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Measurement and modeling of drape using digital image processing

B K Behera[a] & Ajit Kumar Pattanayak
Department of Textile Technology, Indian Institute of Technology, New Delhi 110 016, India

A drapemeter based on image processing technique has been designed and developed for complete analysis of the drape profile of apparel fabric. Image processing helps to determine some new drape parameters. Multiple regression equations for drape parameters have been developed from low stress mechanical properties of fabric to predict the drapability and the results are compared with the drape value obtained from image processing method. The interdependence between drape parameters and the mechanical properties of fabrics are also studied. A very good correlation has been found with bending and shear properties of the fabric. A higher drape coefficient is accompanied with less number of nodes. A fabric with higher tensile energy is less susceptible to draping or falling from the edge of a contour, whereas a fabric with higher extensibility always favours the folding and hanging of fabric at the edges of the platform, resulting in low drapability.

Keywords: Bending rigidity, Concave mirror, Digital image processing, Drape coefficient, Shear rigidity, Tensile energy

1 Introduction

Fabric drape is one of the most important properties of flexible material. It is also one of many factors that influence the aesthetic appearance of a fabric and has an outstanding effect on the formal beauty of the cloth. Drape is important for the selection and development of textile material for apparel industries. Studies of drape were first done by Chu *et al.*[1], when they established a measuring method for fabric drape using FRL drapemeter. They quantified the drapability of a fabric into a dimensionless value called "drape coefficient", which is defined as the percentage of the area from an angular ring of the fabric covered by a vertical projection of the draped fabric. The apparatus was further studied and then revised by Chu *et al*[2]. Finally, Cusik investigated the experimental method again by using a parallel light source that reflects the drape shadow of a circular specimen from hanging disc into a piece of ring paper to calculate drape coefficient.[3]

The most widely accepted method of drape test, according to IS 8357:1977, uses the drapemeter. In this test, a circular cloth sample of the diameter 10 inch is placed on a disk of diameter of 5 inch. The cloth drapes and compresses internally owing to gravity, finally resulting in a flared shape. Then the drape coefficient, described as the ratio of the vertical projection area to the entire sample area, is used to evaluate cloth drapeability.[4,5]
All these methods have several disadvantages, such as the testing is time consuming, tracing of the pattern by hand is highly dependent on the skill of the operator, the light source needed is of special type, the mass variation in the paper or presence of wrinkles to wet treatment may cause error in the calculation of the drape coefficient.

Besides these drawbacks, only drape coefficient is not sufficient to describe the aesthetic appearance. This may be influenced by such geometrical factors as the number of nodes and the curvature of the draped fabric. Equivalent drape coefficient is possible for two different fabrics, depending on the node values. Thus, it may be better to use the distribution of the number of nodes with the drape values to describe the aesthetic appearance.[6] According to Matsudaria and Zhang[7], drape constant is not always constant for each fabric. The coefficient changes mostly with the number of nodes. Therefore, more reliable and meaningful methods to measure the drape coefficient are necessary.

As discussed above, drape is an essential parameter to decide both appearance and handle of fabrics. It is also a secondary determinant of fabric mechanical properties and influenced by the low stress mechanical properties, like bending rigidity, formability, tensile & shear properties, and compressibility of the fabric.[8] All these mechanical

[a]To whom all the correspondence should be addressed
E-mail: behera@textile.iitd.ernet.in

properties have a direct bearing with basic fibre properties and fabric construction.[9] It is observed over a decade that the consumers prefer to wear light weight fabrics. At the same time, fabric comfort has gained priority over fabric durability. When fibre composition is changed along with fabric areal density, fabric drapability is expected to be influenced significantly. With the decrease in fabric areal density, the fabric becomes more flexible and may get loose structural stability. The drape parameters, such as number of folds, depth of folds, evenness of folds together with the drape coefficient need to be examined. The relationship between these parameters and fabric mechanical properties is already established.[10,11]

It is therefore thought worthwhile to make a study on drapability of some fabrics produced from various non-conventional fibre blends. An instrument based on image processing technique has been developed to obtain drape profile of fabric samples. Various drape parameters, like drape coefficient, number of nodes, drape distance ratio, fold depth index and amplitude to radius ratio have been determined and correlated with the fabric low stress mechanical properties tested on the Kawabata evaluation system (KES).[12] Multiple regression equations for drape parameters are developed from low stress mechanical properties of fabric to predict the drapability and the results are compared with the drape value obtained from image processing method.

2 Materials and Methods

2.1 Materials

Twenty-two fabric samples of non-conventional blends were developed in a wide range of areal densities and compositions. The constructional specifications of these fabrics are given in Table 1.

2.2 Methods

In order to overcome the above-mentioned problems in measuring drape coefficient, an instrument using image analysis technique is developed. In this instrument, a digital camera is used which captures the image of draped shadow and stores the image to PC to calculate all drape parameters like drape coefficient (DC), drape distance ratio (DDR), amplitude to average radius ratio (ARR), number of folds (N), and fold depth index (FDI), with a software developed in MATLAB. This procedure was based on Indian standard IS-8357: 1977 where sample size is 10 inch and disc size is 5 inch.

Table 1 — Constructional parameters of fabric samples

Sample No.	Ends/Inch	Picks/Inch	Fabric weight, gsm
1	70	60	124
2	70	60	141
3	64	54	154
4	60	48	181
5	48	32	282
6	82	68	123
7	82	68	122
8	82	68	124
9	82	68	127
10	82	68	128
11	82	68	130
12	78	60	125
13	78	60	129
14	84	64	134
15	84	64	148
16	42	56	160
17	68	54	221
18	54	64	191
19	70	52	162
20	56	48	177
21	38	36	311
22	60	52	155

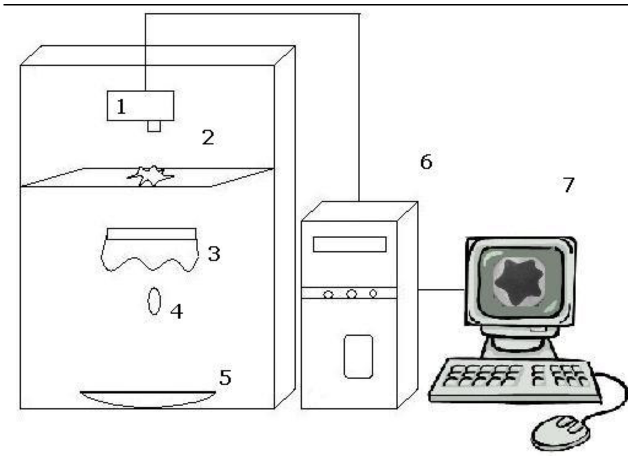

Fig. 1 — Schematic diagram of the digital drapemeter [1-Digital camera, 2-Top glass plate, 3-Bulb, and 6&7- Computer]

2.2.1 Design of Instrument

To measure the drapeability of the fabric using image processing technique, an instrument was fabricated based on the basic idea of Cusik's drapemeter. It is designed in such a way that it can be used for conventional as well as for image processing technique for accurate results.

2.2.1.1 Image Acquisition System

The schematic diagram of the drapemeter is shown in Fig. 1. In this design, the draped shadow image was captured at top glass plate (**2**). For this, a bulb (**3**) was lightened up which throws the light on concave mirror

(**5**) placed underneath. Then light reflected from the concave mirror would be parallel rays. This gives an exact shadow of the draped fabric. For capturing the image without the background a thin uniform density paper was placed on the top glass plate. Thus, the digital camera (**1**) mounted above, operated by the computer, captures the clear image formed. This image was then saved in computer (**6** & **7**) and processed by the program to give the various drape parameters, such as drape coefficient, drape distance ratio, amplitude to radius ratio, fold depth index and number of nodes.

2.2.1.2 Image Processing Algorithm

In this measurement technique, first image is grabbed by the CCD camera and that image is processed by the software developed in the MATLAB to calculate the various drape parameters. The sequence of image processing operations used for determination of drape parameters is given in Fig. 2.

2.2.1.3 Estimation of Drape Parameters

For this, the digital image obtained is made clearly visible by using thresholding technique. Thus, the image is converted into binary image, which is then processed. The image boundary of a draped fabric consists of a number of discrete points, and the discrete points define a polygon, which is used to calculate the drape value. Thus, an image consists of n-1 triangles, where n is the number of points that form the boundary of the image.

Hence, from Fig. 2, $X_i = r_i \cos\theta_I$ & $Y_i = r_i \sin\theta_i$
Average radius is $r_a = (1/n)\Sigma r_i$
Area for the triangle (A) of (0, 0), (X_1, Y1) and (X_2, Y2) points can be given by following relationship:

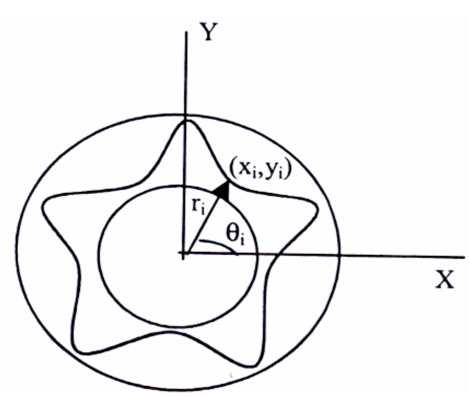

Fig. 2 — Draped fabric image

$$A = \frac{1}{2} r_1 \times r_2 \times \sin\theta$$

Therefore, total area for the boundary curve (S) can be given by the following relationship:

$$S = \sum_{i=1}^{n=1} \frac{1}{2} r_i \times r_{i+1} \sin\theta$$

where r_1 & r_2 are the radius of the supporting disc and undraped fabric sample respectively.

Thus, one needs angle and radius at different points to get the area. For this, first of all centre point of the binary image is located and then it is rotated by a constant angle and radius is calculated at all points. For the calculation, boundary of fabric shadow is approximated by 1^o . Thus, there are 360 points on the boundary of the image.

Hence, $\theta=1^0$ and n=360

With these parameters now one can calculate different drape parameters, such as drape coefficient (DC), average radius (r), maximum radius (r_{max}), minimum radius (r_{min}), drape distance ratio (DDR), amplitude to average radius ratio (ARR), number of nodes (N), and fold depth index (FDI).

2.2.1.4 Definition of Drape Parameters

Various drape parameters can be determined using the following relationships:

$$\text{Drape coefficient (DC)} = \frac{A_S - A_1}{A_2 - A_1}$$

$$\text{Drape distance ratio (DDR)} = \frac{r_2 - r_{avg}}{r_2 - r_1} \times 100\%$$

$$\text{Fold depth index (FDI)} = \frac{r_{max} - r_{min}}{r_2 - r_1} \times 100\%$$

$$\text{Amplitude to radius ratio (ARR)} = \frac{r_{max} - r_{min}}{2}$$

where A_S is the area of draped fabric image; A_1, the area of fabric supporting disc; A_2, the area of undraped fabric sample; r_1, the radius of fabric supporting disc; r_2, the radius of undraped fabric sample; r_{max}, the maximum radius of draped fabric image profile; r_{min}, the minimum radius of draped fabric image profile; and r_{avg}, the average radius of draped fabric image profile.

2.2.2 Fabric Testing Methods

In order to test the accuracy of the instrument, a set of fabric samples was tested on the instrument using image processing technique and the results were compared with conventional method. The comparisons were made between various image processing measures such as pixel counting, boundary approximation method and Fourier series methods and also each of these methods with conventional method.

2.2.2.1 Measurement of Bending Rigidity

Bending rigidity of fabric samples was measured on the KES FB2 pure bending tester. This measures the bending rigidity of the fabric in warp and weft directions separately and then the average value is taken for analysis. The sample is bent accurately in an arc of constant curvature, and the curvature is changed continuously. The bending rigidity is calculated using the following equation:

$$G = \frac{M}{\rho}$$

where M is the bending moment; and ρ, the curvature.

Sample size taken was 20 cm × 5 cm (warp way and weft way separately) and maximum curvature was 2.5 cm^{-1}.

2.2.2.2 Measurement of Fabric Tensile Properties

Fabric tensile properties were measured on the KES FB1 tensile tester. The standard test procedure for fabrics was followed to measure the tensile energy and extensibility. The test parameters are: speed, 0.0002 m/s and load, 5 N/s.

2.2.2.3 Measurement of Shear Rigidity

The shear properties were measured on KES FB1 tensile tester. This gives the shear rigidity and shear hysteresis. However, for this study only shear rigidity values were considered. Parameters of shear test are: rate of shear strain, 0.00834/s and speed, 0.477 deg/s.

2.2.2.4 Measurement of Compressional Properties

Compressional properties were measured on KES FB3 compression tester. The instrument gives linearity of compression, compressional energy and compressional resilience apart from the thickness of the sample. In this study only compressional energy is considered. The test parameters are: compression rate, 0.00000667 m/s; compressional area, 2 cm^2; and compressional pressure, 0.50 N/cm^2.

3 Results and Discussion

The results for drape coefficients of 22 different fabric samples obtained by image processing technique and conventional method are given in Table 2.

3.1 Comparison of Drape Coefficient

Very good correlation is observed between all drape coefficients measured by Cusick's method and image processing technique (Fig. 3). This new technique is able to measure the other important parameters for the in-depth description of drape profile.

3.2 Prediction of Drape Parameters

3.2.1 Effect of Bending Rigidity on Drape Parameters

Drape or the falling behaviour of fabrics is greatly influenced by the bending rigidity. The correlation of bending rigidity and drape parameters is shown in Fig. 4. There is a strong correlation between fabric bending rigidity and drape papameters. This is because drapability or falling behaviour under the influence of gravity is significantly affected by the bending properties. At the edges of the supporting disc, the fabric sample actually bends in order to get those folds. A higher bending rigidity prevents the folds to be formed and thus the fabric remains more towards the flattened state, thereby having a higher drape coefficient, DDR, ARR and FDI. Lower bending rigidity, on the other hand, offers less resistance to formation of folds and a smaller

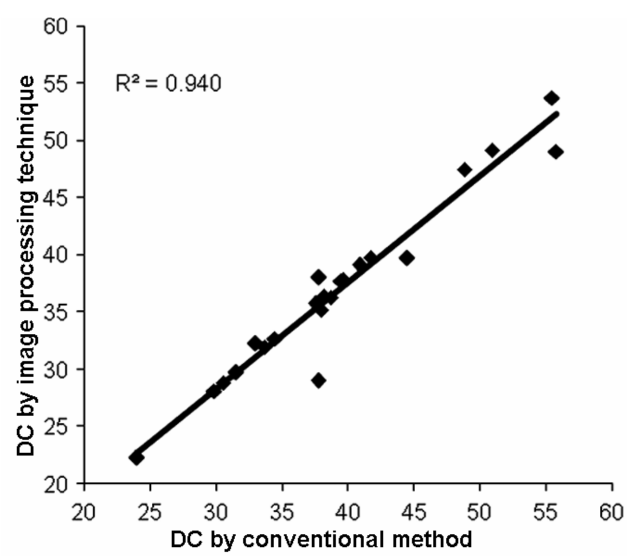

Fig. 3 — Correlation between drape coefficient measured by conventional method and image processing method

Table 2 — Comparison of drape parameters measured by image processing and conventional technique

Sample No	Image processing					Conventional
	DC%	DDR	FDI	ARR	N	DC%
1	38.03	87.92007	48.88013	1.397	6	37.75
2	39.78	94.07655	52.94135	1.421582	5	41.67
3	47.47	104.9683	63.57015	1.563016	5	48.79
4	22.27	67.57408	28.35771	1.174487	6	23.99
5	28.81	69.54784	35.65164	1.276853	6	30.53
6	35.21	77.95752	43.9427	1.330756	7	37.93
7	35.77	81.01093	45.93092	1.358623	5	37.49
8	36.33	80.81448	46.32076	1.349303	5	38.63
9	37.74	84.37797	48.80285	1.379157	6	39.46
10	37.85	83.4937	47.84876	1.376846	4	39.57
11	39.12	91.64813	54.07545	1.433648	5	40.84
12	28.1	63.65995	30.80237	1.185084	6	29.82
13	29.02	69.55983	36.6553	1.241538	5	37.74
14	29.76	66.35537	33.11036	1.234678	6	31.48
15	32.25	70.62618	37.70035	1.28069	7	32.97
16	36.41	76.73759	41.68303	1.334152	7	38.13
17	39.73	89.45787	53.70254	1.486583	6	44.45
18	32.72	62.44177	20.70746	1.120692	5	34.44
19	31.95	55.46273	26.27165	1.146841	6	33.67
20	49.01	116.2703	72.97301	1.702828	4	55.73
21	53.7	142.9687	97.08852	2.044674	4	55.42
22	49.17	131.4713	84.87195	1.864105	4	50.89

DC–Drape coefficient, DDR–Drape distance ratio, FDI–Fold depth index, ARR–Amplitude to radius ratio, and N–Number of nodes.

shadow is generated giving low coefficient value with more number of nodes. Negative correlation is observed between bending rigidity and number of nodes. Nodes in the draped fabric shadow are basically the folded apexes formed due to hanging of the fabric from the supporting disc or platform. A higher bending rigidity most of the times prevents the formation of folds. However, a higher drape coefficient value may not always be supported by less number of nodes.

3.2.2 Effect of Tensile Properties on Drape Behaviour

It is well known that bending rigidity is related to the tensile properties as shown by the following relationship:

$$G = E \times I$$

where G is the bending rigidity; E, the Young's modulus; and I, the inertia and for a circular cross-section it is $\pi r^4/4$.

Since drapability is directly related to bending rigidity, it is obvious that it should be influenced by tensile properties of fabric particularly at low stress level. Hence, a study was conducted to establish a relationship between tensile properties of fabrics and their drape behaviour. Tensile properties of the fabric samples tested on KES FB1 were correlated to drape parameters. The results of such tests are shown in Fig. 5.

Good correlation between tensile energy and drape parameters indicates that a fabric with higher tensile energy is less susceptible to draping or falling from the edge of a contour. Tensile energy is analogous to initial modulus of the fabric and this actually enables the fabric to overcome tensile deformations. Draping under gravitation is also a tensile phenomenon against this energy. Thus, a higher tensile energy means less tensile deformation under gravity. This enables the fabric to remain towards the flatter side. Thus, a higher drape coefficient value is obtained. There seems to be a negative correlation between tensile

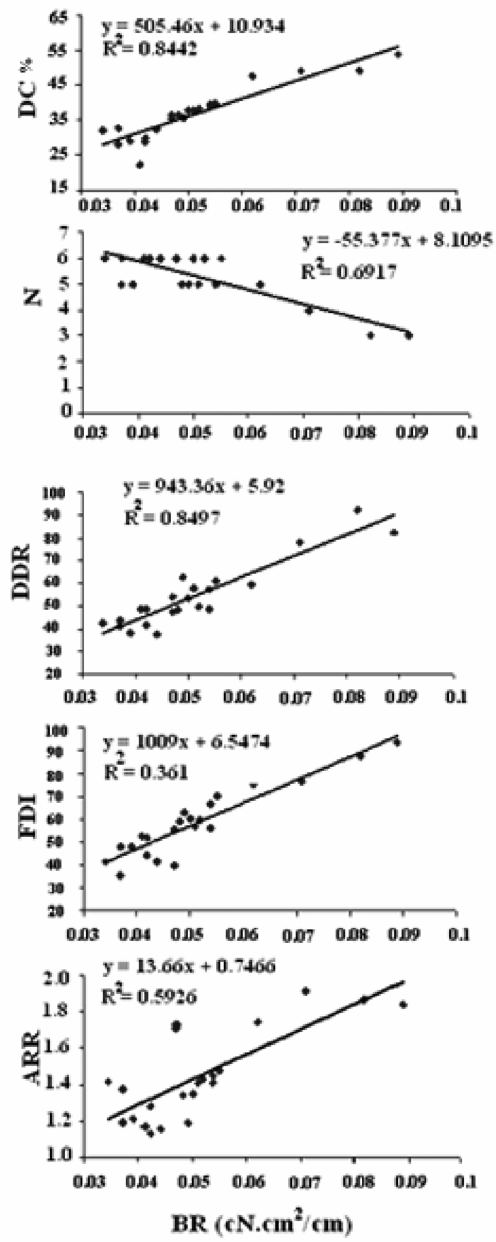

Fig. 4 — Correlation between bending rigidity and drape parameters

energy and number of nodes formed. Less number of nodes are formed with a fabric having higher energy/initial modulus and high drape coefficient.

3.2.3 Effect of Low Stress Extensibility on Drape Behaviour

The fabric low stress extensibility was measured on KES FB1 and correlated to drape properties. Correlation between extensibility at low load and drape parameters is shown in Fig. 6. The correlation between low stress extensibility and drape parameters is found to be negative. A higher extensibility always favours the folding and hanging of fabric at the edges of the platform and thus a smaller shadow is formed giving lower drape coefficient. Further, it is related to the number of nodes. A higher extensibility at the edges causes more folding at points of stress accumulation and thus more number of nodes are formed. However, the correlations with extensibility are considerably smaller and it needs a much deeper analysis.

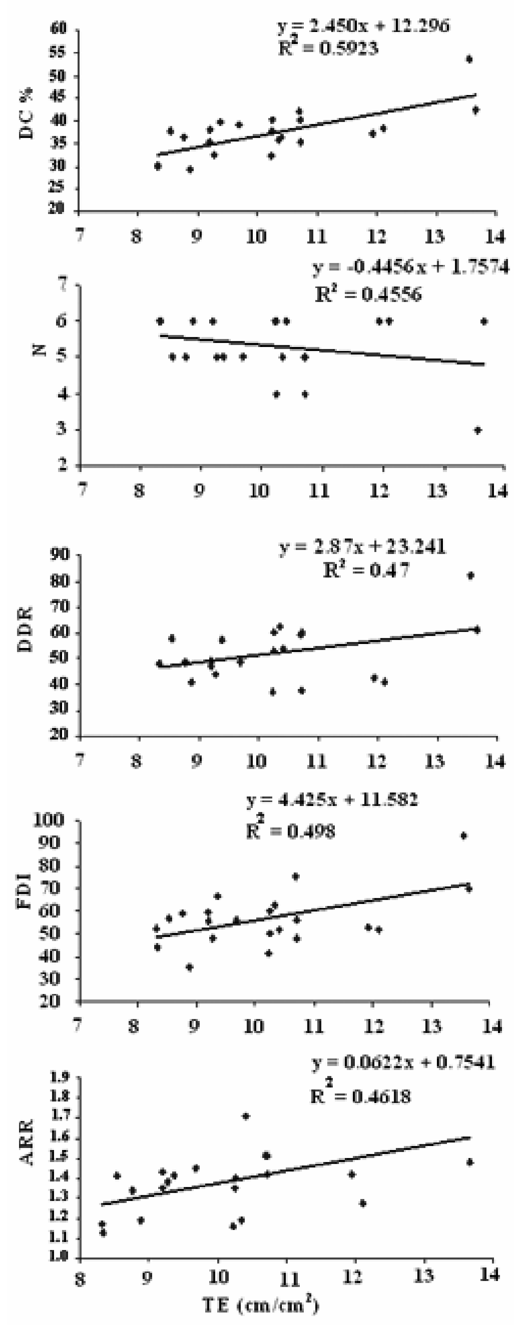

Fig. 5 — Correlation between tensile energy and drape parameters

3.2.4 Effect of Shear Properties on Drape Parameters

The tangential deformation in a fabric is caused when a tangential force acts on one edge of the fabric while the other parallel edge remains undeformed and undisplaced. This property in a fabric is more practical in predicting the end use performance similar to that in real life situations, where the fabric is subjected to stresses in all possible directions. The shear rigidity was measured on KES FB1 tensile tester and its correlation with drape parameters is shown in Fig. 7.

The shear rigidity of fabrics shows very good correlation with the drape parameters. This is a clear indication of the fact that drape is strongly affected by

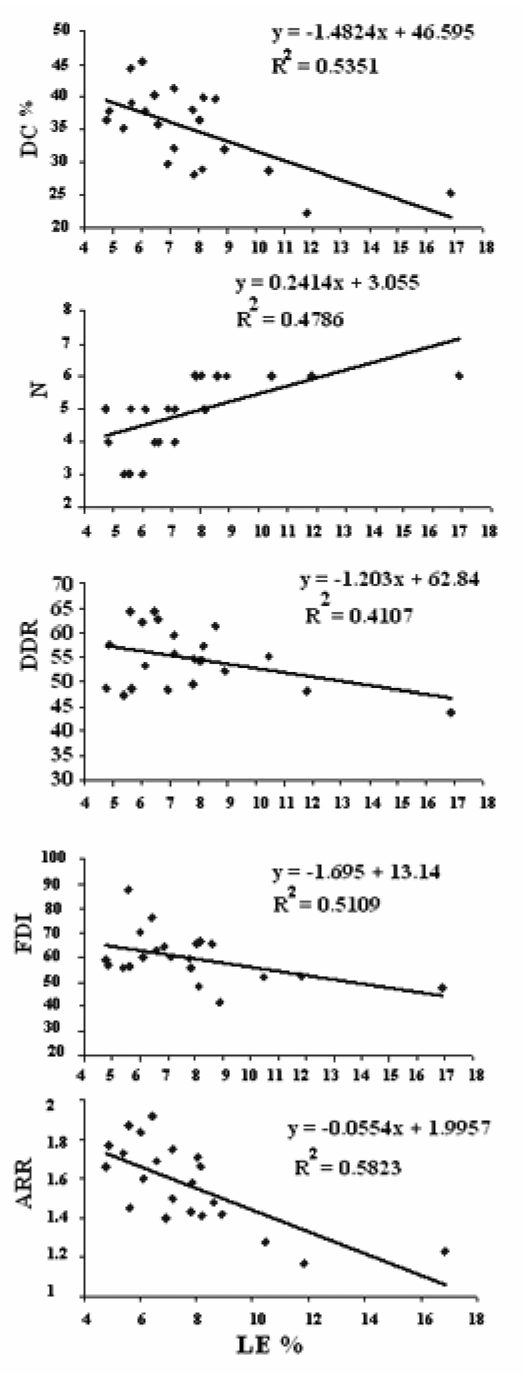

Fig. 6 — Correlation between low stress extensibility and drape parameters

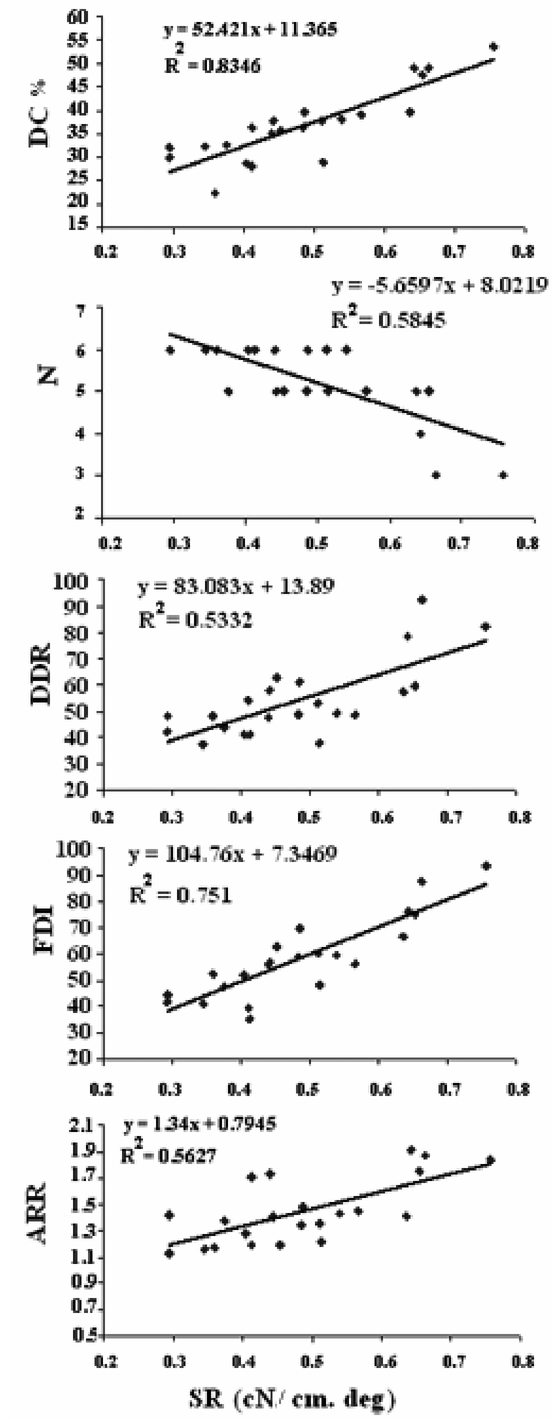

Fig. 7 — Correlation between shear rigidity and drape parameters

the shear properties. When the fabric sample is supported on the disc, it hangs down from the edges at all possible points of deformation. A combination of forces come into play and there is every possibility of tangential stresses being generated. A higher rigidity to tangential deformation prevents folding or hanging and thus a high drape coefficient is obtained. When correlated with number of nodes, again a strong negative trend emerges. This may be because the formation of downwardly hanging folds is not simply a radial or axial phenomenon and it is an interaction between multiple forces acting in all possible directions and orientations.

3.2.5 Effect of Compressional Properties on Drape Behaviour

When a fabric is draped on the edges of a contour, there is a compressional deformation at the point of bending. Thus, the fabric compressibility is yet another parameter which needs emphasis. The KES FB3 compression tester was used to measure the compressional energy. The results of this analysis and its correlation with drapability are shown in Fig. 8.

The correlation shows that fabrics with higher compressional energy give higher drape parameters. This can be explained in the following way. Compressional energy is the work done in compressing the fabric within the elastic limit. This is calculated from the area under the compression curve or by multiplying compressive force with change in thickness. A highly compressible fabric does have high compressional energy and can absorb/withstand compressive forces to a greater extent at the deforming points. This prevents the folding at the deforming points and a higher drape coefficient results. Negative correlation is found between compressional energy and number of nodes as usual.

3.3 Multiple Correlation of Drape Parameters with Low Stress Mechanical Properties

In order to determine the combined effect of fabric low stress mechanical properties on drape parameters and the contribution of individual properties in deciding the falling behaviour, a multiple correlation is exercised and following regression equations are derived with respect to all drape parameters discussed above:

DC = 1.70 + 403 BR + 0.641 TE - 0.049 LE + 13.8 SR +0.21 CE (R^2 = 0.87)

N = 7.66–42.1 BR–0.130 TE + 0.0269 LE–1.66 SR – 2.75 CE (R^2 = 0.76)

DDR= 2.8 + 1373 BR + 0.232 TE–0.771 LE + 34.8 SR + 2.07 CE (R^2 = 0.886)

FDI = –16.1 + 979 BR + 1.18 TE–1.06 LE + 25.3 SR + 2.51 CE (R^2 = 0.91)

ARR= 0.548 + 13.6 BR + 0.0126 TE–0.0081 LE + 0.096 SR + 0.194 CE (R^2 = 0.61)

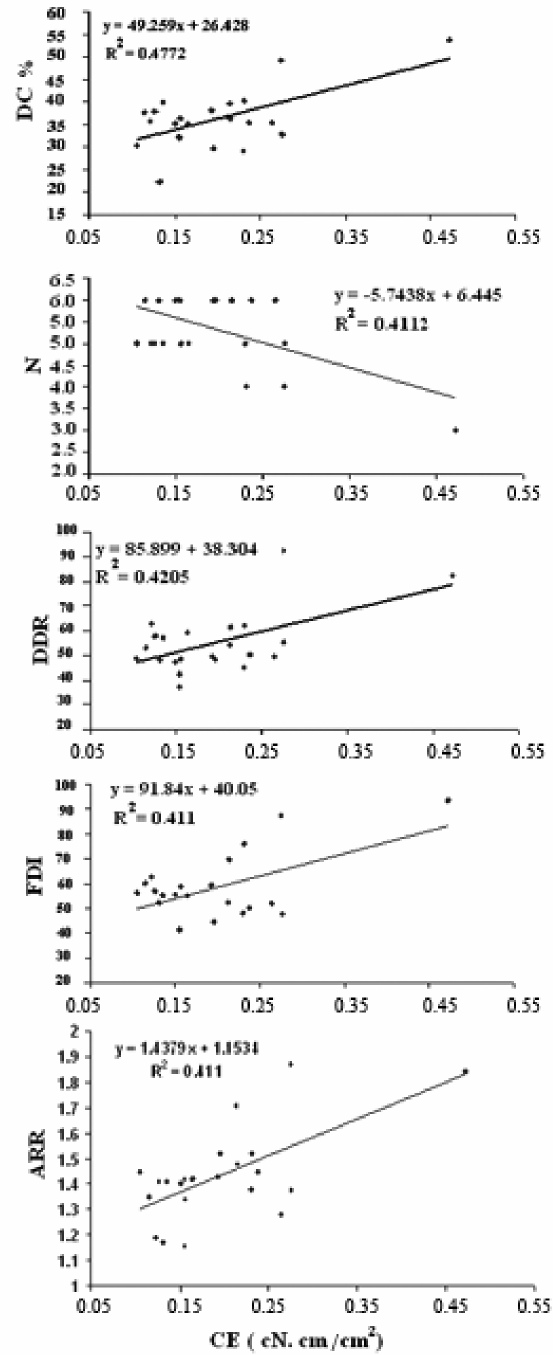

Fig. 8 — Correlation between compressional energy and drape parameters

These regression equations are used to predict drape parameters and the results are compared with the drape value obtained from image processing method. The interdependence between drape parameters and the mechanical properties of fabrics are also studied.

4 Conclusions

There is a strong correlation between fabric bending rigidity and drape parameters. Negative correlation is observed between bending rigidity and number of nodes. Normally, in majority of cases a higher drape coefficient is accompanied with less number of nodes. A good correlation between tensile energy and drape coefficient indicates that a fabric with higher tensile energy is less susceptible to draping or falling from the edge of a contour. A higher extensibility always favors the folding and hanging of fabric at the edges of the platform and thus a smaller shadow is formed giving lower drape coefficient. The shear rigidity of fabrics shows very good correlation with the drape parameters. A higher rigidity to tangential deformation prevents folding or hanging and thus a high drape coefficient is obtained. A highly compressible fabric does have high compressional energy and can absorb/withstand compressive forces to a greater extent at the deforming points. This prevents the folding at the deforming points and results in higher drape coefficient, DDR, FDI and ARR.

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