CHAPTER - 3

METHEODOLOGY

Fabric selection and sample preparation.

Fabric properties contributing to fabric performance during use largely depend on fabric sett. As discussed in section 2.2.1, maximum sett of fabric depends on the yarn count and the weave interlacement. But in actual practice other factors such as the cost of fabric and the weaving efficiency may influence selection of fabric sett. This deviate it from the theoretical maximum limit. So any fabric sett produced in laboratories will be vague and may not represent the actual market trend. For this reason, PV suiting fabrics from wide range of weave and counts commercially produced on Sulzer projectile looms are collected for this study rather than preparing sample in laboratories.

Although a series of finishing techniques and chemicals as discussed in section 2.4 are used to get desired properties of the finished fabric, the fabric samples here are given a fairly simple processing sequence of

- Singeing at 100 mts /min speed and 3 mm flame height for one round of each side of cloth.
- Scouring in relaxed state on Jigger at 70-80° C for one hour in Sodaas (2 gm per litre), soda (2 gm per litre) and Emulsifier (2 gm per litre).
- Drying on drying range at 150°C for 20 seconds contact time.

It serves the primary object of this project to see the yarn and weave effect on the fabric performance. Further effect of any chemical or finishing technique can be accessed at a later stage.

Table 1 Particulars of the fabric samples.

	warp count		weft count			Loom sett		Fabric sett	
Fabric code	English (Ne)	Tex (T)	English (Ne)	Tex (T)	Weave	Reed	Picl	Ends/inch	Picks/inch
A. Plain weave fabric from various yarn counts.									
A1	2/15	78.77	2/15	78.77	Plain	36/2	36	42.4	36.0
A2	2/18	65.65	2/18	65.65	Plain	44/2	40	51.0	41.0
A3	2/18	65.65	2/18	65.65	Plain	40/2	36	50.0	40.0
A4	2/20	59.08	2/20	59.08	Plain	44/2	42	52.0	40.0
A5	2/30	39.39	2/30	39.39	Plain	52/2	50	62.0	51.8
A6	2/30	39.39	2/30	39.39	Plain	44/4	42	95.6	40.8
A7	2/30	39.39	2/30	39.39	Plain	56/2	52	66.2	53.4
A8	2/40	29.54	2/24	49.23	Plain	62/2	62	75.6	63.2
A9	2/40	29.54	2/40	29.54	Plain	52/2	52	64.0	53.6
A10	2/40	29.54	2/60	19.69	Plain	72/3	58	117.2	67.8
A11	2/60	19.69	2/60	19.69	Plain	72/2	68	87.6	70.8
B. Plain weave fabric from the same warp but different weft counts.									
B1	2/20	59.08	2/18	65.65	Plain	44/2	38	50.0	40.8
B2	2/20	59.08	2/20	59.08	Plain	44/2	40	50.0	42.0
B3	2/20	59.08	2/24	49.23	Plain	44/2	44	49.8	48.6
B4	2/20	59.08	2/30	39.39	Plain	44/2	50	54.8	46.6
B5	2/20	59.08	2/40	29.54	Plain	44/2	56	52.4	62.6
C. Fabric samples with different weaves.									
C1	2/30	39.39	2/30	39.39	plain	54/2	50	66.0	55.2
C2	2/30	39.39	2/30	39.39	plain	56/3	48	85.5	56.5
C3	2/30	39. 39	2/30	39.39	2/1twill	52/3	58	88.4	62.4
C4	2/30	39.39	2/30	39.39	2/2twill	36/4	64	79.4	72.2
D. Twill fabrics from different yarn counts.									
D1	2/24	49.23	2/30	39.39	2/1 twill	42/3	56	49.2	57.6
D2	2/30	39.39	2/30	39.39	2/1 twill	52/3	52	87.0	67.0
D3	2/30	39.39	2/30	39.39	2/1 twill	44/3	54	77.0	58.0
D4	2/40	29.54	2/40	29.54	2/1 twill	58/3	66	121.7	66.3

Table 2 Yarn used in the fabric samples:

Yarn count			
English(Ne)	Tex(T)	Yarn code	Fabric code*
2/15	78.77	Y1	A1 in both warp and weft directions.
2/18	65.65	Y2	A2 in both warp and weft directions.
		Y3	B1 in weft direction.
		Y4	A3 in both warp and weft directions.
2/20	59.08	Y5	B1, B2, B3 & B5 in warp and B2 in we
		Y6	A4 in both warp and weft directions.
		Y7	B4 in warp direction.
2/24	49.23	Y8	D1 in warp direction.
		Y9	A8 in weft direction.
		Y10	B3 in weft direction.
2/30	39.39	Y11	C4 in both warp and weft directions.
		Y12	A7 in both warp and weft directions.
		Y13	A6 in both warp and weft directions.
		Y14	B4 in weft direction.
		Y15	C1, C2 & D2 in both warp and weft
		Y16	C3, D3 in both warp and weft
		Y17	A5 in both warp and weft directions.
		Y18	D1 in weft direction.
2/40	29.54	Y19	D4 in both warp and weft directions.
		Y20	A10 in warp direction.
		Y21	A9 in both warp and weft directions.
		Y22	B5 in weft direction.
		Y23	A8 in warp direction.
2/60	19.69	Y24	A11 in both warp and weft directions.
		Y25	A10 in weft direction.

- *fabric code as in table 1.*
- *same yarns used in either warp or weft or in both directions in more than one fabric samples have been assigned the same yarn code.*

Properties of fabric samples and its constituent yarns samples are evaluated in the subsequent sections.

Testing of yarn properties.

Following Yarn properties are identified which influence the fabric low stress mechanical and surface properties and also thermal properties.

Yarn properties	Symbol	Test Method	Sample size
Twist (twist per inches)	TPI	KMI yarn twist tester	20 inches.
Hairiness (number of hairs more than 3 mm length)	s3 value	Zweigle yarn hairiness tester	100 mts.
Tensile modulus @ 5% extension (grams per denier)	E_y	Instron tensile tester	50 cms.
Flexural rigidity (10^{-4} x gm-cm^2)	m	Shirley Ring loop method (fabricated)	2.83 cm circumference .

3.2.1 Modules for Yarn testing:

The yarn testing is done on four modules shown in Fig.36.

Module I Twister tester.

It is a motor driven electronic yarn twist tester. Rotation of motor while yarn untwisted gives twist in the yarn. Thus it is fast and accurate instrument.

Module II Tensile tester.

Instron tensile tester with auto stop at predetermined extension can be used for getting load at 5% extension which is then converted into modulus value.

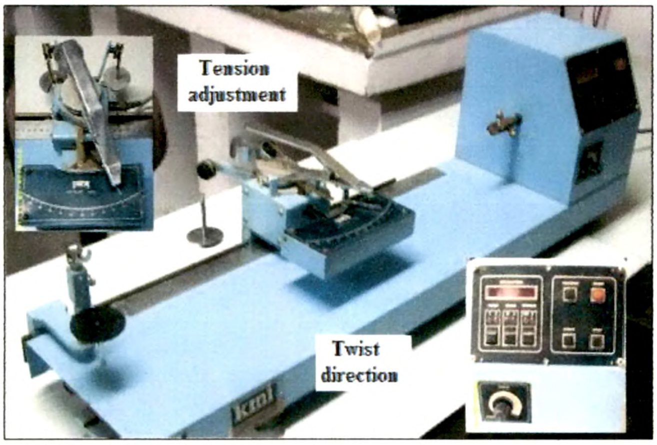
Module III. Yarn rigidity tester.

Based on Shirley weighted ring loop method this fabricated device measures deflection of the circular yarn loop by means of a traveling microscope and yarn Flexural rigidity is obtained as described below.

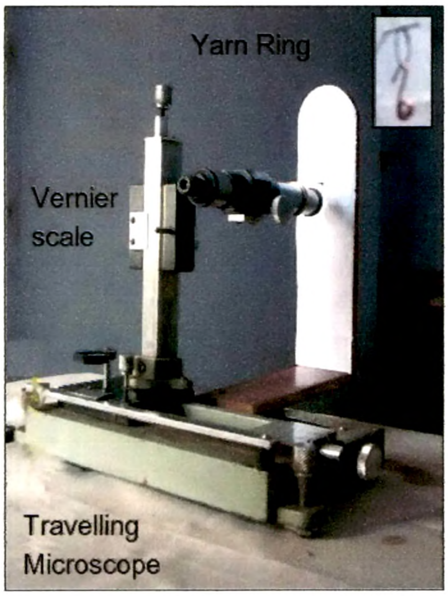
Module IV. Hairiness tester.

Zweigler Yarn hairiness tester measures yarn hairiness in s3 – value (number of hairs less than 3mm length)

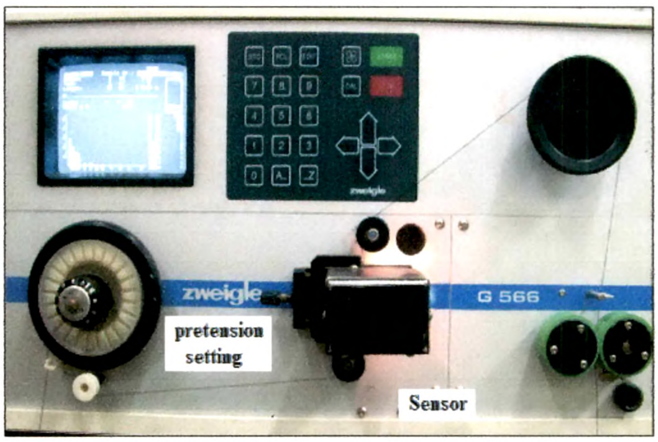
Module 1
Twist Tester



Module 2
Tensile Tester



Module 3
Flexural Rigidity Tester



Module 4
Hairiness Tester

Fig.36. Test modules for yarn properties.

3.2.2 Measurement of yarn twist:

Twist is the measure of the spiral turns given to a yarn in order to hold the constituent fibres or thread together. Yarn may be twisted in normal direction called S twist or reverse direction called Z twist. Two ply yarns in warp as well as in weft directions are used in the PV suiting fabrics samples. Ply twist in the yarn greatly affect the circularity of yarn cross section, its hairiness, bending properties, yarn extension and also the fabric appearance.

In Indirect system of yarn numbering, the measure of twist is given by $TPI = TM \times \sqrt{\text{count in Indirect system}}$ where TM ranges from 3 to 6 turns per inch / $(Ne)^{1/2}$ for cotton counting system (N_e).

Test apparatus:

Module I KMI yarn twist tester.

Test procedure:

The yarn twist direction and a gauge length of 20 inches i.e the distance between two clamps has been set. The yarn is clamped under pretension of tex/2 grams by weight washers hanged at the end of the tension lever. Through motor driven fixed clamp yarn is untwisted. The end point when yarn is completely untwisted may be observed by a small lens or judged at edge with the use of a needle pin. Number of turns are read directly from the dials, dividing it by 20 gives ply twist per inches of the yarn.

Table 3 Ply twist (twists per inches) of Yarn :

Yarn code	turns per inches TPI	Standard deviation	Coefficient of variation %
Y1	11.74	4.86	4.14
Y2	13.08	4.21	3.22
Y3	12.81	5.30	4.14
Y4	10.36	2.99	2.89
Y5	13.52	4.54	3.36
Y6	12.48	6.48	5.19
Y7	14.14	6.08	4.30
Y8	13.13	6.25	4.76
Y9	14.11	3.21	2.28
Y10	12.03	10.65	8.85
Y11	14.83	5.95	4.01
Y12	15.98	7.41	4.63
Y13	16.28	5.43	3.34
Y14	14.37	6.43	4.47
Y15	15.99	8.65	5.41
Y16	14.97	8.01	5.35
Y17	15.38	5.47	3.56
Y18	16.41	3.38	2.06
Y19	17.26	10.76	6.24
Y20	17.34	12.67	7.31
Y21	17.61	13.58	7.71
Y22	16.72	3.01	1.80
Y23	16.78	4.21	2.51
Y24	19.87	7.76	3.91
Y25	19.63	2.98	1.52

3.2.3 Yarn Hairiness:

The protruding fibers covering the yarn surface are termed as hair. The degree of yarn hairiness is decided by the numbers of protruding fiber ends as well as their length. Yarn hairiness is analysed in terms of S3 value which refers to the number of hairs greater and equal to 3 mm length. It influence fabric surface smoothness, fabric softness, Shear stiffness, air permeability, thermal resistance etc.

Test apparatus:

Module II Zweigle yarn hairiness tester

ZWEIGLE HAIRINESS TESTER is based on photoelectric principle. It counts the number of protruding fibres in 12 different groups of 1, 2, 4, 6, 8 , 10, 12, 15, 18, 21 & 25 mm displayed in form of histogram.

Test procedure:

Test length of 100 meters of yarn is run at a pretension in Centi Newton (cN) set on a dial scale of 1 -10. Zero yarn setting is done through the magnifying window prior to starting the test.

Table 4 Yarn Hairiness-s3 value:

Yarn code	s3 value	Standard deviation	CV%
Y1	966	42.23	4.37
Y2	529	57.65	10.91
Y3	627	32.14	5.13
Y4	507	97.50	19.24
Y5	348	58.53	16.81
Y6	419	40.53	9.67
Y7	444	30.40	6.85
Y8	403	34.27	8.50
Y9	298	64.21	21.55
Y10	264	18.73	7.11
Y11	173	43.43	25.10
Y12	193	27.29	14.16
Y13	154	12.50	8.10
Y14	109	10.02	9.23
Y15	282	77.10	27.34
Y16	124	18.61	15.04
Y17	78	3.30	4.25
Y18	236	14.72	6.24
Y19	135	21.59	15.99
Y20	99	9.75	9.90
Y21	200	29.35	14.69
Y22	77	4.55	5.90
Y23	142	27.11	19.06
Y24	56	14.33	25.59
Y25	44	7.32	16.73

3.2.4 Measurement of yarn Flexural rigidity:

Flexural rigidity is defined as the couple required to bend the yarn to unit curvature. It reflects the yarn bending property and thus affects crimp balance in the fabric. Fabric low stress tensile and bending properties are influenced by the crimp.

Test Apparatus:

Module IV Shirley ring loop method for Yarn Flexural Rigidity (Fabricated)

Flexural Rigidity is tested by a Weighing Yarn Ring loop method. As shown in module 3 in fig.36, a traveling microscope with a least count of 0.001 cm is used to measure the deflection of a circular ring under an applied load and yarn Flexural rigidity is calculated by the equation given by Dr.F.T.Pierce[1]

$$\text{Flexural Rigidity (m)} = kwL^2 \frac{\cos\theta}{\tan\theta} \text{ gm-cm}^2 \quad \text{.............................(38)}$$

Where k (constant given by Pierce) = 0.0047

w = Applied load in grams to be selected in such a way so as get θ in the range of 40 to 50°.

$\theta = 493 \times d/L$

d = deflection of lower end of the yarn ring in cm.

L = circumference of yarn ring = π X diameter of rod = 2.83 cms.

Test procedure:

Yarn ring are prepared on a glass rod of 0.906 cm diameter covered with cellophane sheath using reef knot. Loops are conditioned for 24 hours at 70 ± 1°F and 65± 2% RH. Care has been taken not to distort the rings while taking out from the rod. For that the cellophane paper tube is slid along the tube until the portion bearing the yarn loops project beyond the end of the tube. By compressing the projected cellophane tube the ring are

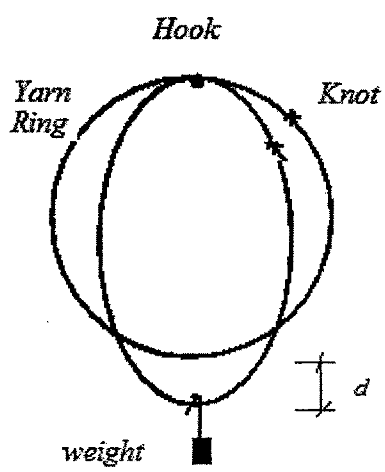


Fig.37. Shirley Yarn Ring Loop method

released with minimum handling. Perfectly circular rings are then selected for test. With the use of tweezers Loop is then supported on a fine hook with the position of knot as shown in figure 38 and a weight is hang for 30 sec. The deflection of distorted loop is measured with a traveling microscope and Flexural rigidity is calculated by the equation (1).

Table 5 Flexural rigidity of Yarn:

Yarn code	Wt hung w gms	Deflection of ring (in cms) Initial	Final	d	Angle θ degree	Flexural Rigidity m $x10^{-4}$ gm-cm^2	Standard deviation	C.V. %
YI	0.287	6.829	6.557	0.272	47.43	67.88	12.44	18.33
Y2	0.263	6.831	6.580	0.251	43.79	74.10	13.08	17.65
Y3	0.227	6.822	6.554	0.268	46.69	56.30	13.88	24.66
Y4	0.263	6.808	6.549	0.259	45.14	70.27	12.61	17.95
Y5	0.227	6.814	6.553	0.261	45.53	59.04	7.35	12.45
Y6	0.227	6.832	6.558	0.274	47.85	51.16	9.33	18.23
Y7	0.227	6.816	6.537	0.279	48.65	50.50	11.37	22.52
Y8	0.199	6.850	6.570	0.280	48.82	43.12	6.96	16.14
Y9	0.199	6.823	6.549	0.274	47.85	44.63	13.48	30.20
Y10	0.199	6.816	6.539	0.277	48.30	44.76	7.28	16.26
Y11	0.172	6.823	6.557	0.267	46.50	42.39	3.95	9.32
Y12	0.172	6.827	6.552	0.274	47.85	39.72	6.96	17.52
Y13	0.172	6.823	6.551	0.272	47.43	40.97	9.09	22.18
Y14	0.172	6.815	6.549	0.266	46.38	43.42	10.56	24.31
Y15	0.172	6.822	6.554	0.268	46.69	42.66	10.52	24.66
Y16	0.172	6.813	6.542	0.271	47.27	41.03	7.61	18.55
Y17	0.172	6.822	6.539	0.283	49.40	36.00	7.68	21.33
Y18	0.172	6.850	6.590	0.260	45.34	44.95	11.64	25.89
Y19	0.166	6.822	6.549	0.273	47.66	39.64	7.31	18.45
Y20	0.166	6.812	6.550	0.262	45.72	42.58	6.62	15.55
Y21	0.166	6.819	6.553	0.266	46.30	40.81	7.83	19.18
Y22	0.166	6.814	6.540	0.274	47.78	38.86	9.44	24.28
Y23	0.166	6.810	6.539	0.271	47.27	39.63	7.69	19.41
Y24	0.082	6.809	6.539	0.270	47.08	19.73	3.30	16.71
Y25	0.082	6.794	6.530	0.264	46.11	20.84	3.95	18.94

3.2.5 Tensile modulus of yarn.

Load-extension curve of the yarn is non-linear. Yarn is more extensible at the beginning. From the load at 5 % extension of yarn on tensile a tester, mass stress[61] (grams per denier) is obtained by dividing load value with yarn denier value. This has been converted to modulus at 5% extension.

Test apparatus:

Module IV - Instron tensile tester.

Test procedure:

On the Instron tensile tester 25 mm i.e. 5% extension of test length of 500 mm is set on the extension counter. At a traverse rate of 300 mm/min the cross head automatically stops at 25 mm extension. From the load read from the counter yarn tensile modulus is calculated in table below.

Table 6 Yarn tensile modulus at 5 % extension.

Yarn code	Load @ 5% extension gf	Denier of Yarn	Stress X 10^{-4} gms / denier	Modulus Ey x 10^{-3} gms/denier	Standard deviation x 10^{-4}	Cv%
YI	0.739	709	10.42	20.85	7.09	3.40
Y2	0.587	591	9.93	19.86	5.68	2.86
Y3	0.631	591	10.68	21.36	5.25	2.46
Y4	0.617	591	10.45	20.90	4.28	2.05
Y5	0.658	532	12.37	24.74	5.84	2.36
Y6	0.576	532	10.83	21.66	8.06	3.72
Y7	0.617	532	11.61	23.22	6.55	2.82
Y8	0.511	443	11.53	23.05	7.75	3.36
Y9	0.523	443	11.81	23.63	10.30	4.36
Y10	0.498	443	11.24	22.48	5.33	2.37
Y11	0.430	354	12.12	24.23	8.75	3.61
Y12	0.452	354	12.76	25.52	12.89	5.05
Y13	0.467	354	13.18	26.35	11.17	4.24
Y14	0.448	354	12.65	25.30	8.15	3.22
Y15	0.381	354	10.75	21.51	12.47	5.80
Y16	0.427	354	12.04	24.08	4.79	1.99
Y17	0.442	354	12.46	24.92	4.31	1.73
Y18	0.435	354	12.28	24.56	8.99	3.66
Y19	0.385	266	14.49	28.98	6.84	2.36
Y20	0.340	266	12.77	25.55	8.30	3.25
Y21	0.368	266	13.83	27.67	8.52	3.08
Y22	0.309	266	11.61	23.22	6.71	2.89
Y23	0.322	266	12.12	24.23	17.16	7.08
Y24	0.239	177	13.48	26.96	9.57	3.55
Y25	0.255	177	14.39	28.78	12.40	4.31

3..3 Test methods for fabric properties.

Fabric constructional, low stress mechanical & surface properties and also thermal properties contributing to the cloth comfort have been identified as below.

Fabric parameter	Test Method	Sample size
A. Mechanical properties:		
1. Yarn crimp (c %)	Prolific crimp tester	20 cm
2. Fabric weight (w gm/ sq. meter)	Electronic Balance.	155 mm diameter
3.Fabric thickness (t mm)	Thickness Gauge.	Free size
4.Bending length (b cm)	Flexometer	25.4 mm x 150 mm
5.Tensile modulus @ 1% ext. (E_1 Newton/ sq. mm)	Instron Tensile Tester	1 inch x 10 cm raveled strip
6.Bias extension at critical shear angle (eb %)	Instron Tensile Tester	1 inch x 40 mm cut strip
7.Friction amplitude of stick-slip curve (Fa gf)	Instron Tensile Tester with Sled Test apparatus	50 mm x 200 mm
B. Thermal tests.		
8. Air permeability value (P $m^3/m^2/$ hr)	Metefem Air Permeability Tester	10 sq. cm area circular.
9.Thermal Insulation Value (r clo) 1 clo = 0.155 m^2 °K/watt	Sashmira Guarded Hot Plate.	155 mm diameter
10.Moisture vapour transfer rate (MVTR mgm/cm^2/hr)	Turl Dish Method	2.5 inch diameter
11.Wicking coefficient (w_c cm/min^{1}	Horizontal Wicking Test	50 mm x 200 mm
12. Fluid filling fraction (f)		

3.3.1. Modules for Fabric tests:

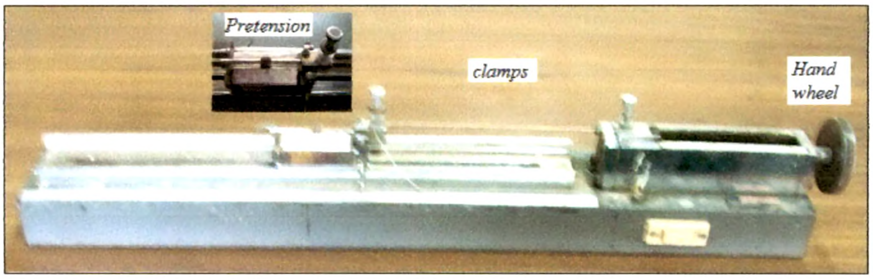
Fabric tests are divided into three modules.

A. Fabric constructional parameters.
B. Fabric mechanical properties.
C. Fabric thermal properties.

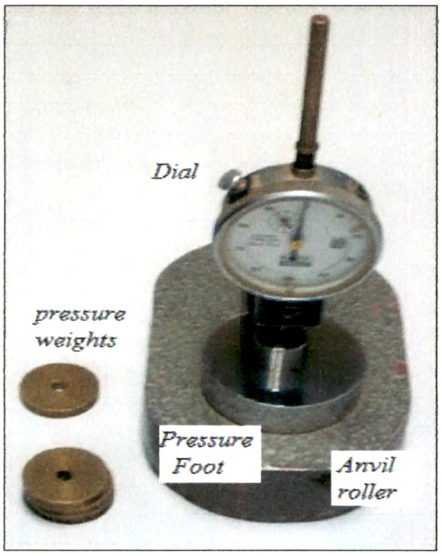
Various apparatus used are shown in figure below and the tests methods are described in subsequent pages.

A) Modules for fabric constructional parameters.

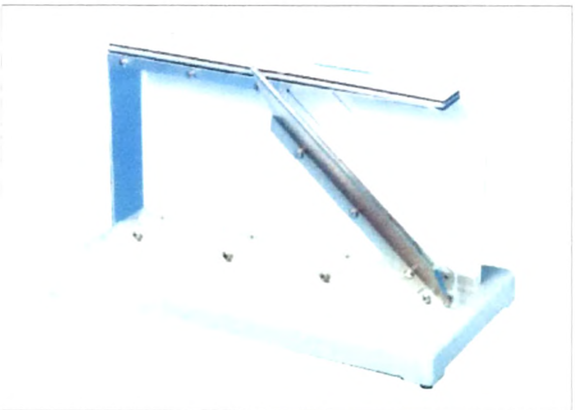
Module 5 Crimp Tester.



Module 6 Fabric thickness Gauge.



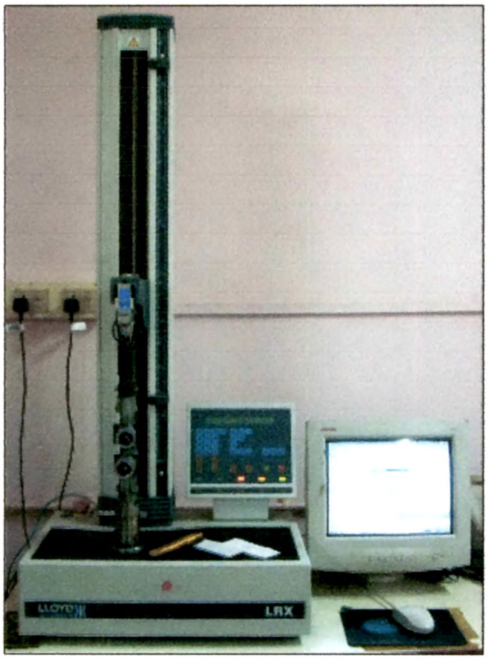
Module 7 Electronic Balance



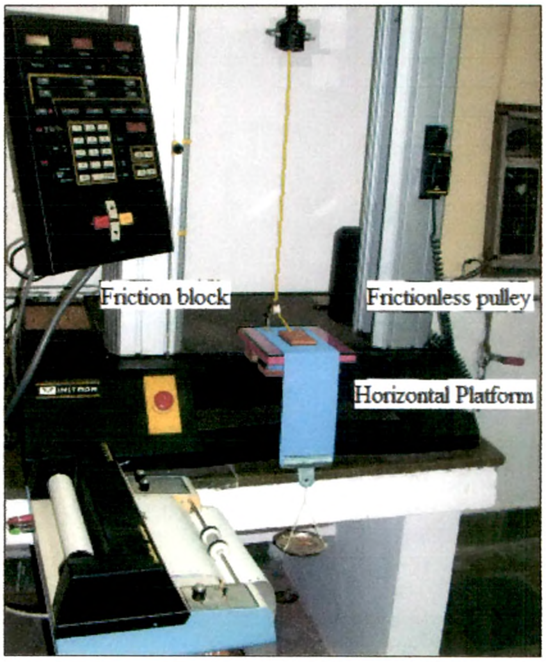
Module 8 Flexometer

Fig.38 Test modules for fabric constructional parameters

B) Modulus for fabric Mechanical Properties



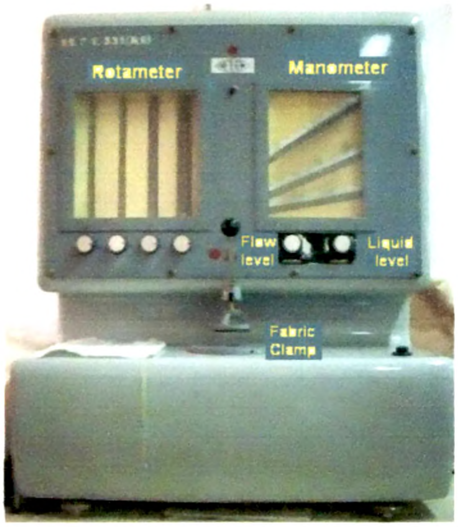
Module 9
Tensile and Shear Test.



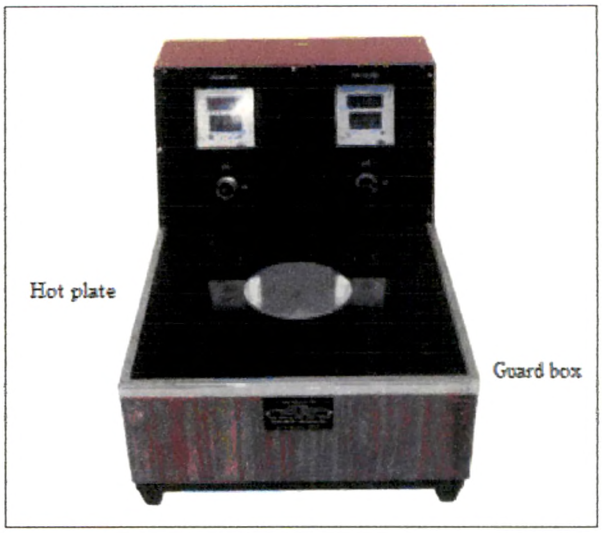
Module 10
Friction apparatus.

Fig. 39 Test modulus for fabric Mechanical Properties.

C) Modules for fabric thermal properties:



Module 11
Air Permeability Tester.



Module 12
Thermal Insulation Value Tester.

Module 13
MVTR tester.

Module 14
Horizontal Wicking Test apparatus (fabricated)

Fig. 40 Test modules for fabric Thermal properties.

3.3.2 Sample layout and cutting:

Proper layout of sample cutting can help getting maximum tests from the available fabric sample. Moreover it is preferred to randomly distribute samples over the width and length directions so that no two samples have the same warp and weft yarns.

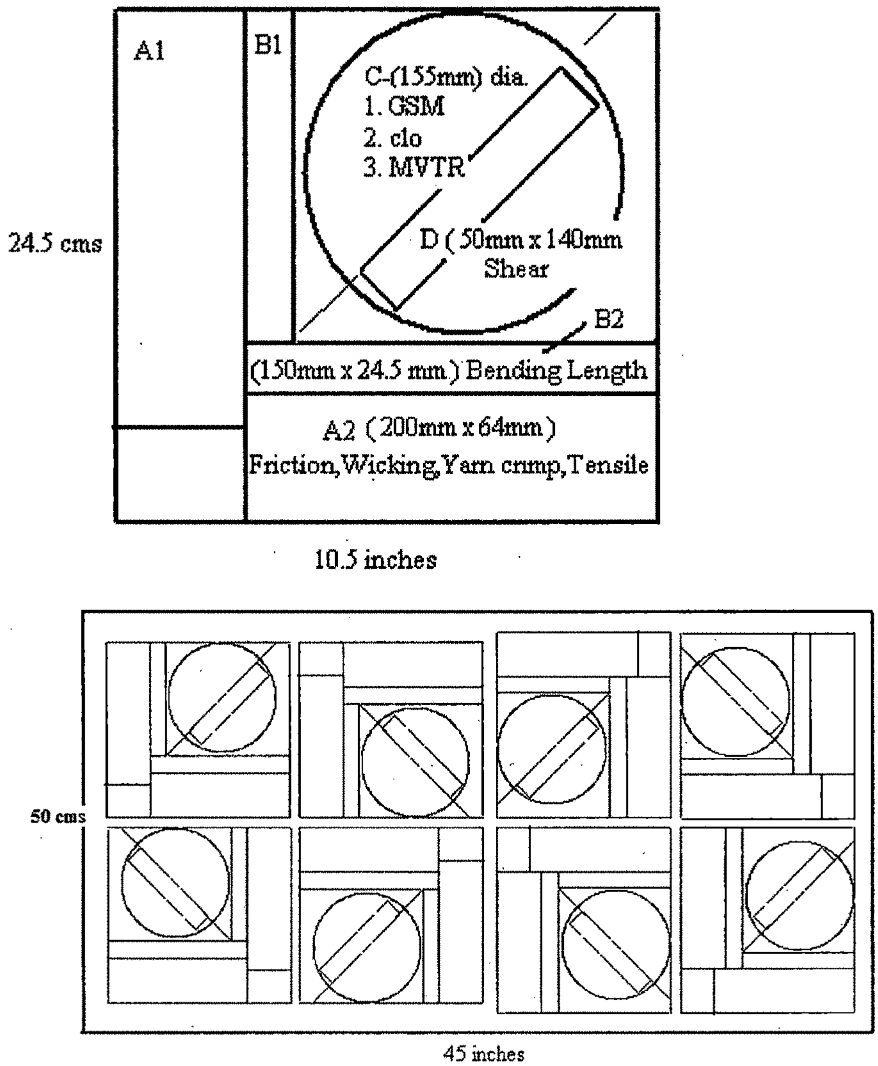


Figure 41. Layout for Fabric sample cutting

Figure 41 gives layout for sample cutting to make optimum use of cloth for getting samples for all the tests.

Friction and wicking tests are non-destructive in nature and their sample size matches with the sample size of tensile testing on Instron. While raveling sample for Instorn Tester the yarn removed can be used for yarn crimp testing. Two stripes A1 & A2 of 200mm x 64mm in warp and weft directions can serve for these four tests. B1 & B2 samples are for the bending length in warp and weft direction respectively. Similarly a circular sample C of 155mm diameter cut for clo value testing can be used for fabric GSM on electronic balance and also for MVTR test. After these three testes are performed, a bias cut sample (D) in warp and weft directions of size 1 inch x 140mm is cut from this circular sample for fabric shear test. Thus a 25 cm x 11 inch size fabric sample as in fig. 39 can serve for all the fabric tests and an half a meter of full width fabric is sufficient for eight samples of each test with no two samples having the same warp and weft yarns.

3.3.3 Yarn crimp

Crimp is defined[61] as the mean difference between the straighten thread length under standard pretension and the distance between the ends of the thread while in the cloth, expressed as a percentage.

$$\text{Crimp \%} = \frac{ls - lc}{lc} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (39)$$

Where ls - Straightened length of yarn removed from the fabric.

lc - Crimped length of yarn within the fabric i.e. cloth length.

Test Apparatus: Prolific crimp tester

Test procedure:

Gauge length 20 cm yarn is set between two yarn clamps. Yarn under a pretension is then straightened by rotating the hand wheel. Pretension is applied to straighten the yarn to remove all the kinks without stretching it. This pre-tension of tex/2 gms is set on the scale by adjusting the position of the weight. The crimped yarn length can be read directly on the scale when the load is lifted and light is put off.

Table 7 Yarn crimp:

Fabric code	c_1%	Standard deviation	CV%	c_2%	Standard deviation	CV%
A1	5.2	0.51	9.86	14.6	1.39	9.53
A2	7.5	0.65	8.67	11.8	0.28	2.33
A3	5.0	0.38	7.53	12.2	0.82	6.69
A4	4.6	0.50	10.83	12.1	0.96	7.91
A5	5.6	0.50	8.93	14.7	1.31	8.91
A6	11.4	0.53	4.61	2.7	0.49	17.98
A7	5.4	0.38	7.11	13.6	0.58	4.25
A8	5.4	0.36	6.61	12.6	0.83	6.59
A9	2.2	0.25	11.29	15.4	0.78	5.04
A10	10.5	0.74	7.07	3.3	0.58	17.63
A11	2.9	0.24	8.43	16.2	1.79	11.04
B1	5.3	0.84	15.81	13.8	0.58	4.18
B2	3.3	0.14	4.11	15.6	1.46	9.33
B3	3.8	0.51	13.42	15.0	1.26	8.38
B4	7.0	0.49	7.00	15.2	0.58	3.80
B5	1.3	0.13	10.00	21.7	0.48	2.21
C1	8.4	1.02	12.09	11.6	0.96	8.25
C2	15.2	0.93	6.10	5.3	0.58	10.89
C3	8.8	1.14	12.90	9.2	1.26	13.68
C4	6.2	0.49	7.86	14.3	1.99	13.89
D1	5.5	0.31	5.62	11.7	0.82	6.98
D2	8.0	0.78	9.80	9.3	0.96	10.29
D3	6.3	0.37	5.82	13.2	0.29	2.19
D4	9.4	0.50	5.37	6.5	0.82	12.56

3.3.4 Fabric weight:

It is weight of fabric as it lies on table without stretching or wrinkle. It is expressed in grams per square meter (GSM).

Test apparatus : Electronic balance.

Test procedure:

Circular samples of 155 mm diameter (Area = 188 sq. cm) cut for the thermal insulation testing have been weighed on electronic balance with accuracy of 0.001 gm. Fabric weight has been converted into GSM.

Table 8 Fabric weight in GSM::

Sample code	Gms per sq. meter GSM	Standard deviation	CV%
A1	273	4.3	1.58
A2	265	2.5	0.94
A3	253	1.7	0.67
A4	234	4.8	2.05
A5	194	3.9	2.01
A6	235	5.7	2.43
A7	210	7.5	3.57
A8	180	1	0.56
A9	152	7.5	4.94
A10	218	8.1	3.71
A11	140	1	0.71
B1	243	3.9	1.60
B2	239	2.5	1.05
B3	233	4.7	2.01
B4	228	6.6	2.89
B5	219	3.3	1.51
C1	212	2.5	1.18
C2	248	2.21	0.89
C3	261	8.5	3.26
C4	269	4.8	1.78
D1	267	4.8	1.80
D2	260	9.1	3.49
D3	233	6.2	2.66
D4	256	4.3	1.68

3.3.5 Fabric Thickness:

Fabric is comprisable. Hence its thickness is measured at two different pressures: t_{10} refers to thickness at 10 gm per sq.cm and t_{50} is the thickness at 50 gm per sq.cm pressure.

Test apparatus : Prolific fabric thickness gauge.

Test procedure:

Fabric thickness gauge with accuracy 0.01 mm in accordance with ASTM D1777-64 measures fabric thickness. For no weight put, the weight of pressure roller gives 10 gm per sq. cm pressure. Each weight washers weight 10 gm. Putting four such weight washers the thickness is measured at 50 gm per sq. cm. ten readings of t_{10} and t_{50} are taken for each samples.

Table 9 Fabric thickness in mm:

Fabric code	Thickness (t_{10}) @10gms per sq.cm	Standard deviation	CV%	Thickness (t_{50}) @50gms per sq.cm	Standard deviation	CV%
A1	0.556	0.0139	2.50	0.528	0.0027	0.52
A2	0.498	0.0035	0.70	0.478	0.0078	1.64
A3	0.485	0.0071	1.46	0.460	0.0081	1.76
A4	0.439	0.0022	0.50	0.417	0.0027	0.66
A5	0.383	0.0120	3.14	0.348	0.0050	1.44
A6	0.452	0.0043	0.94	0.422	0.0058	1.39
A7	0.391	0.0134	3.43	0.354	0.0024	0.67
A8	0.324	0.0059	1.81	0.297	0.0026	0.87
A9	0.325	0.0075	2.30	0.291	0.0051	1.74
A10	0.358	0.0050	1.39	0.334	0.0068	2.05
A11	0.281	0.0026	0.94	0.247	0.0056	2.26
B1	0.487	0.0042	0.87	0.460	0.0050	1.09
B2	0.477	0.0049	1.02	0.447	0.0027	0.61
B3	0.459	0.0102	2.23	0.430	0.0094	2.18
B4	0.432	0.0115	2.66	0.401	0.0082	2.04
B5	0.424	0.0060	1.42	0.389	0.0076	1.95
C1	0.397	0.0051	1.29	0.361	0.0089	2.48
C2	0.437	0.0088	2.02	0.404	0.0096	2.38
C3	0.455	0.0084	1.85	0.422	0.0076	1.80
C4	0.460	0.0073	1.59	0.423	0.0056	1.33
D1	0.438	0.0045	1.02	0.411	0.0026	0.64
D2	0.444	0.0127	2.87	0.414	0.0082	1.98
D3	0.422	0.0076	1.80	0.393	0.0105	2.66
D4	0.453	0.0052	1.15	0.426	0.0053	1.23

3.3.6 Bending length :

Test apparatus : Shirley Fabric stiffness tester

Test procedure:

It uses Cantilever Test (ASTM D 1388-96) to measure the Stiffness or Bending resistance of fabrics. The fabric specimen one inch by eight inches was slid in a direction parallel to its long dimension until the tip of the specimen depressed under its own mass makes contact with the plane at a 41.5° angle with the horizontal. The over hanging length of fabric strip is twice the bending length. The slide calibrated in centimeters is used to measure the length of the overhang directly. Four reading are taken for each sample, one face up and one face down of the first end and the same for the second end. $b = \sqrt{b_1 \times b_2}$ is the geometrical mean of bending length in warp and weft way is taken and the Flexural rigidity and bending stiffness are calculated.

Table 10 Bending length of fabric:

Fabric code	b1 cms	Standard deviation	CV%	b2 cms	Standard deviation	CV%	b cms
A1	1.99	0.025	1.26	1.64	0.043	2.65	1.81
A2	2.09	0.025	1.20	1.84	0.025	1.36	1.96
A3	1.96	0.025	1.27	1.67	0.017	1.04	1.81
A4	1.75	0.048	2.72	1.45	0.048	3.28	1.59
A5	1.58	0.029	1.83	1.27	0.039	3.11	1.41
A6	1.75	0.048	2.72	1.58	0.057	3.62	1.66
A7	1.76	0.063	3.57	1.56	0.075	4.80	1.66
A8	1.63	0.029	1.78	1.50	0.010	0.67	1.56
A9	1.55	0.058	3.72	1.20	0.075	6.24	1.36
A10	1.65	0.058	3.50	1.48	0.081	5.49	1.56
A11	1.56	0.075	4.80	1.21	0.010	0.83	1.37
B1	1.81	0.025	1.38	1.57	0.039	2.52	1.69
B2	1.81	0.012	0.64	1.46	0.025	1.71	1.63
B3	1.80	0.000	0.00	1.52	0.047	3.11	1.65
B4	1.86	0.015	0.81	1.45	0.066	4.57	1.64
B5	2.34	0.025	1.07	1.30	0.033	2.54	1.74
C1	1.81	0.025	1.38	1.44	0.025	1.74	1.61
C2	1.79	0.144	8.03	1.79	0.221	12.38	1.79
C3	1.61	0.085	5.30	1.61	0.085	5.30	1.61
C4	1.68	0.029	1.72	1.43	0.048	3.33	1.55
D1	1.93	0.079	4.08	1.45	0.048	3.28	1.67
D2	1.78	0.065	3.64	1.53	0.091	5.92	1.65
D3	1.61	0.063	3.90	1.41	0.062	4.37	1.51
D4	1.78	0.054	3.04	1.48	0.043	2.92	1.62

3.3.7 Fabric tensile modulus:

Fabric load elongation curve has no distinct straight part representing hooken's region. The determination of initial modulus i.e. the slope of curve in the hooken's zone is difficult. As shown in fig.42 load at initial elongation in the region up to 5 % extension depends on yarn crimp in the fabric.

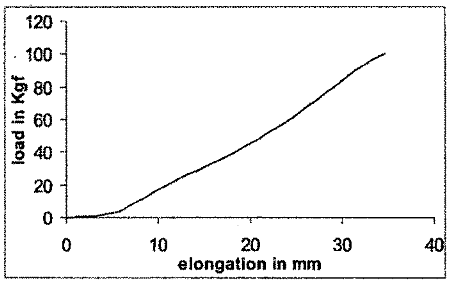


Fig.42 Fabric load –elongation curve

From the load-elongation curve load at 2 % elongation is converted to stress in Newton/sq. mm. Fabric thickness at 10 gm per sq. cm is considered for determining fabric cross sectional area. From the stress at 2 % extension modulus is calculated to represent the fabric tensile behavior in low stress zone.

Test Apparatus: Lloyd tensile tester.

Test procedure :

It is a computer attached tensile tester. 100mm x 1 inch raveled strip in warp as well in the weft directions are tested at 120 mm/min rate of traverse. From the load –elongation curve of fabric, load at 2% extension is converted to stress value by dividing the load by the area of cross section of fabric strip. Fabric thickness at 10 gms per sq. cm is considered for calculating the fabric cross sectional area.

Further the modulus is calculated by dividing the stress in Newton per sq. mm by the extension i.e. elongation divided by gauge length. Here modulus at 2% extension is calculated in table 11.

Table 11 Fabric modulus at 2% extension:

			warp					weft				
Sample code	Thickess @ 10 gm/sq. cm pressure	Cross sectional area of sample	Load at 2 % extension Gf	stress N/sq mm	$E2_1$ Modulus N/sq mm	standard deviation	CV%	Load at 2 % extension gf	stress N/sq mm	$E2_2$ Modulus N/sq mm	SD	CV%
A1	0.556	1.412	560	3.89	195	25.48	13.10	119	0.83	42	4.69	11.3
A2	0.498	1.264	469	3.63	182	11.92	6.57	189	1.47	74	6.78	9.23
A3	0.485	1.232	622	4.95	248	34.45	13.92	132	1.05	53	5.13	9.77
A4	0.439	1.114	518	4.57	229	12.16	5.32	134	1.18	59	2.97	5.03
A5	0.383	0.973	466	4.7	235	16.57	7.05	109	1:1	55	4.66	8.48
A6	0.452	1.148	529	4.52	226	17.61	7.79	990	8.46	423	27.58	6.52
A7	0.391	0.993	559	5.53	277	31.52	11.40	130	1.28	64	5.72	8.94
A8	0.324	0.824	387	4.6	230	20.98	9.12	139	1.66	83	6.08	7.33
A9	0.325	0.827	1183	14.04	702	29.69	4.23	141	1.67	84	3.87	4.64
A10	0.358	0.908	472	5.1	255	24.35	9.55	427	4.61	231	11.06	4.8
A11	0.281	0.714	831	11.42	571	40.08	7.02	89	1.22	61	5.14	8.43
B1	0.487	1.236	589	4.67	234	10.83	4.64	112	0.89	45	5.22	11.73
B2	0.477	1.213	729	5.9	295	21.86	7.41	99	0.8	40	5.82	14.56
B3	0.459	1.166	893	7.52	376	36.55	9.72	107	0.9	45	5.21	11.58
B4	0.432	1.097	569	5.09	255	12.88	5.06	70	0.62	31	3.10	10.01
B5	0.424	1.076	2284	20.81	1041	33.40	3.21	114	1.03	52	3.64	7.07
C1	0.397	1.009	764	7.42	371	36.21	9.76	79	0.77	39	3.83	9.96
C2	0.437	1.109	332	2.94	147	20.21	13.75	365	3.23	162	12.08	7.48
C3	0.455	1.156	359	3.04	152	14.88	9.79	175	1.49	75	7.90	10.6
C4	0.460	1.168	451	3.79	190	13.40	7.07	132	1.1	55	4.09	7.44
D1	0.438	1.113	498	4.39	220	21.84	9.95	100	0.88	44	3.33	7.57
D2	0.444	1.127	363	3.16	158	6.00	3.80	208	1.81	91	9.84	10.87
D3	0.422	1.072	395	3.61	181	12.27	6.80	114	1.04	52	5.22	10.03
D4	0.453	1.151	539	4.59	230	12.99	5.66	232	1.97	99	15.88	16.12

3.3.8 Critical shear angle:

During shear deformation of fabric

threads slide over each other at the intersections due to compressive stress in transverse direction, changing the angle between warp and weft threads.

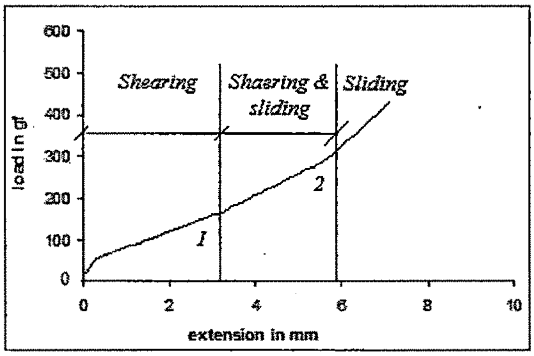


Fig 43 Load-extension plot of bias cut fabric.

As explained in section 2.2.2.3, extension at pt.1 in the graph represents the state at which critical has been reached.

At critical shear angle locking of threads take place and no further sliding is possible. Fabric starts buckling. The extension at critical shear angle which depends on fabric sett and yarn hairiness affects the appearance of garment. It causes surface waviness of stretched fabric at shoulder and ankles. Objectively it can be estimated from the plot of the uniaxial tensile test of a bias cut specimen on tensile tester with computer attached to plot the load – elongation curve.

Test Apparatus: Lloyd tensile tester.

Test procedure:

40 mm gauge length and 1 inch wide fabric cut at 45° to warp and/or weft direction are tested on Lloyds tensile tester at 10 mm/min traverse rate. From the load-elongation plot the extension at pt.1 as illustrated in fig.45 is converted into % extension and tabulated below.

Table : 12 Shear Extension at critical shear angle.

Fabric code	Extension %	STDEV	CV%
A1	2.95	0.08	2.82
A2	3.98	0.38	9.48
A3	4.53	0.33	7.21
A4	2.90	0.24	8.44
A5	3.10	0.18	5.93
A6	3.83	0.23	6.01
A7	2.70	0.35	13.02
A8	3.13	0.13	4.04
A9	5.63	0.39	6.97
A10	1.38	0.07	4.81
A11	4.18	0.42	10.1
B1	4.00	0.19	4.7
B2	5.05	0.43	8.57
B3	2.80	0.22	7.68
B4	3.63	0.19	5.32
B5	4.25	0.48	11.24
C1	4.30	0.24	5.56
C2	1.13	0.09	7.7
C3	12.35	0.25	2
C4	5.05	0.59	11.59
D1	3.03	0.04	1.17
D2	2.55	0.18	7.06
D3	4.58	0.06	1.21
D4	2.90	0.25	8.68

3.3.9 Frictional Amplitude:

Surface roughness of fabric is evaluated objectively from the amplitude of the stick-slip curve given in fig. 44. The highest peak at the commencement of motion is the static frictional resistance (F_s) The mean of peaks & troughs (equivalent to drawing a straight line to the middle of the stick slip pulses) can be taken as a kinetic frictional resistance (F_k). But these two quantities are affected by the normal pressure between two surfaces. So the surface roughness of the fabric is indicated by the height of stick-slip pulses.

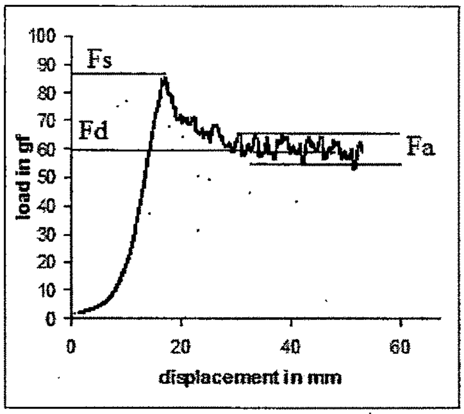


Fig 44 Stick-slip curve of fabric.

Test Apparatus:

A Flat bed friction apparatus consists of a rubber covered wooden block to slide on the fabric placed on a horizontal platform attached to Instron tensile tester. The motion of the wooden block is plotted on load-extension curve by connecting the block to the cross head of Instron Tensile tester as shown in the module 10.

Test procedure:

Fabric sample of 200 mm x 50 mm is held creaseless by means of the weight placed on the tray attached to fabric by dog clip. A sliding block covered with rubber (to simulate the human skin) is pulled at 10 mm/min traverse rate over the fabric on the horizontal platform by the cross head attached to load cell of 100 gms.

Table 13 Fabric friction amplitude:

Fabric code	Face Side							Back Side						
	Fa_1 gf	Warp way Standard deviation	CV%	Fa_2 gf	Weft way Standard deviation	CV%	Resultant Fa_f gf	Fa_1 gf	Warp way Standard deviation	CV%	Fa_2 gf	Weft way Standard deviation	CV%	Resultant Fa_b gf
A1	4.35	0.57	13.17	3.75	1.16	30.77	**4.04**	3.72	0.42	11.42	4.38	0.78	17.72	**4.04**
A2	4.25	0.69	16.34	4.08	0.39	9.6	**4.16**	5.2	0.77	14.86	3.39	0.36	10.53	**4.2**
A3	4.72	0.52	10.95	5.32	0.58	10.87	**5.01**	4.57	0.69	15.18	4.99	0.61	12.18	**4.78**
A4	4.6	0.61	13.25	4.93	0.67	13.66	**4.76**	5.05	1.01	20	4.33	0.66	15.31	**4.68**
A5	4.44	0.81	18.34	4.93	0.62	12.49	**4.68**	6.26	0.87	13.92	6.88	0.84	12.23	**6.56**
A6	3.19	0.51	16.07	3.92	0.32	8.13	**3.54**	3.74	0.5	13.31	3.7	0.31	8.45	**3.72**
A7	4.04	0.64	15.8	3.85	0.49	12.63	**3.94**	4.15	0.59	14.15	4.66	0.56	12.05	**4.4**
A8	5.64	0.98	17.43	6.46	0.58	8.91	**6.04**	6.04	1.06	17.58	6.13	0.84	13.64	**6.08**
A9	3.65	0.76	20.76	2.68	1.07	39.81	**3.13**	4.31	0.61	14.12	2.81	0.21	7.45	**3.48**
A10	4.47	0.96	21.55	8.54	1.33	15.58	**6.18**	5.12	0.72	13.97	5.07	0.7	13.89	**5.09**
A11	5.53	1.03	18.71	4.72	0.36	7.69	**5.11**	4.46	1.7	38.06	3.84	0.57	14.93	**4.14**
B1	5.34	0.64	12.01	4.45	0.47	10.56	**4.87**	5.04	0.47	9.26	4.54	0.76	16.82	**4.78**
B2	4.29	0.85	19.82	3.89	0.51	13.11	**4.09**	4.17	0.48	11.39	4.09	0.44	10.69	**4.13**
B3	4.83	1.07	22.06	3.63	0.45	12.4	**4.19**	4.69	0.44	9.36	4.22	0.51	12.16	**4.45**
B4	3.04	0.47	15.4	2.66	0.26	9.76	**2.84**	3.19	0.46	14.48	2.52	0.93	36.92	**2.84**
B5	3.03	0.35	11.72	3.26	0.34	10.31	**3.14**	3.18	0.29	9	3.26	0.4	12.26	**3.22**
C1	4.67	0.75	15.99	4.9	0.9	18.42	**4.78**	6.47	1.25	19.27	7	1.1	15.65	**6.73**
C2	6.79	1.37	20.24	4.31	0.81	18.92	**5.41**	6.34	1.12	17.69	4.76	0.65	13.75	**5.49**
C3	3.68	0.8	21.87	3.95	0.83	21.1	**3.81**	3.85	0.43	11.16	3.63	0.29	8.05	**3.74**
C4	8.29	1.44	17.35	8.73	1.28	14.66	**8.51**	7.83	1.11	14.23	7.36	1.03	13.95	**7.59**
D1	5.62	0.8	14.29	5.18	0.94	18.07	**5.4**	6.38	0.96	15.02	5.31	0.99	18.65	**5.82**
D2	6.5	1.24	19.13	5.06	1.24	24.51	**5.73**	5.83	0.71	12.23	4.93	0.83	16.82	**5.36**
D3	5.18	1.1	21.31	6.16	0.49	7.94	**5.65**	6	1.35	22.47	6.71	2.37	35.26	**6.35**
D4	3.37	0.37	10.95	3.83	1.03	26.87	**3.59**	2.82	0.26	9.38	3.53	0.46	12.91	**3.16**

Fa_f and fa_b are the geometrical mean of Fa_1 and Fa_2 of the face and back of the fabric respectively.

3.3.10 Air Permeability:

Air permeability is a measure of the rate of air flow through a fabric under a given pressure difference. It affects the heat and moisture transfer through fabric and decides fabric thermal comfort.

Test Apparatus: Metefem air permeability tester.

The instrument has four Rota meters having range of 4 - 40, 20 - 200, 120 – 1200 and 800 – 8000 litres per hour for measurement of air flow through fabrics depending on the flow resistance offered by fabric. The pressure on manometers in a range from 0-30, 30 – 100 and 100 – 200 mm of water column can be used for the measurement of air flow in different applications. 10, 20, 50 or 100 sq. cm test cross sectional area can be used

Test procedure:

When all Rota meters are closed zero mark on manometer is set with liquid level knob. For 10 sq. cm cross sectional area, the flow rate is measured by opening one of the manometers, maintaining a pressure of 100 Pa by the flow control knob. The rate of flow in one of the rotameters gives air permeability value of the fabric in liters per hr. per one sq. meter area of the fabric.

Table 14 Air permeability in litres /hr / sq.cm:

Fabric code	P $m^3m^{-2}hr^{-1}$	Standard deviation	CV%
A1	774	34.70	4.48
A2	583	25.10	4.31
A3	648	33.12	5.11
A4	751	64.53	8.59
A5	492	15.71	3.19
A6	252	10.03	3.98
A7	573	12.14	2.12
A8	429	13.93	3.25
A9	1913	84.78	4.43
A10	117	1.75	1.49
A11	573	56.36	9.83
B1	588	42.97	7.30
B2	498	16.05	3.23
B3	378	6.06	1.60
B4	708	48.96	6.92
B5	405	20.98	5.18
C1	478	47.29	9.89
C2	166	5.72	3.44
C3	157	2.14	1.36
C4	212	6.06	2.86
D1	288	11.25	3.90
D2	181	15.94	8.82
D3	335	13.78	4.11
D4	206	8.01	3.89

3.3.11 Thermal insulation value :

Thermal insulation of fabric is measured in clo unit (1 clo = 0.155 cubic m °K / watt). Clo value of zero corresponds to a naked person while one clo corresponds to a person wearing a typical business suit.

Test Apparatus: Sashmira TIV tester.

An electrically heated plate (main heater) is surrounded by a guard heater. By thermostat on both sides of the gap separating the main and the guard heaters, the guard heater is maintained at 50°C temperature. This prevents lateral heat flow from hot plate and ensures that all heat energy flows in the direction of the sample. The thermostat of the hot plate cuts off electric supply at 51°C, cooling the hot plate and is activated again 45° C.

<u>Testing procedure :</u>

Time taken for the hot plate covered with fabric sample (155 mm diameter) to cool down from 50° C to 49° C is noted. From the clo value chart fig.47 cloth clo value is determined for (cooling time / 2) min.

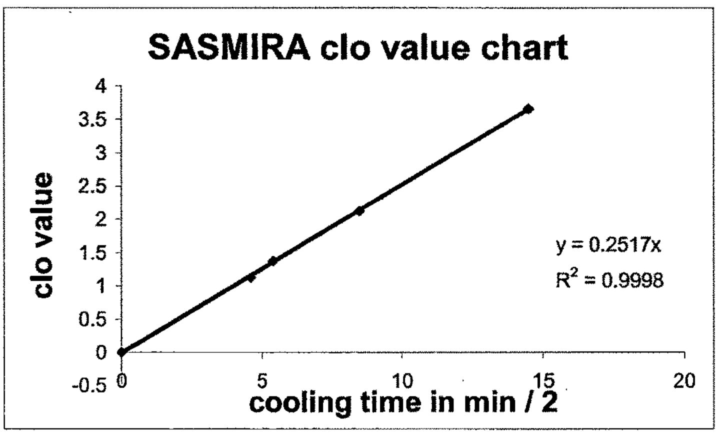


Fig.45 Clo chart of Sasmira Thermal insulation value.

Table 15. Clo value of fabric:

Fabric code	clo	Standard deviation	CV%
A1	0.500	0.004	0.72
A2	0.490	0.012	2.53
A3	0.493	0.003	0.60
A4	0.485	0.004	0.82
A5	0.472	0.011	2.39
A6	0.491	0.002	0.41
A7	0.477	0.004	0.92
A8	0.470	0.006	1.33
A9	0.475	0.003	0.57
A10	0.477	0.011	2.23
A11	0.472	0.019	4.12
B1	0.501	0.010	2.06
B2	0.498	0.011	2.24
B3	0.494	0.020	4.14
B4	0.486	0.004	0.75
B5	0.494	0.022	4.52
C1	0.486	0.009	1.92
C2	0.481	0.001	0.25
C3	0.487	0.006	1.13
C4	0.491	0.002	0.35
D1	0.481	0.001	0.22
D2	0.479	0.001	0.25
D3	0.485	0.001	0.22
D4	0.486	0.011	2.21

3.2.3.12 Moisture Vapour Transfer Rate:

It determines the evaporative heat loss from body to prevent heat accumulation and thus reduces sweating. In a Cup method, water evaporated in mgm per hr. from a cup covered with fabric sample divided by the area of the sample gives water evaporated in mgm per sq. cm per hr.

Test Apparatus: Turl dish method.

It consists of six cups of diameter 2.5 inch (cross sectional area = 31.67 sq. cm) filled with 100 gm of water. Cups are covered by circular fabric sample of 15 cm diameter and held tightly by means of a copper wire band. This leaves about 2 mm layer of air below the fabric sample. Cups are placed in a water bath in which the temperature of water is maintained at 33°C by a thermostat. This simulates human body temperature.

Test procedure:

At relative humidity of the room at 64 % with dry and wet bulb temperature of 89°C and 79 °C respectively, the loss in weight of water of the cup is observed after every half hour intervals using electronic balance. Ten such readings are taken for each sample.

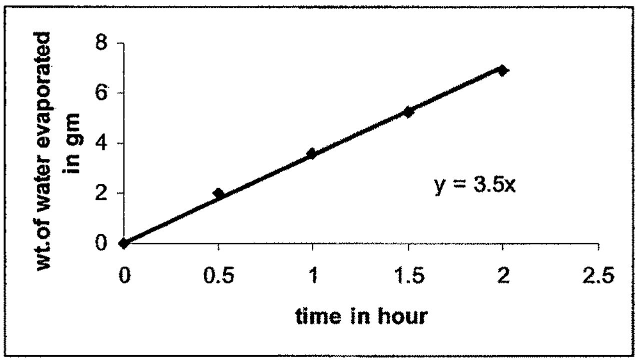


Fig.46 Rate of Moisture evaporation through fabric.

The plot of wt of water evaporated v/s time in hour is a straight line passing through origin. The slope of the line gives water evaporated per hr. through the samples. Dividing it by the area of the sample gives water evaporated in mgm per sq. cm per hr.

Table 16. MVTR in mgm per sq.cm per hour:

Fabric code	MVTR mgm/cm^2 per hour	Standard deviation	CV%
A1	40.42	3.32	8.22
A2	34.39	3.98	11.56
A3	28.65	1.97	6.87
A4	31.70	2.92	9.2
A5	32.64	2.58	7.89
A6	25.16	2.41	9.56
A7	31.42	2.07	6.59
A8	35.79	2.43	6.78
A9	39.49	3.29	8.34
A10	18.79	1.65	8.79
A11	29.26	3.95	13.5
B1	31.85	2.37	7.45
B2	29.32	3.69	12.6
B3	24.20	1.37	5.67
B4	39.81	2.97	7.45
B5	34.91	3.25	9.32
C1	27.96	2.89	10.34
C2	26.47	1.51	5.69
C3	32.32	3.78	11.68
C4	17.52	0.87	4.96
D1	33.76	3.90	11.56
D2	32.33	4.11	12.72
D3	31.90	2.41	7.56
D4	21.34	1.99	9.34

3.2.3.13 Wicking test:

Wicking is a phenomenon of water transport through fabric capillaries. It brings the sweat on the surface of the fabric from where it can be easily evaporated in the atmosphere. This keeps the body dry and comfortable. Quantitatively it is analysed in terms of the rate of wicking through the fabric and also the amount of sweat the fabric can hold.

Test Apparatus:

In a horizontal wicking test apparatus, the length of water wicked through the sample is measured and plotted against the time to get wicking coefficient. From the weight of water wicked by fabric the fluid filling fraction is obtained.

Wicking coefficient :

Typical shape of wicking height L versus time $t^{1/2}$ graph in figure 54 is straight till saturation is reached. Beyond this point wicking ceases. The slope of the plot is called the wicking coefficient w_c which represents the rate of wicking through the sample.

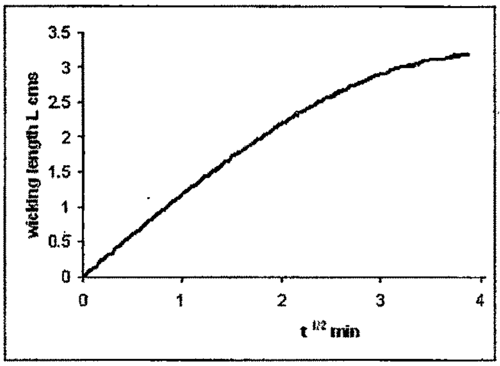


Fig.47 wicking length v/s time relationship

Fluid filling fraction :

It is a measure of saturation level. It is the ratio of the weight of water held by the unit volume of sample. It is calculated as $f = \frac{V_{fluid}}{V_{fabric}}$ where V_{fluid} is the wt. of water considering density = 1, V_{fabric} is calculated from the width of sample i.e. 5 cms, its thickness measured at 10 grams per sq. cm pressure and the wicking length at intervals of time during test.

Test procedure:

50mm x 200mm in warp and weft way fabric samples are dipped one cm length in water reservoir as shown in the figure 49. Length of water wicked by the fabric (on the horizontal scale) and the reduction in weight of water in reservoir (Using electronic balance ensuring that stand do not make contact with water reservoir) are noted at one minute interval till it reaches to saturation. And the wicking coefficient and fluid filling fractions are calculated from the plot.

Table 17. Wicking parameters of horizontal wicking test:

Fabric code	wicking length cm		wicking coefficient wc cm-min$^{-1/2}$			Fluid filling fraction f		
	warp	weft	warp	weft	mean	warp	weft	mean
A1	10.2	11	3.07	2.89	2.98	1.29	1.03	1.15
A2	8.7	7.5	2.03	1.72	1.87	0.47	0.89	0.65
A3	9.4	10.3	2.17	2.86	2.49	1.08	0.89	0.98
A4	7.4	5.9	1.89	1.63	1.76	0.81	0.8	0.8
A5	4.3	5.2	1.76	1.55	1.65	1.25	0.74	0.96
A6	9.1	6.6	2.28	1.42	1.8	0.67	0.78	0.72
A7	8.6	7	2.08	1.89	1.98	0.99	0.91	0.95
A8	3	3.2	0.84	0.84	0.84	1.68	1.49	1.58
A9	7.8	7.1	2.01	1.8	1.9	1.31	1.72	1.5
A10	4.6	2.8	1	0.72	0.85	1.87	2.74	2.26
A11	3	3.5	0.79	0.99	0.89	2.12	2.42	2.27
B1	8.4	7	2.04	1.62	1.82	0.82	0.78	0.8
B2	6.1	5.9	1.51	1.51	1.51	1.2	0.91	1.05
B3	10.1	9.2	2.45	2.63	2.54	0.81	0.76	0.78
B4	9.3	7.8	2.32	2.11	2.21	0.93	1.43	1.15
B5	7.4	6.7	1.68	1.54	1.61	1.04	1.4	1.21
C1	4	3.7	0.94	0.69	0.81	1.21	1.25	1.23
C2	6.3	4.2	1.83	1.06	1.39	1.74	1.35	1.53
C3	5.6	5.5	1.31	1.34	1.33	1.08	1.35	1.21
C4	3	3.3	0.67	1.06	0.84	2.46	2.34	2.4
D1	6.9	5.3	1.94	1.28	1.58	0.67	1.15	0.87
D2	4.6	3.6	1	0.82	0.91	1.45	1.16	1.3
D3	3.4	4.5	1.05	1.1	1.07	1.68	1.6	1.64
D4	8.6	5.5	1.81	1.36	1.57	1.22	2.33	1.69

3.4 Objective evaluation of fabric comfort:

In the literature sited it is evident that systematic approach has been given all over the world to measure fabric objective properties and correlate them with the subjective terms used by common people to express the fabric feel. But the subjective assessment is influenced by human psychology and therefore sensitive to local factors involved. Such a system of evaluation may not be reliable and accepted to all.

An objective assessment of fabric performance characteristic from its properties needs to be established to develop an actual profile of fabric comfort. This specifies to design and produce a fabric with the right combination of performance characteristics for a particular end use.

Comfort is evaluated in terms :

1. Mechanical comfort referred to as fabric hand and
2. Thermal comfort.

using weighted Euclidean distance[28] from the real origin i.e. zero co-ordinate. It is totally an objective method based on mathematical calculation of the data obtained from testing of the fabrics for their mechanical and thermal properties and thus eliminate the personal element of subjective evaluation.

3.4.1. Mechanical comfort or Handle of cloth.

Quantitative specification of fabric handle from fabric mechanical properties is a key to the objective measurement of handle.

These mechanical properties include

1. Tensile modulus (E_2 Newton per sq. mm): It is a measure of stiffness (resistance to extension) measured in two principle direction of warp as well weft on Lloyds tensile tester. It refers to fabric extensibility.
2. Flexural Rigidity (G gm-cm): It is a measure of resistance to bending or the stiffness appreciated by fingers. Flexural rigidity $G = w \times b^3/10^4$ where w = fabric weight in gm per sq meter (GSM) & b - the geometrical mean of the bending lengths in warp and weft direction in cm.
3. Bending Modulus (q kg/cm^2): It is intrinsic stiffness that takes account of thickness. $q = 12 X G / t^3$ kg per sq. cm where t is fabric thickness in mm measured at 10 gm per sq.cm pressure. It reflects the degree of compactness hence describes a fuller handle or thin and papery feel.
4. Extension at critical shear angle (e_b): It is a measure of shear stiffness appreciated when fabric conforms to curved surfaces such as elbow, shoulder etc in garments. It is the extension (in bias direction) at which fabric wrinkles or folds appear, expressed as percentage.
5. Hardness (H mgm per cubic cm): It is the difference of thickness appreciated by pressing with a finger tip. $H = \frac{\text{Difference in pressure}}{\text{Difference in thickness}} = \frac{(50-10)}{(t_{10} - t_{50})} X\, 10^4\ mgm/cm^3$; where t_{10} and t_{50} are the thickness of fabric in millimeters at two different pressures of 10 and 50 grams per sq. cm.
6. Compression modulus (h gm/cm^2): It is a measure of compactness normal to the plane of fabric i.e. softness of fabric. The ratio of stress (difference in pressure) to strain (difference in thickness/original thickness) gives a

Young's modulus' for the material in a direction normal to the surface. It is evaluated from the hardness H.

$h = H \, X \, t_{10}$ grams per sq. cm.

7. Fabric Density (ρ): It is measure of compactness influenced by thread spacing and is related to cover. The density is obtained by dividing the weight in grams per sq. meter (GSM) by the thickness in mm grams per sq. cm pressure.

$\rho = \frac{GSM}{t_{10}}$ mgm per cubic cm. ; where t_{10} is the thickness in mm at .

8. Friction amplitude (F_a): It is the measure of surface roughness. The geometrical mean of the value of frictional amplitude measured from the stick-slip curve in warp and weft direction has been considered for over all roughness of fabric surface. It is obtained in both face as well as the back side of fabric.

Feel of the cloth as appreciated by common people is generally expressed in terms of few parameters such as softness, stiffness, smoothness, fullness etc. All these parameters are considered for the assessment of fabric mechanical comfort characteristic. In subsequent analysis the detailed procedure has been described for evolving various comfort factors for PV blended suiting fabrics.

Ten mechanical parameters obtained through testing of 24 PV suiting fabrics are $E2_1$ N/mm^2, $E2_2$ N/mm^2, Ggm-cm, q kg/cm^2, Eb %, $H10^4$ mgm/cm^3, h gm/cm^2, ρ mg/cm^3, Fa_f gf and Fa_b gf considered for the analysis.

Table 18 Matrix M with fabric mechanical properties for comfort evaluation:

j	1	2	3	4	5	6	7	8	9	10
i	$E2_1$ N/mm^2	$E2_2$ N/mm^2	G gm-cm	q kg/cm^2	Eb %	H 10^4 x mgm/cm^3	h gm/cm^2	ρ mg/cm^3	Fa_f gf	Fa_b gf
A1	195	42	0.162	11.30	2.95	1429	794	491	4.04	4.04
A2	182	74	0.200	19.39	3.98	2000	996	532	4.16	4.20
A3	248	53	0.150	15.78	4.53	1600	776	522	5.01	4.78
A4	229	59	0.094	13.34	2.9	1818	798	533	4.76	4.68
A5	235	55	0.054	11.62	3.1	1143	438	507	4.68	6.56
A6	226	423	0.107	13.97	3.83	1333	603	520	3.54	3.72
A7	277	64	0.096	19.28	2.7	1081	423	537	3.94	4.40
A8	230	83	0.068	24.11	3.13	1481	480	556	6.04	6.08
A9	702	84	0.038	13.37	5.63	1176	382	468	3.13	3.48
A10	255	231	0.083	21.65	1.38	1667	597	609	6.18	5.09
A11	571	61	0.036	19.47	4.18	1176	331	498	5.11	4.14
B1	234	45	0.117	12.19	4	1481	721	499	4.87	4.78
B2	295	40	0.104	11.44	5.05	1333	636	501	4.09	4.13
B3	376	45	0.105	12.99	2.8	1379	633	508	4.19	4.45
B4	255	31	0.101	14.97	3.63	1290	557	528	2.84	2.84
B5	1041	52	0.115	18.16	4.25	1143	485	517	3.14	3.22
C1	371	39	0.088	16.97	4.3	1111	441	534	4.78	6.73
C2	147	162	0.142	20.45	1.13	1212	530	568	5.41	5.49
C3	152	75	0.109	13.88	12.35	1212	552	574	3.81	3.74
C4	190	55	0.100	12.35	5.05	1081	497	585	8.51	7.59
D1	220	44	0.124	17.76	3.03	1481	649	610	5.40	5.82
D2	158	91	0.117	16.01	2.55	1333	592	586	5.73	5.36
D3	181	52	0.080	12.81	4.58	1379	582	552	5.65	6.35
D4	230	99	0.109	14.05	2.9	1481	671	565	3.59	3.16

This produces an original matrices M_{ij}, where i = 24 (no. of fabric samples) and j = 10 (low stress mechanical & surface properties). Arising from the fact that the comparison of properties measured in different measurement units become meaningless, the original matrix has been standardized as

$$M_S = (M_{ij} - E_j)/ V_j ;$$

Where E_j and V_j are the values of mean and variance of j^{th} variable. Then by using Linear Algebra software[65], the n eigen values C_i and the corresponding eigenvectors R_i , i = no. of eigen value of the covariance matrix V_M of standard matrix M_s is obtained. Refer to Appendix I for details of these matrices.

By matrix multiplication a new Feature Matrix M_F = M x R is obtained in which fabric properties are transformed into ten components of the feature matrix.

Table 19. Feature Matrix M_F of the original matrix M

Component Ri	**10**	**9**	**8**	**7**	**1**	**6**	**2**	**3**	**5**	**4**
Eigen values(Ci)	3.20E-08	2.33E-05	9.99E-05	3.53E-05	1300.018	3.65E-04	1.131714	0.214179	0.104971	5.77E-02
Wi	4.96E-06	1.34E-04	2.77E-04	1.65E-04	9.99E-01	5.29E-04	2.95E-02	1.28E-02	8.98E-03	6.66E-03
A1	437	488	-402	401	0.382	473	-11.66	2.49	-21.41	17.58
A2	699	761	-652	652	0.485	521	-12.60	4.74	-27.14	24.44
A3	567	625	-529	529	0.373	501	-13.19	2.34	-24.68	22.87
A4	707	767	-665	665	0.337	515	-13.19	3.77	-24.41	20.30
A5	482	529	-456	456	0.197	488	-14.05	1.54	-19.97	21.50
A6	497	551	-466	466	0.297	567	-11.13	4.18	-25.37	23.08
A7	446	495	-421	420	0.244	515	-12.69	4.03	-24.24	29.04
A8	691	743	-660	659	0.242	541	-15.84	5.33	-27.85	33.09
A9	515	602	-487	486	0.160	415	-9.20	0.61	-21.64	24.11
A10	737	797	-701	701	0.294	618	-15.82	7.71	-30.44	30.96
A11	560	634	-533	532	0.156	451	-12.15	3.04	-24.90	29.62
B1	522	577	-487	487	0.324	478	-12.73	1.69	-22.28	19.36
B2	474	530	-442	441	0.290	474	-11.51	0.33	-21.75	19.85
B3	503	568	-470	469	0.291	475	-12.04	3.02	-22.26	21.24
B4	501	553	-471	471	0.286	502	-10.48	2.56	-23.30	23.86
B5	398	515	-367	364	0.243	428	-9.36	3.24	-24.63	29.61
C1	449	507	-423	422	0.225	500	-14.43	1.64	-22.57	27.68
C2	470	512	-443	442	0.318	574	-15.26	6.31	-26.38	29.39
C3	455	498	-427	427	0.285	564	-11.56	-6.27	-25.26	25.73
C4	399	442	-374	373	0.247	568	-18.38	-0.64	-24.11	23.29
D1	573	627	-539	539	0.331	588	-15.65	3.76	-26.58	27.56
D2	512	557	-482	482	0.308	578	-15.32	3.73	-25.66	25.43
D3	551	598	-520	520	0.262	536	-15.15	0.80	-23.10	22.43
D4	557	611	-522	522	0.325	553	-11.72	3.69	-25.09	22.83

Wi = sqrt(Ci / tr Vm) is the weight of i^{th} component of Y_M where tr Vm = $\sum$ Ci,

For selection of the fabric mechanical comfort factor, correlation coefficients of the components of the feature matrix with the fabric mechanical properties are taken.

Table 20. Correlation coefficients of components of M_F with fabric properties of M :

Ri	10	9	8	7	1	6	2	3	5	4
$E2_1$ N/mm^2	-0.25	-0.08	0.25	-0.25	-0.49	**-0.69**	0.55	0.00	0.17	0.26
$E2_2$ N/mm^2	0.16	0.14	-0.16	0.16	0.05	**0.45**	0.01	0.36	-0.43	0.17
G gm-cm	0.00	-0.02	0.03	-0.03	**0.92**	0.22	0.00	0.14	-0.20	-0.25
q kg/cm^2	0.45	0.47	-0.46	0.46	-0.01	0.30	-0.27	**0.61**	-0.79	**0.91**
Eb%	-0.29	-0.28	0.29	-0.29	-0.14	-0.13	0.28	**-0.90**	0.18	-0.12
H 10^4mgm/cm^3	0.82	0.81	-0.80	0.80	**0.77**	0.24	-0.07	0.39	-0.43	-0.19
h gm/cm^2	0.41	0.38	-0.38	0.38	**0.95**	0.17	0.03	0.16	-0.15	**-0.51**
ρ mg/cm^3	0.25	0.18	-0.26	0.26	0.20	**0.91**	**-0.70**	0.17	-0.71	**0.45**
Fa gf	0.18	0.11	-0.19	0.19	-0.04	0.52	**-0.93**	0.10	-0.33	0.21
Fa gf	0.02	-0.06	-0.03	0.04	-0.16	0.37	**-0.89**	0.01	-0.02	0.14

Values in bold indicate fairly good correlations for determining the comfort factor

From the correlation analysis in table 20 five components of the feature vector having good correlation (in bold) with fabric mechanical properties are chosen. Rest of the eigen vectors either over laps information with these selected vectors or have very poor correlation coefficient to satisfy any relationship with the fabric mechanical properties and are therefore discarded.

These five components of the feature matrix satisfy the condition $\sum_{i=1}^{p} C_i / \mathrm{tr}\, V_M \geq 0.85$, (as discussed in section 2.4.4.4) where $\mathrm{Tr}\, V_M = \sum C_i$ is the trace of the covariance matrix V_M It indicates almost all data of the original matrix M containing fabric properties are covered by these fewer factors. So other factors can be rejected without much data loss. These factors are termed the fabric mechanical comforts factors. They describe the individual comfort property of the cloth more precisely.

Overall comfort value is obtained analytically from these comfort factors using weighted Euclidean distance as discussed in section 2.4.4. Detailed calculation is in appendix I.

Table 21. Over all mechanical comfort of fabric:

Mechanical Comfort factors	Hardness	Extensibility	Smoothness	Shear stiffness	Fullness	
Wi	0.999	5.30E-04	0.0295	0.0128	6.66E-03	$WD_{0M} = \left(\sum_{i=1}^{n}(W_i(Y_{Mi} - 0)^2)\right)^{1/2}$
Y_{Mi} (i =1 ...5)	1	2	3	4	5	
A1	0.382	473	-11.66	2.49	17.58	11.17
A2	0.485	521	-12.60	4.74	24.44	12.36
A3	0.373	501	-13.19	2.34	22.87	11.91
A4	0.337	515	-13.19	3.77	20.30	12.19
A5	0.197	488	-14.05	1.54	21.50	11.61
A6	0.297	567	-11.13	4.18	23.08	13.33
A7	0.244	515	-12.69	4.03	29.04	12.29
A8	0.242	541	-15.84	5.33	33.09	13.05
A9	0.160	415	-9.20	0.61	24.11	9.88
A10	0.294	618	-15.82	7.71	30.96	14.72
A11	0.156	451	-12.15	3.04	29.62	10.87
B1	0.324	478	-12.73	1.69	19.36	11.34
B2	0.290	474	-11.51	0.33	19.85	11.21
B3	0.291	475	-12.04	3.02	21.24	11.27
B4	0.286	502	-10.48	2.56	23.86	11.87
B5	0.243	428	-9.36	3.24	29.61	10.29
C1	0.225	500	-14.43	1.64	27.68	11.98
C2	0.318	574	-15.26	6.31	29.39	13.69
C3	0.285	564	-11.56	-6.27	25.73	13.31
C4	0.247	568	-18.38	-0.64	23.29	13.57
D1	0.331	588	-15.65	3.76	27.56	13.99
D2	0.308	578	-15.32	3.73	25.43	13.73
D3	0.262	536	-15.15	0.80	22.43	12.74
D4	0.325	553	-11.72	3.69	22.83	13.03

Wi = sqrt(Ci / tr Vm) is the weight of i^{th} component of Y_M where tr Vm = $\sum$ Ci

For comparison of fabric samples each comfort factors as well as the over all mechanical comfort value of fabrics are expressed in the percentage ranks on a scale of 0 to 1.

Table 22. Percentage ranks for fabric mechanical comfort:

Fabric code	Hardness	Extensibility	Smoothness	Shear stiffness	Fullness	Overall Mechanical comfort
A1	0.956	0.217	0.826	0.391	0	0.086
A2	1	0.608	0.652	0.739	0.521	0.652
A3	0.913	0.478	0.391	0.26	0.304	0.521
A4	0.869	0.304	0.434	0.565	0.13	0.26
A5	0.086	0.565	0.347	0.347	0.217	0.391
A6	0.521	1	0.869	0.304	0.347	0.782
A7	0.173	0.173	0.565	0.869	0.826	0.478
A8	0.217	0.391	0.13	0.913	1	0.739
A9	0.043	0.043	1	0.043	0.478	0
A10	0.478	0.782	0.086	1	0.956	1
A11	0	0.086	0.608	0.695	0.869	0.173
B1	0.826	0.347	0.478	0.217	0.043	0.217
B2	0.565	0.26	0.782	0.086	0.086	0.13
B3	0.608	0.434	0.695	0.608	0.173	0.304
B4	0.391	0.521	0.956	0.478	0.608	0.434
B5	0.347	0	0.913	0.521	0.782	0.043
C1	0.13	0.13	0.304	0.434	0.739	0.347
C2	0.695	0.826	0.26	0.956	0.913	0.956
C3	0.434	0.695	0.521	0.041	0.565	0.695
C4	0.26	0.913	0	0.13	0.434	0.913
D1	0.782	0.869	0.043	0.782	0.695	0.869
D2	0.652	0.956	0.217	0.826	0.652	0.826
D3	0.304	0.652	0.173	0.173	0.26	0.608
D4	0.739	0.739	0.739	0.652	0.391	0.565

3.4.2. Thermal comfort measurement.

As discussed in section 2.2.3 air permeability largely affects dry heat exchange as well as moisture vapour transfer. Combined with thermal insulation property it governs heat balance of the body providing comfort or causing discomfort. Wicking also plays vital role in wet humid atmosphere when inadequate evaporative heat loss causes sweating. Thus thermal comfort is a complex phenomenon. Test methods explained in section 3.3 measures important fabric thermal properties which include

1. Air permeability (P $m^3/m^2/hr$) – It provides breathing effect through clothing.
2. Thermal insulation (r in clo unit) - In summer it resists outside heat to affect body temperature preventing heat stroke. Winter clothing prevents body heat to escape and provide warmth.
3. Moisture permeability (MVTR in $mgm/hr/cm^2$) –It enable evaporative heat loss from body to prevent sweating.
4. Wicking property: Accumulated sweat from skin is taken away to the outer layer of fabric and spread so that it can escape in the atmosphere. Fabrics wicking performance are assessed by two parameters:

   i) Wicking coefficient wc – It expresses the rate at which water is transported through the fabric capillaries. Higher the value, faster it takes the sweat away from body keeping fabric dry close to skin.

   ii) Fluid filling fraction f – It is a measure of amount of water a fabric can hold. Higher value provides relief to the wearer in case of profuse sweating.

These five parameters measured in section 3.3 for 24 fabric samples are arranged in a matrix T_{ij}, I = 24(no. of fabric samples) and j = 5 (thermal properties) of fabric.

Table 23. Matrix T with fabric thermal parameters:

j = 5 i = 24	P $m^3m^{-2}hr^{-1}$	r clo	MVTR $mgm/cm^2/hr$	wc cm-min-1/2	f
A1	774	0.5	40.42	2.98	1.15
A2	583	0.49	34.39	1.87	0.65
A3	648	0.493	28.65	2.49	0.98
A4	751	0.485	31.7	1.76	0.8
A5	492	0.472	32.64	1.65	0.96
A6	252	0.491	25.16	1.8	0.72
A7	573	0.477	31.42	1.98	0.95
A8	429	0.47	35.79	0.84	1.58
A9	1913	0.475	39.49	1.9	1.5
A10	117	0.477	18.79	0.85	2.26
A11	573	0.472	29.26	0.89	2.27
B1	588	0.501	31.85	1.82	0.8
B2	498	0.498	29.32	1.51	1.05
B3	378	0.494	24.2	2.54	0.78
B4	708	0.486	39.81	2.21	1.15
B5	405	0.494	34.91	1.61	1.21
C1	478	0.486	27.96	0.81	1.23
C2	166	0.481	26.47	1.39	1.53
C3	157	0.487	32.32	1.33	1.21
C4	212	0.491	17.52	0.84	2.4
D1	288	0.481	33.76	1.58	0.87
D2	181	0.479	32.33	0.91	1.3
D3	335	0.485	31.9	1.07	1.64
D4	206	0.486	21.34	1.57	1.69

Transformation of the matrix T in a similar way as explained above in the analysis of the mechanical comfort, gives feature matrix T_F in which thermal properties are replaced by the components of the feature matrix.

Table 24. Feature Matrix T_F of the matrix T: (Detailed analysis in Appendix II)

R_i	**5**	**4**	**1**	**3**	**2**
Ci	**3.90E-06**	**1.81E-02**	**12019**	**1.14**	**4.19**
Wi	**1.805E-05**	**0.0012**	**0.99**	**0.0097**	**0.019**
A1	-774	-46.90	0.510	-4.40	2.75
A2	-583	-39.27	0.496	-2.93	2.22
A3	-648	-34.08	0.501	-3.62	2.06
A4	-751	-38.02	0.489	-3.05	1.99
A5	-492	-36.77	0.474	-2.80	1.72
A6	-252	-27.24	0.497	-2.46	1.57
A7	-573	-36.22	0.482	-3.14	1.89
A8	-429	-39.42	0.461	-2.43	0.87
A9	-1913	-55.71	0.472	-4.81	2.35
A10	-117	-19.80	0.466	-2.29	-0.57
A11	-573	-34.14	0.459	-2.91	0.10
B1	-588	-36.78	0.505	-2.94	1.96
B2	-498	-33.51	0.499	-2.70	1.43
B3	-378	-27.33	0.505	-3.23	1.94
B4	-708	-45.75	0.490	-3.68	2.27
B5	-405	-38.30	0.494	-2.84	1.55
C1	-478	-32.01	0.480	-2.17	0.83
C2	-166	-27.85	0.478	-2.49	0.69
C3	-157	-33.61	0.486	-2.33	1.17
C4	-212	-19.35	0.479	-2.44	-0.71
D1	-288	-36.15	0.483	-2.50	1.71
D2	-181	-33.84	0.474	-2.05	0.88
D3	-335	-34.73	0.478	-2.52	0.73
D4	-206	-23.07	0.484	-2.70	0.45

Wi = sqrt(Ci / tr V_T) is the weight of i^{th} component of Y_T where tr $V_T = \sum$ Ci,

Three factors are identified based on their correlation coefficient (in bold) with fabric thermal properties.

R_i	5	4	1	3	2
P $m^3m^{-2}hr^{-1}$	-1.00	**-0.80**	0.04	-0.85	0.57
r clo	0.08	0.07	**0.91**	-0.16	0.33
MVTR mgm/cm^2/hr	-0.58	**-0.95**	0.13	-0.54	**0.73**
wc cm-min-1/2	-0.41	-0.43	**0.77**	-0.75	**0.83**
F	0.15	0.37	**-0.68**	0.19	**-0.84**

Three thermal comfort factors are identified to represent permeability, thermal insulation and wicking property of fabrics. The overall thermal comfort is then obtained from these three factor using Weighted Euclidean Distance concept. It represents over all thermal comfort of the fabric. (Detailed matrices analysis is included in appendix II.)

Table 25. Thermal comfort factors.

Thermal comfort factors	Permeability factor	Insulation factor	Wicking factor	$WD_{0T} = \left(\sum_{i=1}^{n} \left(W_i (Y_{Ti} - 0)^2 \right) \right)^{1/2}$
Wi	0.001228	0.999778	0.018674	
Y_{Ti} (i =1 ,2, 3)	1	2	3	
A1	-46.90	0.510	2.75	1.76
A2	-39.27	0.496	2.22	1.49
A3	-34.08	0.501	2.06	1.33
A4	-38.02	0.489	1.99	1.44
A5	-36.77	0.474	1.72	1.39
A6	-27.24	0.497	1.57	1.10
A7	-36.22	0.482	1.89	1.38
A8	-39.42	0.461	0.87	1.46
A9	-55.71	0.472	2.35	2.03
A10	-19.80	0.466	-0.57	0.84
A11	-34.14	0.459	0.10	1.28
B1	-36.78	0.505	1.96	1.41
B2	-33.51	0.499	1.43	1.29
B3	-27.33	0.505	1.94	1.11
B4	-45.75	0.490	2.27	1.70
B5	-38.30	0.494	1.55	1.45
C1	-32.01	0.480	0.83	1.23
C2	-27.85	0.478	0.69	1.09
C3	-33.61	0.486	1.17	1.28
C4	-19.35	0.479	-0.71	0.84
D1	-36.15	0.483	1.71	1.38
D2	-33.84	0.474	0.88	1.28
D3	-34.73	0.478	0.73	1.31
D4	-23.07	0.484	0.45	0.94

Wi = sqrt(Ci / tr Vm) is the weight of i^{th} component of Y_T where tr $V_T = \sum Ci$,

WD_{T0} is the Weighted Euclidean Distance of the fabric from real origin i.e. zero co-ordinates. Lesser the difference in WD_{T0} value of two fabrics, closer the fabrics are with reference to their thermal comfort.

Assigning percentage ranks in the scale of 0 to 1 for Thermal comfort , fabric are compared in Table 26.

Table 26. Percentage ranks of fabric samples for thermal comfort:

Fabric code	Permeability factor	Insulation factor	Wicking factor	Overall Thermal comfort
A1	0.043	1	1	0.956
A2	0.173	0.739	0.913	0.869
A3	0.521	0.869	0.869	0.478
A4	0.26	0.608	0.652	0.739
A5	0.347	0.13	0.565	0.652
A6	0.869	0.782	0.478	0.13
A7	0.391	0.434	0.695	0.608
A8	0.13	0.043	0.304	0.826
A9	0	0.217	0.739	1
A10	0.956	0.086	0.043	0.043
A11	0.565	0	0.086	0.304
B1	0.304	0.956	0.782	0.695
B2	0.695	0.826	0.434	0.434
B3	0.826	0.913	0.826	0.217
B4	0.086	0.652	0.956	0.913
B5	0.217	0.695	0.521	0.782
C1	0.739	0.391	0.173	0.26
C2	0.782	0.26	0.217	0.173
C3	0.652	0.565	0.391	0.391
C4	1	0.304	0	0
D1	0.434	0.521	0.608	0.565
D2	0.608	0.173	0.347	0.347
D3	0.478	0.347	0.26	0.521
D4	0.913	0.478	0.13	0.086

Results of this objective technique of determining the fabric mechanical and thermal comfort are then used to develop a computer software to readily evaluate fabric comfort without going through the rigorous mathematical calculations. From the regression equations obtained in appendix I and II, fabric mechanical and thermal comfort factors can be obtained from fabric properties enlisted in table 18 (Mechanical properties) and table 23 (thermal properties). And the over all mechanical and Thermal comfort value is obtained by regression equation of these predicted values of comfort factor with the WD_0 value calculated in table 21 and table 25 .(see appendix). Regression equations for prediction of fabric comfort are structured in a software FabCOM – fabric comfort by objective measurements, discussed in results and discussions.

The software compares two fabric samples for their mechanical and/or thermal comfort character and ranks the fabrics for their comfort factors.