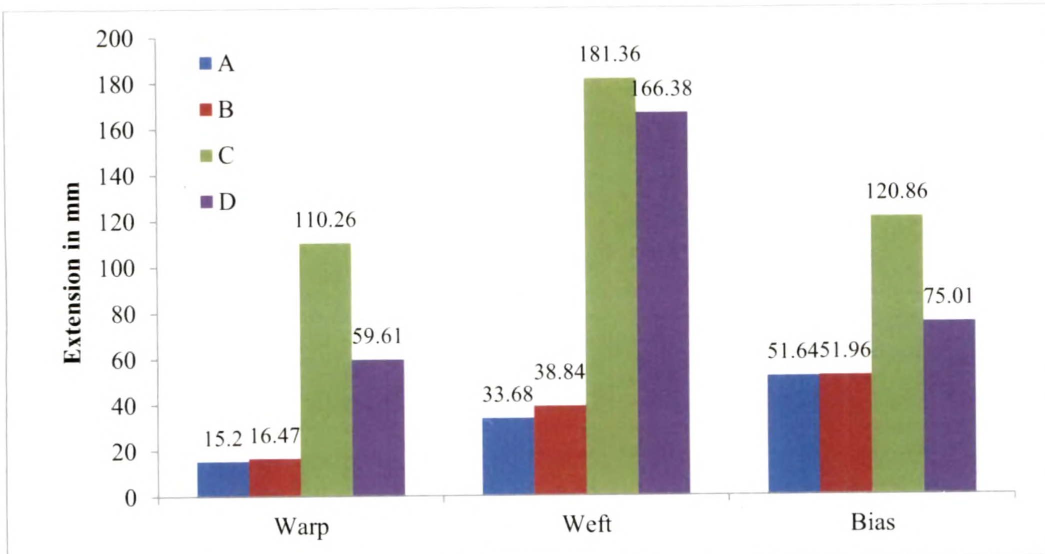


Graph 4.12: Seam strength of knit fabrics

Fabric D, Rib knit structure in wale direction showed 59.61 mm extension at 23.29 kgf load. Rib knit structure in double jersey knit construction showed lower extension than single jersey knit fabric C. Similarly coursewise extension value obtained was 166.38 mm at 20.96 kgf load followed by bias extension value of 75.01 mm at 17.64 kgf load. Rib knit structure with Lycra in weft direction caused maximum extension for seam strength than bias and wale direction values. In all three directions for this fabric D, the seam stitches opened up and broke under applied load due to contraction of seam. No damage in form of breakage of knitted loops or hole was observed for seam strength in all three directions. (Graph 4.12)

The overall seam strength observed was presented in Graph 4.13.

Lowest seam strength was observed in warpwise direction of both woven fabrics A and B. Weftwise with Lycra fabric B exhibited higher strength than fabric A. In bias direction also fabric B showed higher extension than fabric A but lower than rib knitted fabric D.



Graph 4.13: Comparison of seam strength of fabrics under study

Highest seam strength for knitted fabrics C and D in course direction was observed. Single jersey knit fabric C showed better seam strength in wale as well as in bias direction though it was lower than course wise seam strength.

Bias direction of seam strength was higher for knitted fabric C and D compare to woven fabrics A and B but it was lower than course direction seam strength of fabric C and D. It was due to weft knitted structure with Lycra the course direction exhibited better seam strength.

Only Rib knitted fabric D showed seam breakage without any seam slippage in all the three directions. Fabrics A, B and C showed seam slippage i.e., fabric rupture with hole formation or shifting of the yarns in case of woven fabrics. Single jersey fabric C exhibited excellent seam strength showing fabric rupture and no damage to the seam at all.(41)

4.3 Phase III: Garment construction

The tested fabrics were used for construction of upper garment for female as to study the fit and appearance, stretch and recovery behaviour of these fabrics for different body sizes.

4.3.1 Adapted style for final garment construction

The basic pattern of garment standardized for the pilot study with specified design details of round neck, princess line from mid – armhole to waist, for both front and back, was of 81.0 cm bust size pattern block. It was adapted with length alternation and facility for front opening. Two sets of pattern, one sleeveless and another with basic set in sleeves were developed and used for final garment construction (*refer page* 63 - 67)[36][47]

4.3.2 Visual assessment of garments for overall appearance

The garments were marked with datum lines at bust, waist and hip levels for fitting at girth levels. Length of the garment was also marked and observed and analysed. The fit of the garments on standard and various larger size was studied on live models for change of garment fit and recorded through visual assessment.[39][48]

The fit and overall appearance of garments constructed out of four fabrics with standard size (81.0 cm bust) for the study was tried on larger sizes and photographically recorded (Plates 4.2 to 4.13).

Plate 4.2 shows garment A of standard size of 81.0 cm bust. The front as well as back of the garment showed very good fit at the upper part of the body. The lower part from the cage level till the end of the garment showed slight looseness due to amount of ease considered while constructing garment out of woven fabrics (Plate 4.2). This garment was tried by model of one size larger (86.0 cm bust). The wearer felt the garment was fitted and comfortable due to the stretch effect of Lycra (Plate 4.3). Sleeveless garment showed creases at underarm with larger body size 86.0 cm. Sleeved garment rectified this defect by giving support to the shape of the arm scye resulting in good fit.

Front View

Back View

a. Sleeveless garment

Front View

Back View

b. Garment with Sleeves

Plate 4.2: Plain woven garments on 81.0 cm standard size figure

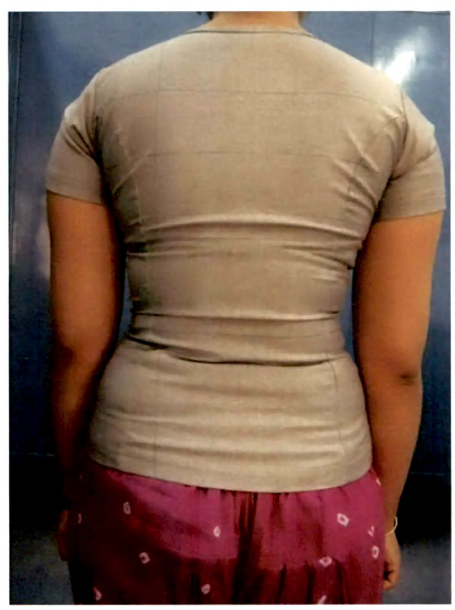
Front View

Back View

a. Sleeveless garment

Front View

Back View



b. Garment with Sleeves

Plate 4.3: Plain woven garments on 86.0 cm size figure

The presence of Lycra in weft made it possible to fit the wearer of a size 86.0 cm. Garment A in plain weave with its limitation of woven construction was tried on large size 86.0 cm, but further it was not possible to fit it beyond that size. Though there was Lycra yarn in the weft direction, with woven construction it could fit only one size larger than the standard size.

Similar effect was observed with garment B as it was also constructed from woven fabric. Comfort with ease was observed with garment B on 81.0 cm size figure in the front as well as at the back (Plate 4.4). Larger size 86.0 cm showed snug fit with widthwise folds, but more comfortable than garment A, as twill construction of garment B showed better stretch. Sleeveless garment was comfortable showing less creases at underarm. Sleeved garment gave better appearance with support of sleeves (Plate 4.5).

It could be suggested from the visual analysis that the sleeveless garment could have the arm scye cut slightly lower and allowance for ease can make the wearer of the larger size comfortable. Limited range of stretch with woven construction actually needs to have individual garment size developed with marginal ease for comfortable body activities.

Knitted garment C was observed with very good fit and appearance without any folds on the garment on standard size 81.0 cm. The garment with cotton / Lycra single jersey knit structure emphasized body contour (Plate 4.6). The wearer of the larger size (86.0 cm bust) felt that the garment was comfortable and well fitted. It was observed that garment C on large size (86.0 cm) did not show any folds with tightness at the bust level (Plate 4.7). Both sleeved and sleeveless garments were very appealing on the figure of larger size.

The wearer of 91.0 cm bust size (Plate 4.8) also felt very comfortable with garment C of standard size 81.0 cm due to very good elastic property of knitted fabric and Lycra added stretch to it. The fit of the garment observed was very good but princess seam lines showed obvious displacement at the bust level and shifted on the sides making the centre panel of the garment appear wider. This effect was observed at the back also (Plate 4.7). Garment showed only slight shift of princess seam line from cage to hip level as the girth measurements at this areas of the body were smaller than bust area.

Front View

Back View

a. Sleeveless garment

Front View

Back View

b. Garment with Sleeves

Plate 4.4: Twill weave garments on 81.0 cm standard size figure

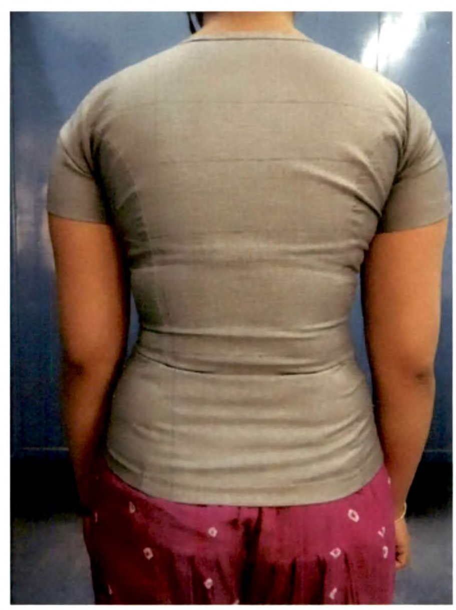
Front View

Back View

a. Sleeveless garment

Front View

Back View



b. Garment with Sleeves

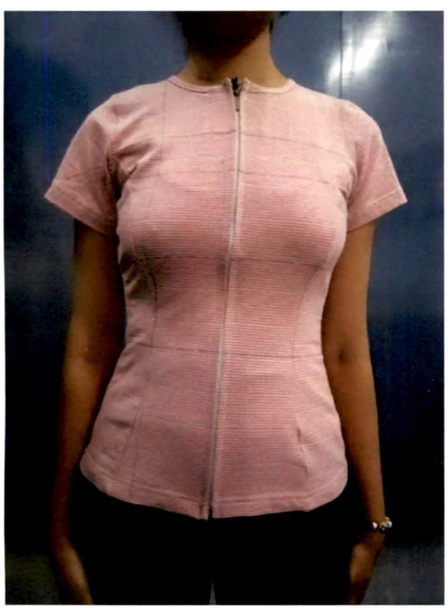
Plate 4.5: Twill weave garments on 86.0 cm size figure

Front View

Back View

a. Sleeveless garment

Front View



Back View

b. Garment with Sleeves

Plate 4.6: Single jersey knit garments on 81.0 cm standard size figure

Front View

Back View

a. Sleeveless garment

Front View

Back View

b. Garment with Sleeves

Plate 4.7: Single jersey knit garments on 86.0 cm size figure

Front View Back View

a. Sleeveless garment

Front View Back View

b. Garment with Sleeves

Plate 4.8: Single jersey knit garments on 91.0 cm size figure

Garment C of 81.0 cm size also fitted well to the largest bust size of 96.0 cm (Plate 4.9). This size also showed location of princess line shifted with increase in the body size. The fit and comfort was otherwise very good with cotton/Lycra single jersey garment. Slight tightness at the under arm was felt in the sleeveless garment. Sleeves in the garment did not show this problem.

Rib knitted Garment D exhibited very good firm fit with cotton / Lycra in double jersey knit construction of the fabric (Plate 4.10). From standard size 81.0 cm to larger size of 96.0 cm showed considerable increase of the body size to fit the garment of 81.0 cm. Rib knit construction with Lycra made it possible to fit without creases or folds were not observed as the garment stretched and fitted to the body with very good elasticity. (Plate 4.11) Like garment C, garment D also showed obvious shift of princess seam line at the bust level with sizes 91.0 and 96.0 cm bust. (Plate 4.12 & 4.13)

Knitted garments with their elastic property exhibited very good fit on — larger body sizes. The style of the garment with princess seam lines in the front and back projected stress on the garment with increased body size by shift in the placement of princess line towards the sides. This suggested that the placement of seam line has its importance while designing garments with knits especially when many sizes are expected to fit in one size.

4.3.3 Assessment of garment stretch and recovery property after wear trials

The garments with 81.0 cm bust size were constructed from all four fabrics with specified design details and marked with benchmarks to be measured for stretch and recovery on larger sizes had been presented as under.

The garment constructed with standard size of 81.0 cm bust was assessed for elastic recovery property after fit trials on larger size figures. Table 4.27 and 4.28 showed the percent recovery of woven and knitted garments for various sizes respectively.

Front View

Back View

a. Sleeveless garment

Front View

Back View

b. Garment with Sleeves

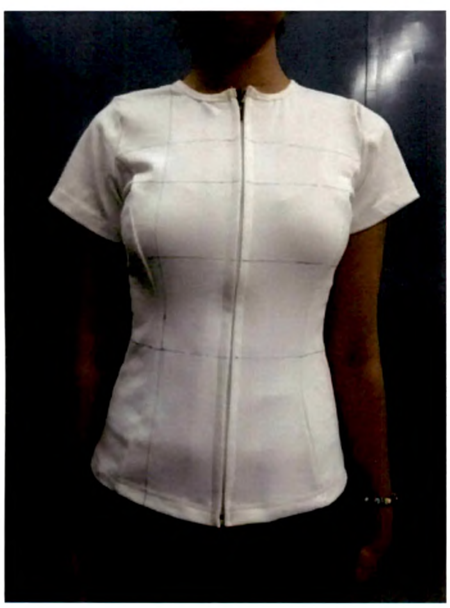
Plate 4.9: Single jersey knit garments on 96.0 cm size figure

Front View

Back View

a. Sleeveless garment

Front View



Back View

b. Garment with Sleeves

Plate 4.10: Rib knit garments on 81.0 cm standard size figure

Front View

Back View

a. Sleeveless garment

Front View

Back View

b. Garment with Sleeves

Plate 4.11: Rib knit garments on 86.0 cm size figure

Front View

Back View

a. Sleeveless garment

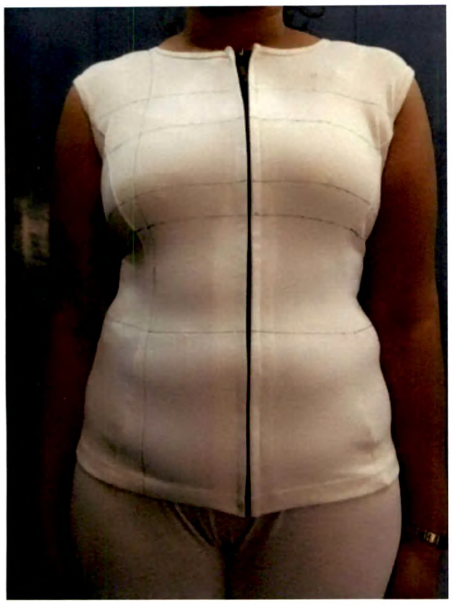
Front View

Back View

b. Garment with Sleeves

Plate 4.12: Rib knit garments on 91.0 cm size figure

Front View



Back View

a. Sleeveless garment

Front View

Back View

b. Garment with Sleeves

Plate 4.13: Rib knit garments on 96.0 cm size figure

Table 4.27: Percent recovery of woven garments

Body Landmarks	**FRONT**		**BACK**	
	A	B	A	B
Armpit level	50	100	50	100
Bust level	**10**	**13.33**	**20**	**25**
Centre front	50	100	0	0
Right front	50	100	50	100
Left front	50	100	50	100
Waist level	**15**	**25**	100	100
Centre	50	100	100	100
Right front	100	100	0	0
Left front	100	100	0	0
Hip level	50	100	100	100
Centre	50	0	100	100
Right front	0	0	0	0
Left front	0	0	0	0

Key: A – Plain weave, B – Twill weave

It was observed from Table 4.27 that woven garment A showed average 50 percent recovery of garment when worn by a larger figure size 86.0 cm. The wider areas of bust and waist grith showed 10 and 15 percent recovery respectively with more extension and lower recovery at these areas. Front side panels of the garment exhibited 100 percent recovery. Back of garment A showed recovery only upto 20 percent at bust level. Other areas of the garment showed 50 and 100 percent recovery.

Garment B showed 13.33 percent recovery at front bust level and 25 percent recovery at back bust level. Recovery of 25 percent was observed at front waist level also. Other areas of the garment showed total recovery. Fabric B showed better recovery than fabric A with slightly higher elastic property.

Though the woven garments with 81.0 cm size gave very good and comfortable fit to the larger (86.0 cm) size figure, the recovery property was found to be poor. So it could not be worn by the larger size figure.

Table 4.28: Percent recovery of knit garments

Body Landmarks	FRONT						BACK					
	C			D			C			D		
	86.0	91.0	96.0	86.0	91.0	96.0	86.0	91.0	96.0	86.0	91.0	96.0
Armpit level	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Bust level	100.0	100.0	**60.0**	100.0	100.0	**95.0**	100.0	100.0	100.0	100.0	100.0	100.0
Centre front	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Right front	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Left front	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Waist level	100.0	100.0	**40.0**	100.0	100.0	**60.0**	100.0	100.0	100.0	100.0	100.0	100.0
Centre	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Right front	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Left front	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Hip level	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	**60.0**	100.0	100.0	**95.0**
Centre	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Right front	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Left front	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Key: C – Single jersey knit, D – Rib knit

Garment C and D made of knit structure showed 100 percent recovery from size 81.0 to 86.0 and 91.0 cm bust size (table 4.28). Only the largest size of 96.0 cm showed 60 percent and 95 percent recovery for garment C and D respectively at the front bust level. Waist level showed 40 percent recovery for garment C and 60 percent for garment D. This was with Lycra in rib knit structure exhibiting more recovery in garment D than garment C.

The back of garment C and D gave 100 percent recovery except at hip level. For garment C it was 60 percent and garment D, 95 percent. Here also garment D showed better recovery than garment C.[39]

Knitted fabrics fitted very well from standard 81.0 cm to larger sizes 86.0 and 91.0 cm, also with excellent recovery. 96.0 cm size could not give better recovery at wider areas of bust, waist and hip levels. The design of the garment with princess seam line assembled together total seven pattern pieces, four in the front and three at the back, contributed in giving total recovery.

Garments constructed out of woven fabrics even at small extensions gave lower percent recovery, whereas knitted garments exhibited excellent percent recovery with higher extension.

4.3.4 Statistical analysis of garments stretch and recovery property

The garment extension and recovery measurements were statistically analysed using paired t-test and one sample t-test. It was calculated for comparison of expanded body sizes with regular (standard) size and extension with recovery of the garment. The recovery of each garment was compared with respective Test value (elastic recovery at yield point) of the garments. (Appendix)

The analysis of front and back of each garment was done and presented as follows:

Table 4.29: Mean comparison for front of garment A with regards to 81.0 and 86.0 cm bust size using paired t-test

N = 13

Size (cm)	Mean	S.D.	t-value	p-value *
Regular (81.0)	20.86	12.112	4.315	0.001
Expanded (86.0)	21.79	12.647		

* If $p \leq 0.05$, significant at 5% level of significance

Table 4.29 showed that t-value (4.315) was found to be significant ($p = 0.001$), so as a result it was concluded that on an average there exist real difference between regular (Mean: 20.86) and expanded (Mean: 21.79) size with S.D. value 12.112 and 12.647 respectively.

Table 4.30: Mean comparison for front of garment A with regards extension and recovery of fabric

N = 13

	Mean	S.D.	t-value	p-value *
Extension	0.93	0.805	2.785	0.015
Recovery	0.364	0.2098		

* If $p \leq 0.05$, significant at 5% level of significance

Looking at Table 4.30 it was observed that t-value (2.785) was found to be significant (p = 0.015), so could be concluded that there exist real difference between extension (Mean 0.93) and recovery (Mean 0.364) with S.D. value 0.805 and 0.2098 respectively.

Table 4.31: Mean comparison for front of garment A with regards to extension and recovery of fabrics with Test value

N = 13

Test value 0.8 (Elastic recovery at yield point)				
	Mean	S.D.	t-value	p-value *
Extension	0.93	0.805	0.597	0.560
Recovery	0.364	0.2098	7.771	0.000

* If $p \leq 0.05$, significant at 5% level of significance

The comparison of average expansion with Test value, it was found that t-value (0.597) was not significant (p = 0.560) while comparing average expansion (Mean 0.93) with Test value (0.8). t-value (7.771) was found to be significant (p = 0.000) while comparing average recovery (Mean 0.364) with Test value (0.8).

The garment in plain weave from standard to expanded (size 81.0 to 86.0 cm) did not recover completely, showing difference with Test value of 0.8.

Table 4.32: Mean comparison for back of garment A with regards to 81.0 and 86.0 cm bust size using paired t-test

N = 13

Size (cm)	Mean	S.D.	t-value	p-value *
Regular (81.0)	20.77	12.969	-3.959	0.002
Expanded (86.0)	20.46	13.395		

* If $p \leq 0.05$, significant at 5% level of significance

Table 4.32 represents t-value (-3.959) which was found to be significant (p = 0.002), so as a result it was concluded that on an average there exist real difference between regular (Mean: 20.77) and expanded (Mean: 20.46) size with S.D. value 12.969 and 13.395 respectively.

Table 4.33: Mean comparison for back of garment A with regards extension and recovery of fabric

N = 13

	Mean	**S.D.**	**t-value**	**p-value ***
Extension	0.69	0.630	3.224	0.007
Recovery	0.300	0.2483		

* If $p \leq 0.05$, significant at 5% level of significance

The above Table 4.33 showed that t-value (3.224) was found to be significant (p = 0.007), so could be concluded that there exist real difference between extension (Mean 0.69) and recovery (Mean 0.300) with S.D. value 0.630 and 0.2483 respectively.

Table 4.34: Mean comparison for Back of garment A with regards to extension and recovery of fabrics with test value

N = 13

Test value 0.8 (Elastic recovery at yield point)				
	Mean	S.D.	t-value	p-value *
Extension	0.69	0.630	-0.616	0.549
Recovery	0.300	0.2483	-7.260	0.000

* If $p \leq 0.05$, significant at 5% level of significance

Table 4.34 showed the comparison of average expansion with standard value. From the table it could be interpreted that t-value (0.616) was not found to be significant (p =0.549) while comparing average expansion (Mean 0.69) with Test value (0.8). t-value (7.260) was found to be significant (p = 0.000) while comparing average recovery (Mean 0.300) with Test value (0.8).

The garment in plain weave also gave similar results with increased size 81.0 to 86.0 cm showing lesser difference in recovery with test value (0.8).

Table 4.35: Mean comparison for front of garment B with regards to 81.0 and 86.0 cm bust size using paired t-test

N = 13

Size (cm)	Mean	S.D.	t-value	p-value *
Regular (81.0)	20.86	12.112	-4.315	0.001
Expanded (86.0)	21.79	12.647		

* If $p \leq 0.05$, significant at 5% level of significance

It was observed from Table 4.35 that t-value (-4.315) was significant ($p = 0.001$), so as a result it was concluded that on an average there exist real difference between regular (Mean: 20.86) and expanded (Mean: 21.79) size with S.D. value 12.112 and 12.647 respectively.

Table 4.36: Mean comparison for front of garment B with regards extension and recovery of fabric

N = 13

	Mean	S.D.	t-value	p-value *
Extension	0.93	0.805	1.414	0.181
Recovery	0.636	0.4162		

* If $p \leq 0.05$, significant at 5% level of significance

From the above Table 4.36 it was found that t-value (1.414) was not significant ($p = 0.181$), so could be concluded that real difference did not exist between extension (Mean 0.93) and recovery (Mean 0.636) with S.D. value 0.805 and 0.4162 respectively.

Table 4.37: Mean comparison for front of garment B with regards to extension and recovery of fabrics with Test value

N = 13

Test value 1.12 (Elastic recovery at yield point)				
	Mean	S.D.	t-value	p-value *
Extension	0.93	0.805	-0.890	0.390
Recovery	0.636	0.4162	-4.354	0.001

* If $p \leq 0.05$, significant at 5% level of significance

While comparing average expansion with standard value (Table 4.37) it could be interpreted that t-value (0.890) was not found to be significant (p = 0.390) while comparing average expansion (Mean 0.93) with Test value (1.12). t-value (-4.354) was found to be significant (p = 0.001) while comparing average recovery (Mean 0.636) with Test value (1.12).

The garment in twill weave did not show good recovery with expanded size (81.0 to 86.0 cm) as the difference in recovery was observed when compared with Test value (1.12).

Table 4.38: Mean comparison for back of garment B with regards to 81.0 and 86.0 cm bust size using paired t-test

N = 13

Size (cm)	Mean	S.D.	t-value	p-value *
Regular (81.0)	20.86	12.112	-4.315	0.001
Expanded (86.0)	21.79	12.647		

* If p ≤ 0.05, significant at 5% level of significance

Table 4.38 represented that t-value (-4.315) was found to be significant (p = 0.001), so as a result it was concluded that on an average there exist real difference between regular (Mean: 20.86) and expanded (Mean: 21.79) size with S.D. value 12.112 and 12.647 respectively.

Table 4.39: Mean comparison for back of garment B with regards extension and recovery of fabric

N = 13

	Mean	S.D.	t-value	p-value *
Extension	0.93	0.805	1.414	0.181
Recovery	0.636	0.4162		

* If p ≤ 0.05, significant at 5% level of significance

Table 4.39 represented that t-value (1.414) was not found to be significant (p = 0.181), so could be concluded that there was no difference between extension (Mean 0.93) and recovery (Mean 0.636) with S.D. value 0.805 and 0.4162 respectively.

Table 4.40: Mean comparison for Back of garment B with regards to extension and recovery of fabrics with Test value

N = 13

Test value 1.12 (Elastic recovery at yield point)				
	Mean	S.D.	t-value	p-value *
Extension	0.93	0.805	-2.446	0.031
Recovery	0.636	0.4162	-3.967	0.002

* If $p \leq 0.05$, significant at 5% level of significance

The comparison of average expansion with Test value showed that t-value (2.446) was found to be significant (p =0.031) while comparing average expansion (Mean 0.93) with Test value (1.12). t-value (3.967) was also found to be significant (p = 0.002) while comparing average recovery (Mean 0.636) with Test value (1.12) (Table 4.40).

Garment in twill weave showed difference in recovery from size 81.0 to 86.0 cm indicating lower recovery of the garment with the expanded size.

Table 4.41: Mean comparison for front of Garment C with regards to 81.0 with 86.0, 91.0 and 96.0 bust size using paired t-test

N = 13

	Size (cm)	Mean	Std. Deviation	t - value	p – value*
Pair 1	Regular (81.0)	20.86	12.112	-4.315	0.001
	Expanded (86.0)	21.79	12.647		
Pair 2	Regular (81.0)	20.86	12.112	-5.016	0.000
	Expanded (91.0)	23.00	13.345		
Pair 3	Regular (81.0)	20.86	12.112	-4.991	0.000
	Expanded (96.0)	25.21	14.335		

* If $p \leq 0.05$, significant at 5% level of significance

The above table showed that t-value for pair 1, 2 and 3 (t= -4.315,-5.016 and -4.991 respectively) were found to be significant (p = 0.001, 0.000 and 0.000 respectively), so as a result it was concluded that on an average there exist real difference between regular and expanded size for pair 1, 2 and 3 with S.D. values.

Table 4.42: Mean comparison for front of Garment C with regards to extension and recovery using paired t-test

N = 13

		Mean	Std. Deviation	t - value	p – value*
Pair 1	Extension	0.93[a]	0.805	-	-
	Recovery	0.93[a]	0.805		
Pair 2	Extension	1.86[a]	1.550	-	-
	Recovery	1.86[a]	1.550		
Pair 3	Extension	4.36	3.267	1.797	0.096
	Recovery	3.26	1.593		

a. The t-test cannot be computed because the standard error of the difference is 0.

* If $p \leq 0.05$, significant at 5% level of significance

The calculations for pair 1 and 2 were not computed as the standard error of the difference was 0. The values for pair 3 showed that t-value (1.797) was not found to be significant (p = 0.096), so could be concluded that there was no difference between extension (Mean 4.36) and recovery (Mean 3.26) with S.D. value 3.267 and 1.593 respectively.

Table 4.43: Mean comparison for front of garment C with regards to extension and recovery of fabrics with Test value 7.2

N = 13

		Mean	Std. Deviation	t - value	p – value*
Pair 1	Extension	0.93	0.805	-29.142	0.000
	Recovery	1.86	1.550	-12.901	0.000
Pair 2	Extension	4.36	3.267	-3.256	0.006
	Recovery	0.93	0.805	-29.142	0.000
Pair 3	Extension	1.86	1.550	-12.901	0.000
	Recovery	3.26	1.593	-9.247	0.000

* If $p \leq 0.05$, significant at 5% level of significance

While comparing average expansion with Test value (Table 4.43), it was found that t-value was significant while comparing average expansion Mean of each pair with Test value (7.2).

Garment C from 81.0 to 91.0 cm size showed similar results of expansion and recovery. Expansion upto 96.0 cm size showed lower recovery.

Table 4.44: Mean comparison for back of Garment C with regards to 81.0 with 86.0, 91.0 and 96.0 bust size using paired t-test

N = 13

	Size (cm)	Mean	Std. Deviation	t – value	p – value*
Pair 1	Regular (81.0)	20.77	12.969	-3.959	0.002
	Expanded (86.0)	21.46	13.395		
Pair 2	Regular (81.0)	20.77	12.969	-4.945	0.000
	Expanded (91.0)	22.46	13.972		
Pair 3	Regular (81.0)	20.77	12.969	-5.353	0.000
	Expanded (96.0)	24.23	14.884		

* If $p \leq 0.05$, significant at 5% level of significance

Table 4.44 represented t-values for pair 1, 2 and 3 (t= -3.959,-4.945 and -5.353 respectively) were found to be significant (p = 0.002, 0.000 and 0.000 respectively), so as a result it was concluded that on an average there exist real difference between regular and expanded size for pair 1, 2 and 3 with S.D. values.

Table 4.45: Mean comparison for back of Garment C with regards to extension and recovery using paired t-test

N = 13

		Mean	Std. Deviation	t – value	p – value*
Pair 1	Extension	0.69[a]	0.630	-	-
	Recovery	0.69[a]	0.630		
Pair 2	Extension	1.62[a]	1.244	-	-
	Recovery	1.62[a]	1.244		
Pair 3	Extension	3.46	2.332	1.000	0.337
	Recovery	3.22	1.950		

a. The t-test cannot be computed because the standard error of the difference is 0.
* If $p \leq 0.05$, significant at 5% level of significance

The calculations for pair 1 and 2 were not computed as the standard error of the difference was 0. The values for pair 3 showed that t-value (1.000) was not found to be significant (p =0.337), so could be concluded that there was no difference between extension (Mean 3.46) and recovery (Mean 3.22) with S.D. value 2.332 and 1.950 respectively.

Table 4.46: Mean comparison for Back of garment C with regards to extension and recovery of fabrics with Test value 7.2

N = 13

		Mean	**Std. Deviation**	**t - value**	**p – value***
Pair 1	Extension	0.69	0.630	-37.219	0.000
	Recovery	1.62	1.244	-16.183	0.000
Pair 2	Extension	3.46	2.332	-5.781	0.000
	Recovery	0.69	0.630	-37.219	0.000
Pair 3	Extension	1.62	1.244	-16.183	0.000
	Recovery	3.22	1.950	-7.367	0.000

* If $p \leq 0.05$, significant at 5% level of significance

While comparing average expansion with Test value (Table 4.46), it was found that t-value was significant while comparing average expansion Mean of each pair with Test value (7.2).

Garment C from 81.0 to 91.0 cm size showed similar results of expansion and recovery. Expansion upto 96.0 cm size did not show complete recovery.

Table 4.47: Mean comparison for front of Garment D with regards to 81.0 with 86.0, 91.0 and 96.0 bust size using paired t-test

N = 13

	Size (cm)	**Mean**	**Std. Deviation**	**t - value**	**p – value***
Pair 1	Regular (81.0)	20.86	12.112	-4.315	0.001
	Expanded (86.0)	21.79	12.647		
Pair 2	Regular (81.0)	20.86	12.112	-5.200	0.000
	Expanded (91.0)	22.71	13.190		
Pair 3	Regular (81.0)	20.86	12.112	-4.991	0.000
	Expanded (96.0)	25.21	14.335		

* If $p \leq 0.05$, significant at 5% level of significance

Table 4.47 represented t-values for pair 1, 2 and 3 (t= -4.315,-5.200 and -4.991 respectively) were found to be significant (p = 0.001, 0.000 and 0.000 respectively), so as a result it was concluded that on an average there exist real difference between regular and expanded size for pair 1, 2 and 3 with S.D. values.

Table 4.48: Mean comparison for front of Garment D with regards to extension and recovery using paired t-test

N = 13

		Mean	Std. Deviation	t - value	p – value*
Pair 1	Extension	0.93[a]	0.805	-	-
	Recovery	0.93[a]	0.805		
Pair 2	Extension	1.86[a]	1.336	-	-
	Recovery	1.86[a]	1.336		
Pair 3	Extension	4.36	3.267	1.549	0.145
	Recovery	3.73	2.187		

a. The t-test cannot be computed because the standard error of the difference is 0.
* If p ≤ 0.05, significant at 5% level of significance

The calculations for pair 1 and 2 were not computed as the standard error of the difference was 0. The values for pair 3 showed that t-value (1.549) was not found to be significant (p =0.145), so could be concluded that there was no difference between extension (Mean 4.36) and recovery (Mean 3.73) with S.D. value 3.267 and 2.187 respectively.

Table 4.49: Mean comparison for front of garment D with regards to extension and recovery of fabrics with Test value 7.79

N = 13

		Mean	Std. Deviation	t - value	p – value*
Pair 1	Extension	0.93	0.805	-31.884	0.000
	Recovery	1.86	1.336	-16.612	0.000
Pair 2	Extension	4.36	3.267	-3.932	0.002
	Recovery	0.93	0.805	-31.884	0.000
Pair 3	Extension	1.86	1.336	-16.612	0.000
	Recovery	3.73	2.187	-6.948	0.000

* If p ≤ 0.05, significant at 5% level of significance

The average expansion when compared with Test value (Table 4.49), it was found that t-value was significant while comparing average expansion Mean of each pair with Test value (7.79).

Garment D from 81.0 to 91.0 cm size showed similar results of expansion and recovery. Expansion upto 96.0 cm size also showed better recovery.

Table 4.50: Mean comparison for back of Garment D with regards to 81.0 with 86.0, 91.0 and 96.0 bust size using paired t-test

N = 13

	Size (cm)	Mean	Std. Deviation	t – value	p – value*
Pair 1	Regular (81.0)	20.77	12.969	-3.959	0.002
	Expanded (86.0)	21.46	13.395		
Pair 2	Regular (81.0)	20.77	12.969	-4.619	0.001
	Expanded (91.0)	22.38	14.039		
Pair 3	Regular (81.0)	20.77	12.969	-5.353	0.000
	Expanded (96.0)	24.23	14.884		

* If $p \leq 0.05$, significant at 5% level of significance

The t-values for pair 1, 2 and 3 (t= -3.959,-4.619 and -5.353 respectively) were found to be significant (p = 0.002, 0.001 and 0.000 respectively), so as a result it was concluded that on an average there exist real difference between regular and expanded size for pair 1, 2 and 3 with S.D. values (Table 4.50)

Table 4.51: Mean comparison for back of Garment D with regards to extension and recovery using paired t-test

N = 13

		Mean	Std. Deviation	t – value	p – value*
Pair 1	Extension	0.69[a]	0.630	-	-
	Recovery	0.69[a]	0.630		
Pair 2	Extension	1.62[a]	1.261	-	-
	Recovery	1.62[a]	1.261		
Pair 3	Extension	3.46	2.332	1.000	0.337
	Recovery	3.43	2.268		

a. The t-test cannot be computed because the standard error of the difference is 0.

* If $p \leq 0.05$, significant at 5% level of significance

The calculations for pair 1 and 2 were not computed as the standard error of the difference was 0. The values for pair 3 showed that t-value (1.000) was not found to be significant (p =0.337), so could be concluded that there was no difference between extension (Mean 3.46) and recovery (Mean 3.43) with S.D. value 2.332 and 2.268 respectively.

Table 4.52: Mean comparison for Back of garment D with regards to extension and recovery of fabrics with Test value 7.79

N = 13

		Mean	Std. Deviation	t - value	p – value*
Pair 1	Extension	0.69	0.630	-40.593	0.000
	Recovery	1.62	1.261	-17.657	0.000
Pair 2	Extension	3.46	2.332	-6.694	0.000
	Recovery	0.69	0.630	-40.593	0.000
Pair 3	Extension	1.62	1.261	-17.657	0.000
	Recovery	3.43	2.268	-6.929	0.000

* If $p \leq 0.05$, significant at 5% level of significance

The average expansion when compared with Test value (Table 4.52), it was found that t-value was significant while comparing average expansion Mean of each pair with Test value (7.79).

Garment D from 81.0 to 91.0 cm size showed similar results of expansion and recovery. Expansion upto 96.0 cm size also showed better recovery.

Woven fabrics showed lower recovery at small extensions whereas knitted fabrics recovered maximum.

It was observed from the results that strength and elongation properties that woven fabrics had lower elongation as compared to knitted fabrics. Similarly performance of seam was better with knitted fabrics. The results of the elastic recovery showed that woven fabrics even with three percent Lycra exhibited poor recovery whereas knitted fabrics showed better elastic recovery.

Elastic recovery property under cyclic loading showed lower recovery values for woven fabrics and higher for knitted fabrics. This property has been reflected in garments also, when studied for fit from standard size to various larger body sizes. Woven garments showed poor recovery even with one size larger from the standard size. Knitted garments could be fitted to two sizes larger giving total recovery.

The results of the study could be useful for designing of woven and knitted fabrics with Lycra.