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Evaluation of Tactile Comfort of Mulberry Silk Waste and Viscose Blended Knitted Fabrics by using Kawabata Evaluation System (KES) for Apparel Use

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Authors' contributions

This work was carried out in collaboration between both the authors. Authors Shikha Bajaj and Sandeep Bains designed the study. Author Shikha Bajaj performed the statistical analysis. Author Sandeep Bains wrote the protocol. Author Shikha Bajaj wrote the first draft of the manuscript and managed the analyses of the study. Author Sandeep Bains managed the literature searches. Both the authors read and approved the final manuscript.

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ABSTRACT

Tactile sensations are among the first parameters, which play an important role in guiding a consumer's decision while selection of fabric. In the present investigation, hand properties of knitted fabrics were studied. Attempt was made on four knitted fabrics, blended in proportions of 50% mulberry silk: 50% viscose and 40% mulberry silk: 60% viscose, each in two unequal counts. Objective assessment of the fabrics has been carried out in order to obtain the scores on various aspects of hand. Parameters like low stress mechanical and surface properties were chosen for experimental design. Blended knitted fabrics were subjected to tests for prediction of tensile, shear, bending, surface and compression properties. The results could bring about the useful data for design and production of ideal fabric having desirable handle. It was witnessed that knitted fabric blended in proportion of 50% mulberry silk: 50% viscose in 20 Nm yarn count carried finest hand properties with total hand value of 3.49; hence same was recommended for apparel use, commercial handling and production.

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1. INTRODUCTION

Textile industry in India has been a leading trade [1] which has witnessed immense progress in the field of fibres and structures in last two decades. A huge range of novel fabric materials and with varied properties has been developed. Smart textiles with boundless possibilities have come into picture, which assure comfort and contentment of the consumer, however, this in turn has increased experimentation complexities [2]. Creating clothes that work with the human form is a complicated task that needs extensive testing and evaluation [3]. Textile materials are to be tested for their performance and comfort parameters so as to suit with the consumer needs. Apart from other performance characteristics, fabric hand is an important parameter for any fabric which largely determines its use and application. As the name itself implies, fabric hand is related to the feel of the material (Angappan and Gopalkrishnan 1997). Pan [4] defined fabric hand or handle as human tactile sensory response towards fabric, which involves physical, psychological, perceptional and social factors. McLoughlin and Sabir [5] reported that fabric hand is sum total of sensations expressed when fabric is handled by touching, flexing of fingers, smoothing and so on. As mentioned by Dawes and Owen [6], the most significant of these sensations are thickness, softness. stiffness, and toughness of fabrics. Fabric hand is one such property of textile materials which has been lesser addressed in the past and in majority of the cases, subjective evaluation of the same has been carried out. According to Das, et al. [7], since the subjective methods are easily influenced by the person's perception and attitude, the objective method is more suitable for evaluation of fabric hand.When measured objectively, sensations for stiffness, limpness, hardness or softness, roughness or smoothness are made use of Kayseri et al. [8]. Kawabata evaluation system has been widely used in textile industry for determination of fabric hand properties [9]. This evaluation system can be utilized to obtain pertinent data of use for quality control, product development and product specification for various fabrics [10]. By using this method, fabric mechanical property parameters are converted to numbers (the hand value or HV) that express three primary hand values which are the constitutional aspects characterizing fabric hand. These hand values are converted into a total fabric quality number or the total hand value (THV) which well describes the subjective hand [11]. McLoughlin and Sabir (1971) were of the view that each of the mechanical properties corresponds to a sensitivity which man detects sensorily regardless of the extent of the sensitivity. Kawabata Evaluation System administers a unique capability, not only to anticipate human response, but also to bring about an understanding of how the variables of fiber, yarn, fabric construction and finish contribute to the concept of softness [12]. In the present study, authors have intended to evaluate fabric hand of blended knitted fabrics. Low stress mechanical and surface properties of fabrics have been determined by using Kawabata evaluation system. According to this method the fabric handle is calculated from measurement of tensile, bending, shearing, compression and surface properties.

2. MATERIALS AND METHODS

2.1 Test Fabrics

Four types of fabrics were knitted by using blended yarns of two different yarn counts, each in two different blending proportions *viz*. 50% mulberry silk: 50% viscose and 40% mulberry silk: 60% viscose. Blended knitted fabrics were utilized for present course of experimentation.

2.2 Fibre Characteristics

Fibres were washed in soft water and dried at room temperature for 48 hours. Mulberry silk waste fiber with linear density 1.87 denier and cut length 130.667 was blended with viscose tops exhibiting linear density 3.96 denier and cut length 139.789 mm (Table 1).

2.3 Development of Blended Yarns

A worsted spinning system was used to blend mulberry silk waste and viscose fibre. Yarns were developed in two different counts. Mulberry silk waste was opened properly by hand and then was fed into carding machine. Further to this, the fibres were blended using gillbox. At this step, fibres were blended in two different ratios of 50:50 and 40:60. After this, drawing procedure was carried out. Sheikhi, et al. (2012) also used gill box machinery for blending of acrylic fibres with varying fineness. Since, twist per inch is a parameter that influences output behavior of yarns, it was viewed as being held constant. Variables are viewed as changing while parameters typically either don't change or change more slowly (Nykamp, 2012), therefore, all the yarns were incorporated with same amount of twist (10 twists per inch).The developed yarn cones weighed 50 g each. Yarn characteristics have been depicted in Table 2.

2.4 Construction of Knitted Fabrics

Table 3 elucidates structural parameters of blended knitted fabrics. Yarn densities, tightness factor and fabric thickness for blended knitted fabrics have been determined. It is apparent from the results depicted that thickness of fabric S_1 and S_3 was more than that of fabric S_2 and S_4. The reason for this difference was the difference in yarn counts of yarns used for knitting the fabrics. S_1 and S_3 was knitted by using a thicker yarn (15 Nm) as compared to S_2 and S_4 (20 Nm) thus carries more thickness. Maximum tightness factor was calculated for fabric S3, however, there was no significant difference found among the values for all the fabrics.

2.5 Methods

The fabric handle or sense was evaluated by using Kawabata Evaluation System. The Kawabata Evaluation System (KES) carries five highly sensitive instruments that measure fabric bending, shearing, tensile and compressive stiffness, as well as the smoothness and frictional properties of a fabric surface [12]. A specimen of 20 x 20 cm fabric was used for testing. Fabrics were subjected to Kawabata testing in both wale-wise and course-wise directions for all the parameters except compression.

- Tensile testing: Test specimen was clamped between two jaws and subjected to a constant force of 10 gf/cm in one direction (wale-wise or course-wise). Force was applied by a weight which was fixed to the drum on which one jaw was mounted.
- Shear: Stability of fabric to withstand in plane mechanical distortion was measured at 0.5º and 5º shear angles.
- Bending: Test specimens were bent between the curvatures –2.5 and +2.5cm^{-1}.
- Surface: The parameter was measured by using a sensor which simulates human finger. A load of 50 gf was applied on the mounted swatch and coefficient of friction was calculated. Geometrical roughness was also determined under this category.
- Compressional properties: The sample was placed between two plates and pressure was increased continuously 0.5 to 50 gf /c^{m2}. The impact of pressure was measured on an area of 2 cm^2.

Table 1. Physical parameters of mulberry silk waste and viscose fibre

Physical parameters	Mulberry silk waste	Viscose
Fibre length (cm)	130.667	139.789
Fineness (denier)	1.87 ± 0.045	3.96 ± 0.119
Fibre diameter (microns)	12.73 ± 0.226	27.46 ± 0.364

Table 2. Physical properties of blended yarns

Yarn density (Nm)	Blended ratio	Twist per inch (TPI)	Unevenness percentage (U %)
15	50% mulberry silk: 50% viscose	10	25.10
15	40% mulberry silk: 60% viscose	10	23.78
20	50% mulberry silk: 50% viscose	10	28.12
20	40% mulberry silk: 60% viscose	10	24.94

Table 3. Structural description of knitted fabrics

Fabric code	Knitted structure	Wales per inch x Courses per inch (WPI x CPI)	Stitch density (square inch)	Tightness factor	Fabric thickness (mm)
S_1	Single jersey	14 x 19	266	4.533^a± 0.002	0.763^b ± 0.012
S_2	Single jersey	14 x 20	280	4.532^a± 0.002	0.663^a ± 0.012
S_3	Single jersey	14 x 20	280	4.534^a ± 0.003	0.883^c ± 0.024
S_4	Single jersey	14 x 18	252	4.529^a ± 0.000	0.703^b ± 0.003
		Critical difference	5.07	NS	0.102

[a,b,c] Significant at 5 % level of significance, same alphabet= no significant difference, different alphabet= significant difference, CD= Critical difference, NS= Not significant

Table 4. Measurement parameters for Kawabata evaluation of blended knitted fabrics

Properties	Parameter
Bending	B, 2 HB
Compression	LC, WC, RC
Shear	G, 2HG, 2HG5
Surface	MIU, MMD, SMD
Tensile	LT, WT, RT, EMT

B- Bending Rigidity, 2 HB- Bending Moment
LC- Linearity of compression, WC- Compressional energy, RC-Compression resilience
G- Shear rigidity, 2 HG, 2HG5- Hysteresis of shear force at 0.5^o and 5^o
MIU-Coefficient of friction of fabric surface, MMD-Mean deviation of coefficient of friction, SMD-Geometrical Roughness, LT- Tensile Linearity, WT-Tensile Energy, RT- Tensile Resilience, EMT- Tensile Extension

The KES instrument provides direct value of primary handle value and total handle value. Total hand value is the final judgement of fabric sensation which was calculated by using linear regression equation with the help of various primary handle values. Knitted fabrics were tested for total handle value using Kawabata evaluation system instrument, which converts the results into numerical values. Measurement parameters for objective evaluation of fabrics have been depicted in Table 4.

Kawabata evaluation was carried out for all the developed fabrics. The scales which were used for evaluation are as follows:

Hand value of Primary Hand (HV)

Hand value	Feeling grade
10	The strongest
5	Medium
1	The weakest
0	No feeling
Total hand value (THV)	
Total hand value (THV)	**Feeling grade**
5	Excellent
4	Good
3	Average
2	Fair
1	Poor
0	Not useful

3. RESULTS AND DISCUSSION

The knitted fabric construction was carried out by yarn blends of 50% mulberry silk: 50% viscose and 40% mulberry silk: 60% viscose, in both 15 Nm and 20 Nm yarn counts. Amount of twist was kept constant for all the yarns (10 twists per inch). All the fabrics were knitted in plain jersey structure.

Developed knitted fabrics were assigned codes for ease of discussion and understanding (Table 5). Fabric knitted in 50% mulberry silk: 50% viscose yarn and 15 Nm count was called S_1 and fabric made in 40% mulberry silk: 60% viscose in the same count was assigned code S_3. In case of 20 Nm yarn count, codes S_2 and S_4 were the assigned to fabrics with 50% mulberry silk: 50% viscose and 40% mulberry silk: 60% viscose respectively.

Data pertaining to low stress mechanical and surface properties have been furnished in Table 6. Loading unloading graphs for tensile parameters, have been depicted Figs. 1 a, b, c and d (wale-wise) and 2 a, b, c and d (course-wise).

3.1 Tensile Properties

3.1.1 Tensile Linearity (LT)

Wearing comfort of the fabric is defined by linearity of tensile property. Lesser value of LT is an indication of higher extensibility in initial strain, range indicating better comfort but dimensional stability of the fabric lowers down. Wale-wise tensile linearity was highest in case of fabric S_3, followed by fabrics S_1, S_2 and S_4. In the direction of courses, highest tensile linearity was calculated for fabric S_1. Second in order was fabric S_3. Fabric S_2 and S_4 obtained least values for tensile linearity.

3.1.2 Tensile Energy (WT)

The toughness of the fabric reflected in mobility of a garment under deformation is indicated by tensile energy. Highest value for tensile energy was obtained by fabric S_1 in the direction of wales. Second in order was fabric S_3 followed by fabrics S_4 and S_2. Regarding course-wise direction, fabric S_4 scored the highest value for tensile energy, while fabric S_2 earned the lowest value. Tensile energy was found to be higher in course-wise direction for all the four fabrics.

3.1.3 Tensile Resilience (RT%)

This property indicates recovery after tensile deformation. In the present investigation, course-wise tensile resilience was found to be more for all the fabrics. Same can be clearly visualized in Figs. 1 a, b, c, d and 2 a, b, c, d, where the line showing after deformation behavior has very less gap from the line showing deformation in case of course-wise direction, in comparison to wale-wise direction. It was highest in case of fabric S_3 followed by fabrics S_2, S_4 and S_1. In case of wale-wise direction, fabric S_2 exhibited the highest value for tensile resilience, while fabric S_1 scored the lowest value for tensile resilience.

Table 5. Coding of developed fabric proportions

Blending proportion	Yarn count (Nm)	Code assigned
50% mulberry silk: 50% viscose	15	S_1
50% mulberry silk: 50% viscose	20	S_2
40% mulberry silk: 60% viscose	15	S_3
40% mulberry silk: 60% viscose	20	S_4

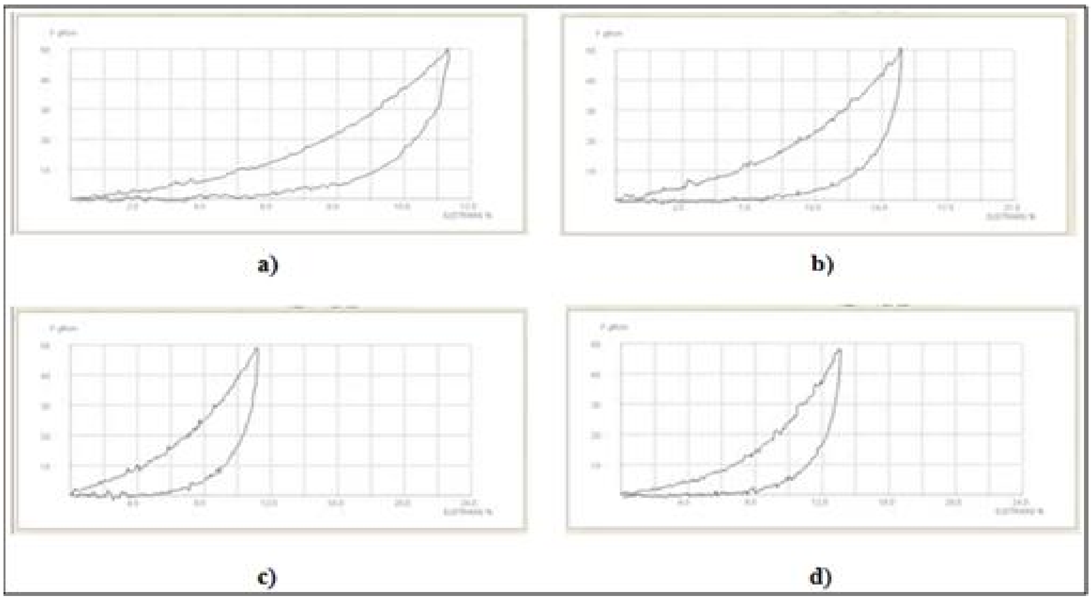

Fig. 1. Tensile behavior of fabrics in wale-wise direction, a) S_1, b) S_2, c) S_3 and d) S_4

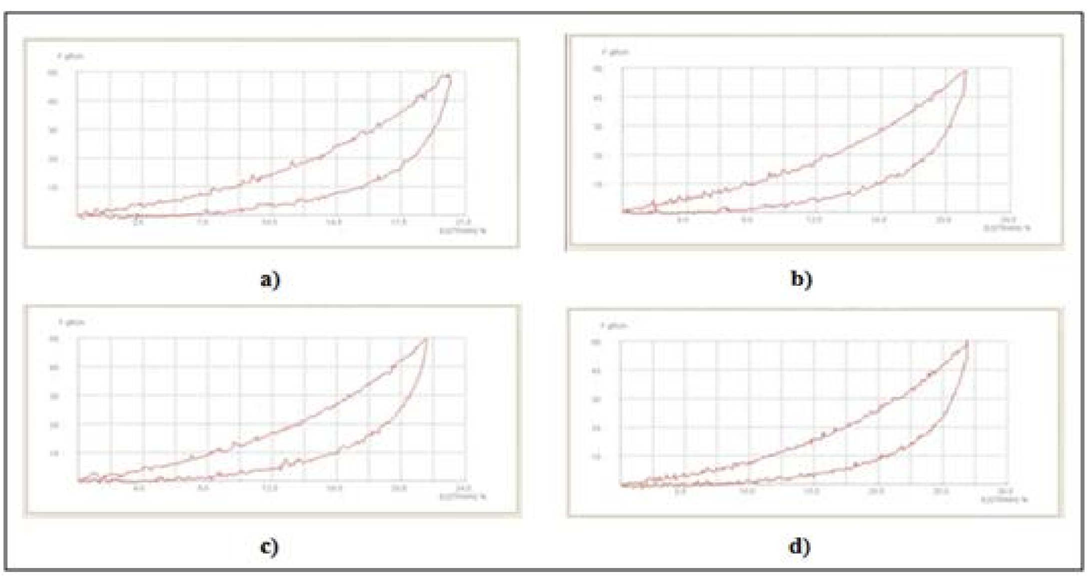

Fig. 2. Tensile behavior of fabrics in course-wise direction, a) S_1, b) S_2, c) S_3 and d) S_4

3.1.4 Tensile extension (EMT%)

This value determines low stress extensibility and is related to crimp removal process during tensile loading. In wale-wise direction, maximum tensile extension was exhibited by fabric S_1, followed by fabrics S_4 and S_2. Least tensile resilience was shown by fabric S_3. Nazar, et al. [13] reported that a hike in the fabric tightness factor significantly decreases tensile extensibility. It can be observed that greater tensile extension was found in course-wise direction for all the four fabrics. Dumitriu [14] also found greater extensibility in course direction during her study. According to Gordon and Hsieh [15], when tensile loading is applied to the fabric, the yarn within the structure moves until it jams and then the yarn elongates until it breaks. Under an applied load, plain knitted fabric has lesser elongation in the wale-wise direction than in course-wise direction because wale-wise jamming occurs sooner than course-wise jamming.

3.2 Shear Properties

The shear behavior of a fabric can be determined by two shear parameters: shear rigidity and shear hysteresis.

3.2.1 Shear rigidity (G)

Shear rigidity determines fabric stiffness or softness. Fabric with low shear rigidity will distort easily, will be difficult to lay up, mark and cut, whereas, a high value of shear rigidity tells that a fabric is difficult to mould [16]. It is a crucial property for which decides drape and pliability of the fabric [17].

The shear curve was plotted with force in gf/cm on Y-axis and shear angle in degrees on the X-axis. The shear stiffness G was obtained from the slope of the hysteresis between 0.5º and 5º. 2HG and 2HG5 were calculated on the curve for 0.5º and 5º respectively. The amount of shear force loss was considered for 2H1G and 2HG5. The average of 2HG values at 0.5º and 0.5º gives the actual shear hysteresis [18].

Data pertaining to shear rigidity values reveal in wale-wise direction, fabric S_3 had highest shear rigidity value. As regards, to course-wise direction, fabric S_1 secured maximum shear rigidity value followed by fabrics S_3, S_2 and S_4. Fabrics S_1 and S_3 obtained higher values due to their more compact structure in comparison to fabrics S_2 and S_4 as the yarn used in fabrics $S_1$and S_3 was thicker than that of fabrics S_2 and S_4. An increase in the fabric tightness factor significantly increased fabric thickness, shear rigidity (Table 6) and hysteresis (Figs. 3 a, b, c and d and 4 a, b, c and d) [13]. Apart from this, higher yarn densities in fabric S_1 and S_3 have lead to higher value of shear rigidity. Penava et al. during their study [19] concluded that more compact structure, higher thickness and larger yarn densities bring about higher values for shear rigidity.

3.2.2 Hysteresis of shear force at 0.5º (2HG) and 5º (2HG5)

Shear hysteresis is the energy loss when the direction of shear is reversed within a shear deformation cycle. This is due to the fact that when a fabric is sheared, most or the force expended is used in overcoming the frictional forces. Shear hysteresis can be related to various handle properties such as crispness, scroopiness and how noisy the fabric is when handled. There is a strong linear relationship, between shear rigidity and shear hysteresis [16].

For 2 HG, Highest value was obtained by fabric S_1 in the direction of wales. Second on order was fabric S_3, followed by fabrics S_2 and S_4. Regarding course wise direction, fabric S_1 scored the highest value as well. Fabric S_4 earned the lowest value. Regarding 2HG5, wale-wise had highest value in case of fabric S_1 with a value, followed by fabrics S_3, S_2 and S_4. In the direction of courses, highest figure was calculated for fabric S_1. Second in order was fabric S_3. Fabric S_2 and S_4 obtained least values in this case as well. For course-wise direction also, fabrics S_1 and S_3 exhibited higher values in comparison to fabrics S_2 and S_4. This also occurred due to utilization of higher yarn counts for knitting of these fabrics. Lindnerg, et al. [20] opined that the mechanics of shear were largely given over to geometric construction of the fabric. Tight fabric structures, close to the jammed condition will behave elastically, whereas, loose fabric's behavior is more dependent on the frictional resistance between the yarns and thus will not recover to much extent after shear force was applied.

3.3 Bending Properties

3.3.1 Bending rigidity (B)

Bending rigidity is dependent on bending rigidity of yarns and their mobility. In wale-wise direction, it was highest in case of fabric S_1 followed by fabrics S_3, S_2 and S_4. In case of course-wise direction, fabric S_1 exhibited the highest value for bending rigidity, while fabric S_4 scored the lowest value. With a very small difference, it is clear from the data, that bending rigidity was found to be more in fabrics S_1 and S_3 than for fabrics S_2 and S_4, for both wale-wise and course-wise. The reason for this can be understood by mentioning that both the fabrics S_1 and fabric S_3 have compact structure because of thicker yarn. Due to this, mobility of the yarns is less. According to Dhingra and Postle [21], thickness or fineness of yarn puts a considerable impact on bending rigidities of fabrics. With finer yarn, fibres have a considerable degree of freedom of movement, whereas, for thicker yarn, this in turn changes into the friction among the fibres, which hinders bending. The higher the tex (higher thickness), higher is the stiffness of yarn. Nazar, et al. [13] reported that a rise in the fabric tightness factor significantly increases fabric thickness, bending rigidity and hysteresis (Figs. 5 a, b, c, d and 6 a, b, c, d).

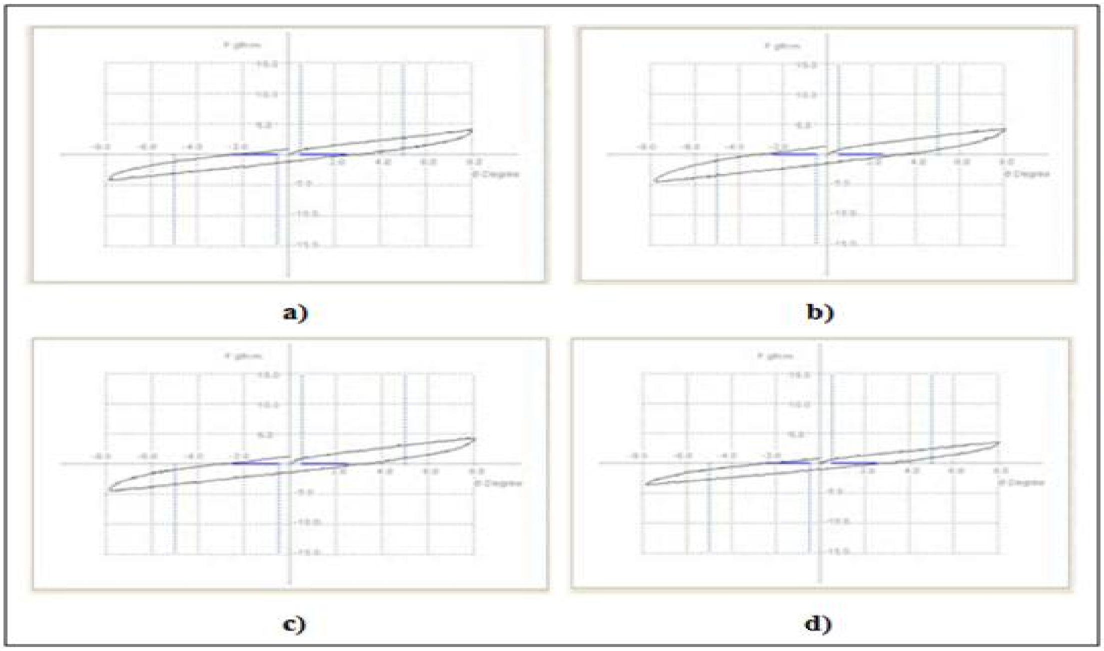

Fig. 3. Shear behavior of fabrics in wale-wise direction, a) S_1, b) S_2, c) S_3 and d) S_4

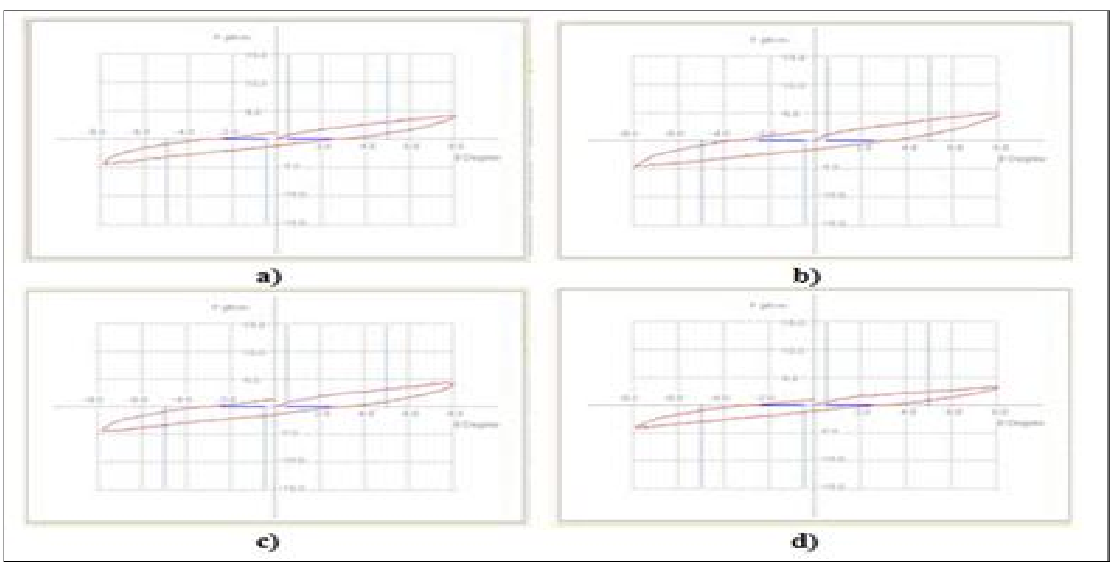

Fig. 4. Shear behavior of fabrics in course-wise direction, a) S_1, b) S_2, c) S_3 and d) S_4

Table 6. Evaluation of low stress mechanical properties for developed knitted fabrics

Properties		S_1		S_2		S_3		S_4		CD	CD
		Wales wise	Course wise	Wales wise	Course wise	Wales wise	Course wise	Wales wise	Course wise	Wales wise	Course wise
Tensile properties	LT	0.696	0.714	0.629	0.705	0.731	0.708	0.618	0.680	0.027	0.027
	WT (gf.cm/cm^2)	2.41	3.78	1.83	3.50	1.99	3.72	1.87	4.40	0.093	0.223
	RT %	26.25	39.36	35.77	40.57	29.15	41.74	32.18	40.12	1.367	NS
	EMT %	13.90	21.15	11.65	19.85	10.90	21.05	12.10	25.90	0.552	0.827
Shear properties	G (gf/cm.deg)	0.48	0.56	0.44	0.49	0.49	0.54	0.42	0.44	0.002	0.452
	2HG (gf/cm)	2.60	2.85	2.00	2.13	2.32	2.31	1.83	1.81	1.902	1.101
	2HG5 (gf/cm)	2.45	2.64	1.90	2.07	2.25	2.41	1.72	1.79	0.033	0.067
Bending properties	B (gf.cm^2/cm)	0.0562	0.0345	0.0410	0.0317	0.0540	0.0301	0.0295	0.0209	0.045	0.002
	2HB (gf.cm/cm)	0.0617	0.0429	0.0402	0.0451	0.0572	0.0391	0.0318	0.0203	1.123	0.750
Surface properties	MIU	0.245	0.194	0.270	0.286	0.254	0.253	0.259	0.241	0.003	1.902
	MMD	0.0221	0.0182	0.0220	0.0213	0.0226	0.0199	0.0262	0.0163	NS	0.003
	SMD (μm)	13.43	13.09	13.42	13.72	12.56	13.01	12.58	13.42	0.034	NS
Compression properties	LC	0.563		0.536		0.563		0.450		0.017	
	WC (g.cm/cm^2)	0.146		0.123		0.164		0.131		0.034	
	RC %	42.62		44.85		39.32		44.51		1.452	
Fabric thickness	(T_0 mm)	1.595		1.410		1.680		1.387		1.035	
Fabric weight	(mg/cm^2)	18.80		17.31		18.68		12.90		2.801	

Results significant at 5 % level of significance, CD: Critical difference, NS: Not significan

Apart from this, course-wise rigidity was found to be lesser than that of wale-wise direction. The slope of force extension curve in course-wise direction is lower than wale-wise direction for all the four knitted fabrics (Figs. 5 a, b, c and d and 6 a, b, c and d). Since elongation is more in course-wise direction, bending rigidity is lower when courses are bent [22].

3.3.2 Bending moment (2HB)

This property determines the hysteresis of bending moment that is a measure of recovery from bending deformation.

Table 6 elucidates that bending moment in wale-wise direction was highest for fabric S_1. This was due to higher rigidity and more oriented microscopic structure of silk fibre in comparison to viscose fibre. Fabric S_3 was placed second. Thickness of yarn and tight structure have led to more rigidity and higher bending recovery. Fabrics S_2 and S_4 scored lowest figures in this case. As regards to course-wise direction, fabric S_2 secured maximum shear rigidity value, followed by fabrics S_1, S_3 and S_4. It is revealed from the data that wale-wise bending moment was more than in course-wise in case of all the fabrics. Since there is a linear relationship between bending rigidity and bending moment in knitted fabrics [23], values of bending moment were apt to be more in wale-wise direction, as it was the case for bending rigidity.

3.4 Surface Properties

Surface properties of a fabric affect its handle, comfort and aesthetic properties. Figs.7 a, b, c and d and 8 a, b, c and d present the findings in graphical form.

3.4.1 Coefficient of friction of fabric surface (MIU)

It is evident from Table 6 that in wale-wise direction, fabric S_2 obtained the maximum MIU followed by fabrics S_4 and S_3. Lowest value was obtained for fabric S_1. In case of course-wise direction, highest figure was computed for fabric S_2, followed by S_3, S_4 and S_1 with MIU values. Since smoother surfaces have higher coefficient of friction in order to slide apart [24], it is clear from the findings that fabric S_2 was smoothest of all. Higher silk content in fabric S_1 might have led to lower smoothness. In case fabric S_2, having same amount silk as fabric S_1, the impact of finer yarn keyed up and a higher value of coefficient of friction was obtained. Since none of the computed value was found too high, it was understood that all the four knitted fabrics were having optimum smoothness.

3.4.2 Mean deviation of coefficient of friction (MMD)

The value of MMD indicates the variation found in MIU. In the direction of wales fabric S_3 fabric exhibited the highest variation among all the fabrics. Second on order was fabric S_4, followed by fabrics S_1 and S_2. Regarding course-wise direction, highest variation was computed for fabric S_2, followed by fabrics S_3, S_1 and S_4.

3.4.3 Geometrical roughness (SMD)

Data pertaining to geometrical roughness of fabric has been furnished in Table 6. It can be observed that fabric S_1 obtained the highest value for geometrical roughness in the direction of wales, whereas, fabrics S_2, S_4 and S_3 obtained lesser values for geometrical roughness. In course-wise direction, highest geometrical roughness was calculated for fabric S_2, followed by fabrics S_4, S_1 and S_3. Findings reveal that fabrics S_1 and S_2 had slightly higher geometrical roughness in comparison to fabrics S_3 and S_4 in both the directions. This was because of higher silk content in fabrics S_1 and S_2. Since silk waste has been used for present study, slight roughness was noticed in fabrics. A similar trend was observed by Verma [25] where higher geometrical roughness was determined for fabrics woven by using silk waste. Apart from this, higher tightness factor of fabric S_3 has led to decrease in geometrical roughness.

3.5 Compression Properties

3.5.1 Linearity of compression (LC)

This property depends on thickness of fabric and compressional characteristic of yarn. The compressibility gives a feeling of bulkiness and spongy property to the fabric [26]. Fabrics S_1 and S_3 were found to be equally compressible as both of these exhibited same amounts of linearity of compression. Higher compressibility was observed in these fabrics as compared to fabrics S_2 and S_4 due to higher fabric thickness. Fabric S_4 exhibited least amount of compressibility. The hysteresis loss (Fig. 9 a, b, c and d) happened due to friction in the fibres [27].

3.5.2 Compressional energy (WC)

Value of compressional energy also rises with rise in thickness of fabric. The results are exactly in accordance with the findings of fabric thickness. Highest amount of compressional energy was calculated for fabric S_3 followed by fabrics S_1, S_4 and least value was attained by fabric S_2. As mentioned by Nayak et al. [28], when fibre to fibre slippage increases energy required to compress the fabric decreases.

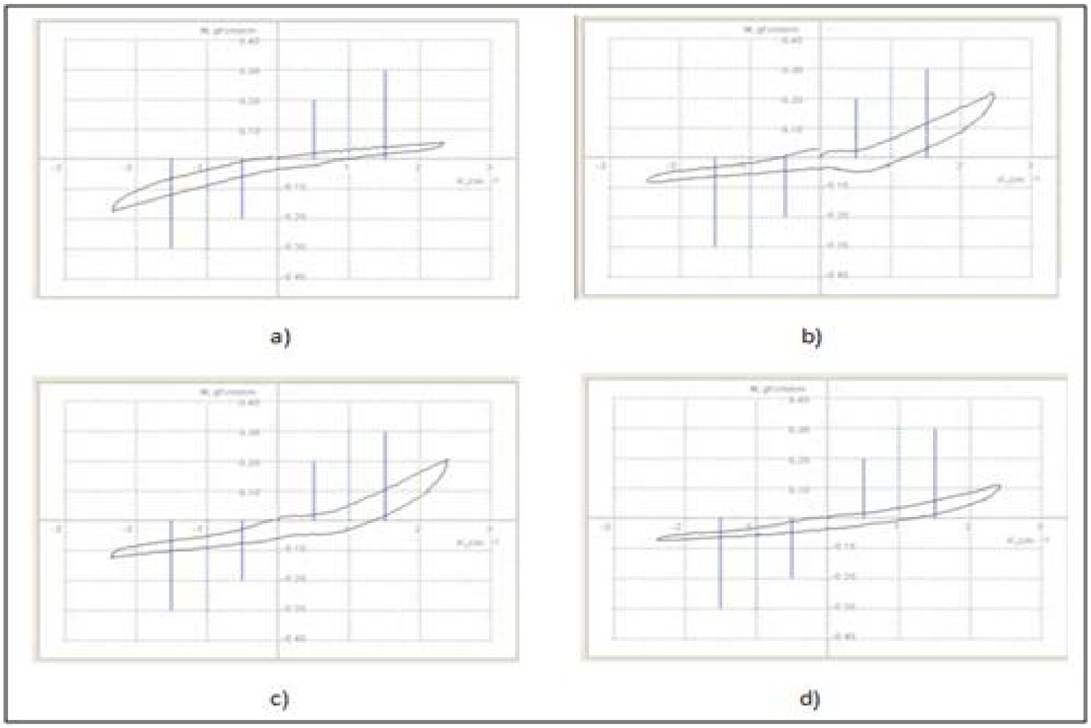

Fig. 5. Bending performance of fabrics in wale-wise direction, a) S_1, b) S_2, c) S_3 and d) S_4

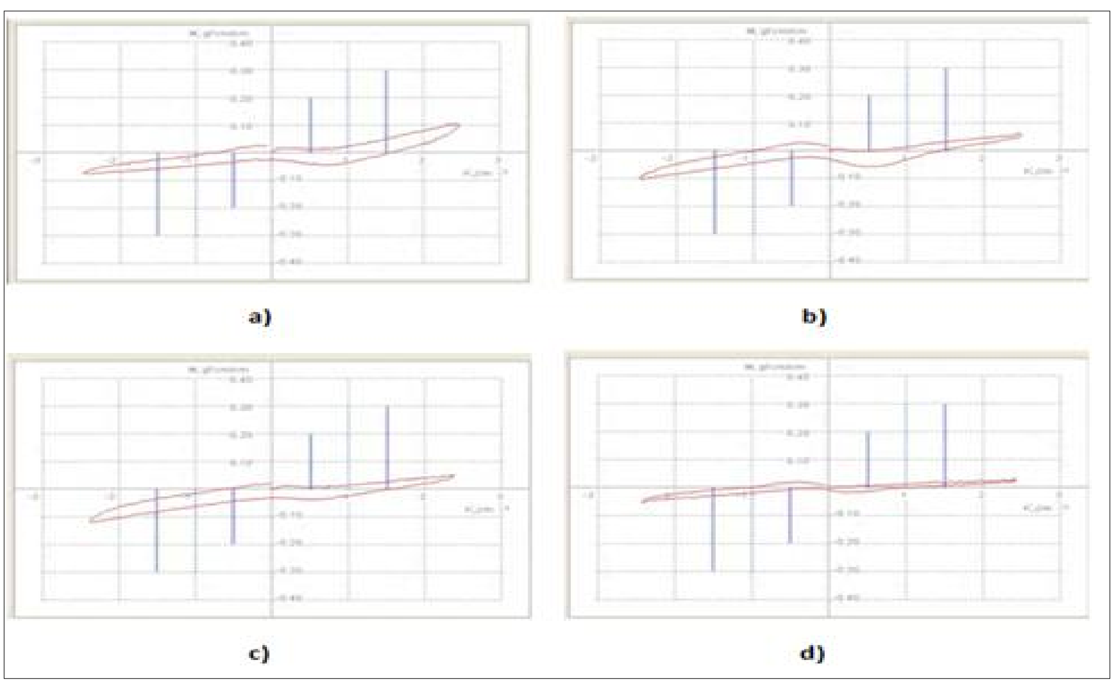

Fig. 6. Bending performance of fabrics in course-wise direction, a) S_1, b) S_2, c) S_3 and d) S_4

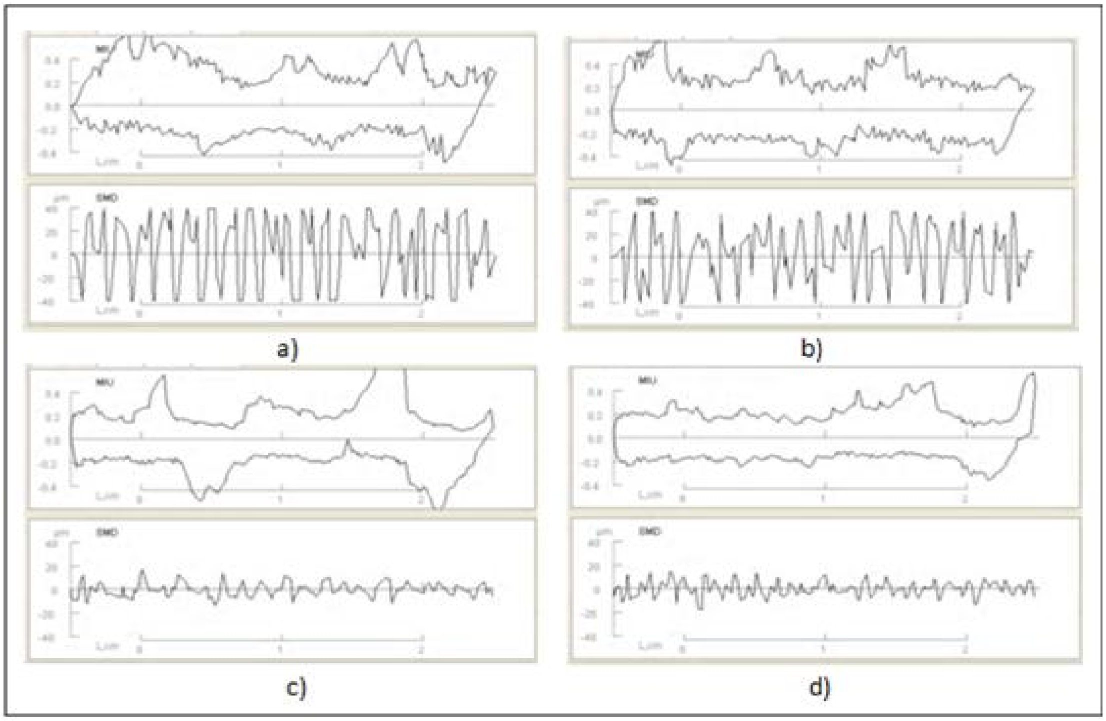

Fig. 7. Surface properties of fabrics in wale-wise direction, a) S_1, b) S_2, c) S_3 and d) S_4

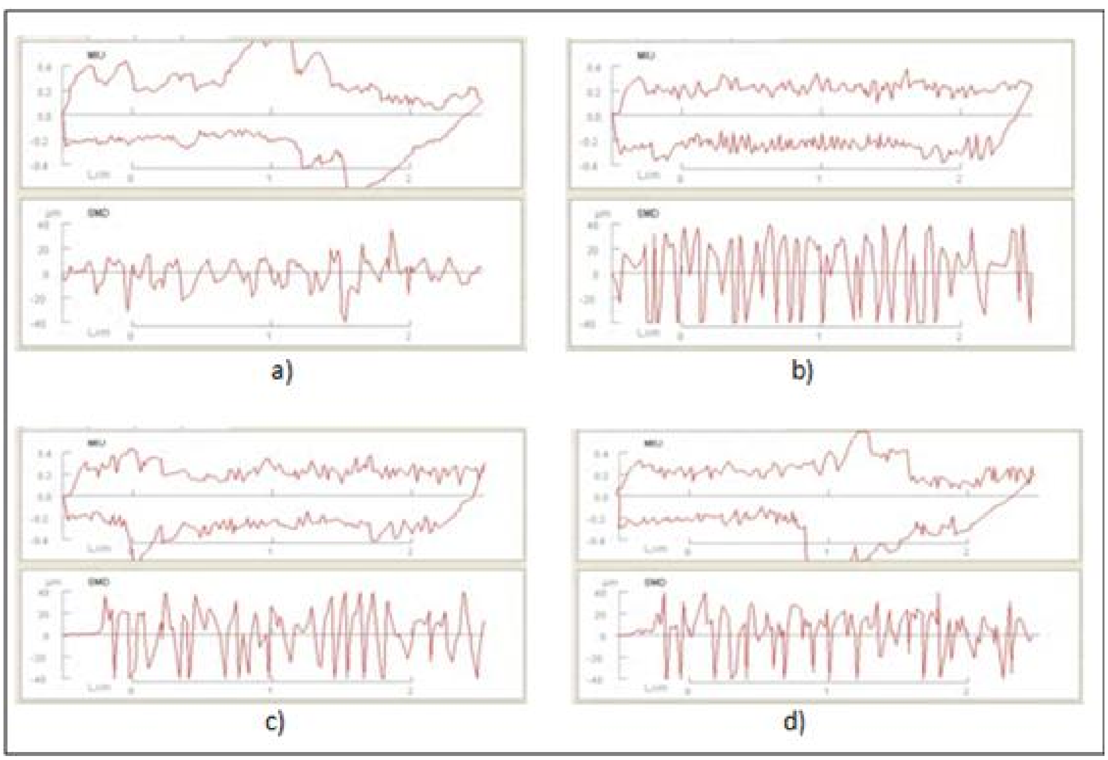

Fig. 8. Surface properties of fabrics in course-wise direction, a) S_1, b) S_2, c) S_3 and d) S_4

3.5.3 Compressional Resilience (RC%)

The ability of the fabric to recover from compression is called “compression resilience”, which means higher the resilience lower will be the energy loss [18]. Compressional resilience of fabrics depends on thickness of fabric and compressional characteristics of yarn. Highest compressional resilience was found for fabric S_2 followed by fabrics S_4, S_1 and least value was calculated for fabric S_3.

3.6 Fabric weight (W)

Highest amount of weight was observed in case of fabric S_1, followed by fabrics S_3 and S_2. Lowest weight was shown by fabric S_4. Higher fabric weight in fabrics S_1 and S_3 were found due to utilization of thicker yarn for knitting.

3.7 Primary Hand Values and Total Hand Values of Knitted Fabrics

Knitted fabrics were evaluated for Primary and total hand values, findings of which have been furnished in Table 7. The values were examined in terms of *koshi, fukumari and Numeri*.

Hand value of primary hand: 10- Strongest, 5- Medium, 1 –Weakest

Total hand value (THV): 5-Excellent, 4-Good, 3- Average, 2 –Fair, 1 –Poor

On the parameter of stiffness, fabric S_1 scored the highest grade, followed by fabrics S_3 and S_2. Fabric S_1 and S_3 exhibited highest stiffness values because of more compact structure by utilization of thicker knitting yarn. Apart from this, higher silk content in these two fabrics have led to more oriented molecular arrangement. Lowest value of stiffness was attained by fabric S_4. Regarding fullness and softness, fabric S_1 scored a highest value followed by fabrics S_3 and S_4. Fabric S_2 obtained lowest grade. On the parameter of smoothness, fabric S_4 scored highest value followed by fabric S_2 and S_1. Fabric S_2 scored lowest score on this criterion. Beheraa and Shakyawar [29] reported that *Numeri* witnesses a rise when same fibres are spun into a finer count. Total hand values of knitted fabrics were evaluated on a scale of 1 to 5 in which fabric S_2 attained the highest grade, followed by fabric S_4 and S_1. Fabric S_3 attained the lowest score. No significant difference was found in total hand values of the four fabrics.

3.8 Analysis of Impact of Fabric’s Constructional Properties on Total Hand Value (THV) of Blended Knitted Fabrics

With an aim to judge the relationship of total hand values with fabrics’ constructional properties and their impact on the former, linear regression analysis was carried out. Table 8 elucidates the findings of regression analysis of

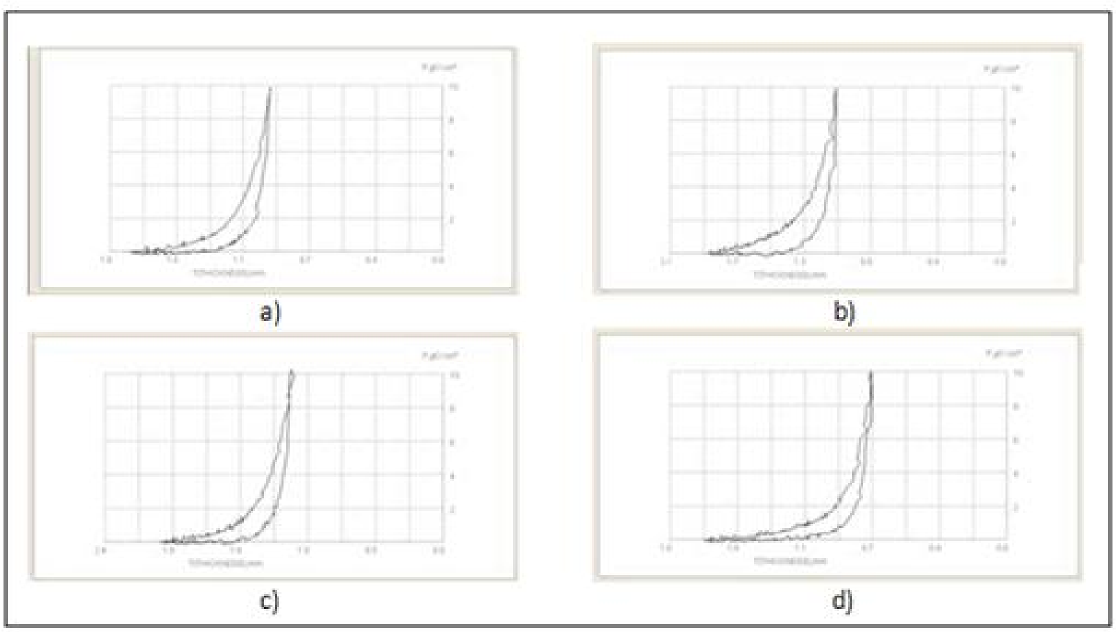

Fig. 9. Compressional properties of fabrics, a) S_1, b) S_2, c) S_3 and d) S_4

Table 7. Primary hand values and total hand values of developed knitted fabrics

Fabric codes	*Koshi* (Stiffness)	*Fukumari* (Fullness & Softness)	*Numeri* (Smoothness)	THV KN-403-KTU
S_1	7.47[d]	8.28[a]	4.91[c]	3.45
S_2	6.81[b]	7.16[c]	5.54[b]	3.49
S_3	7.27[c]	8.23[a]	4.89[c]	3.44
S_4	5.84[a]	7.44[b]	5.84[a]	3.47
Critical difference	0.2	0.27	0.2	NS

[a,b,c] Significant at 5 % level of significance, same alphabet= no significant difference, different alphabet= significant difference, NS= Not significant

Table 8. Effect of stitch density and fabric thickness on total hand values of blended knitted fabrics

Total hand value	Independent parameters	Coefficient	Standard error	t-value	p value
	Constant	3.576	0.496	7.213	0.000
	X1	0.000	0.002	0.258	0.802
	X2	-0.328	0.270	-1.212	0.256
	R^2 (%)	0.141			

*t-value= t statistic value, p= probability value, *Significant at 5 percent level of significance*
X1= Stitch density
X2= Fabric thickness

total hand value in relation to two independent variables *viz.* Stitch density of blended knitted fabrics and their thickness. Regression coefficient shows no impact of stitch density on total hand value, which clearly means that total hand value does not increase or decrease with change in figures of stitch density. As regards to fabric thickness, a negative coefficient reveals a negative relationship. Data says that with a fall in fabric thickness of knitted fabrics, total hand value of the fabrics will witness a rise, leading to better hand properties.

4. CONCLUSION

Defining low stress and mechanical properties of blended knitted fabrics provides data relating to physical comfort provided to the wearer. The results obtained indicate that fabric S_2, proved to be better in performance than fabrics S_1, S_3 and S_4, exhibiting low tensile toughness, high resilience, low shear and bending rigidity in both wale-wise and course-wise directions. Regarding surface properties, fabric S_2 scored maximum value for parameter of smoothness. Fabric S_2, however, showed lower extensibility and less spongy structure, but at the same time, bulkiness of fabric was reduced with this. High figures were obtained for this fabric when primary hand values were calculated. Fabric S_2 was observed have lower grade for criterion of *Koshi* (stiffness) and was seen to have high *Numeri* (smoothness) values. The figures suggest that fabric S_2 will be smoother in use than the rest of three fabrics. Apart from this, highest total hand value was scored by fabric S_2. Analyzing the relationship between lower deformation during low stress and mechanical properties, constructional properties of fabric were found as influential parameters in deciding hand properties of fabrics. A negative relationship was proved between fabric thickness with total hand values of knitted fabrics. KES measurements indicate significant difference between fabric S_2 with fabrics S_1, S_3 and S_4. Keeping in view the unequaled hand characteristics of 50% mulberry silk: 50% viscose in 20 Nm yarn count, it is therefore recommended as best suitable apparel use and commercial production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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