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Prediction of fabric hand characteristics using extraction principle

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Prediction of fabric handle characteristics using extraction principle has been studied. An instrument for objective measurement of fabric handle characteristics has been developed using nozzle extraction method. This instrument measures the force exerted on the periphery of the nozzle by the fabric being drawn out of the nozzle on the periphery of the nozzle. This force, called the radial force, is a measure of the certain low stress mechanical characteristics of the fabric that determine handle. The instrument also measures the force required to extract the fabric through the nozzle. Woven fabric samples have been sourced from industry and categorized into suiting and shirting fabrics. The fabric samples were also tested in KES-F system. An attempt has been made to predict the shear force and bending rigidity by using artificial neural network. It has been observed that there are very good correlations between the extraction force values and the various KES-F parameters. The fabric extraction force obtained through nozzle extraction instrument is found to be well enough to predict fabric handle/feel value.

Keywords: Artificial neural network, Nozzle extraction, Fabric handle, Extraction force, Shear force

1 Introduction

Fabric hand is one of the most important fabric parameters for the textile materials intended for apparel use. Fabric hand value influences customer's inclination towards the material and the usefulness of the product. Therefore, fabric hand has direct impact on the selling ability of the apparel. Fabric hand characteristics are very much important for the fabric manufacturers, garment designers, and merchandisers for the fabric selection and product development[1]. Fabric handle value implies the quantification of the textile materials which can be perceived by touching. It is mainly related with the objective measurement of various low stress mechanical deformations such as tensile, bending, shear and compression. Fabric handle value, measured based on the touching or sensing, helps the consumer to judge the fabric quality. But if the fabric handle value is evaluated with the help of any objective measurement then it will be more commercially acceptable[2]**.** For a textile material, there are many factors, such as yarn structure, fabric structure and finishing treatments, which affect the fabric hand[3].

Fabric hand is influenced by foldability, compressibility, flexibility, pliability, stretch ability, and surface friction. Most of the researchers proposed measuring of the above-mentioned parameters to define the fabric hand value. Others suggested to measure the hand related fabric mechanical parameters related to subjective ratings and preference of sensory attributes[1]. Fabric hand attributes can be obtained through subjective assessment or objective measurements. Subjective assessment is one of the traditional procedures of describing fabric handle based on the experience and variable sensitivity of human beings[4]. Mailis and Harrier[5] reported that the textiles are touched, squeezed, rubbed or otherwise handled to obtain information about physical parameters. In the clothing industry, professionally trained handle experts sort out the fabric qualities. Objective assessment has a different primary goal which is to predict fabric hand by using relationships between sensory reactions and instrumental data. Objective assessment methods include the Kawabata evaluation system for fabrics (KES-F) and the fabric assurance by simple testing (FAST). Both systems measure similar parameters using different instrumental methods. There are simple alternative techniques consisting of the ring or slot tester, which are less accurate but faster and cheaper for practical application. Although objective assessments are precise from a measurement point of view, these methods are not commonly used in the textile and clothing industry. Even today, many companies use subjective evaluation to assess fabric properties. The main reasons for this situation are the repetitive and lengthy process of measurement,

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complexity of test methods and the lack of knowledge for a good interpretation of the test results. Leung *et al.*[6] investigated the relationship among fabric formability, bias extension, and shear resistance. They concluded that there is no strong relationship amomg them. The tensile, bending, and shear properties need to be studied to understand the performance behaviour of woven fabrics.

Attempts have been made to overcome these limitations of complicated objective measurement by designing a simple method which can easily measure the fabric handle value. In this method, the extraction force, required while withdrawing a fabric specimen through a nozzle, is measured. The extraction force is required to overcome the resistance of fabric against combined deformations like bending, shear, tensile, and compression. Ishtiaque *et al.*[7] studied a simple nozzle extraction method for objectively measuring the fabric handle. Their method was based on the use of a simple attachment fitted to a tensile testing machine to measure the force generated while extracting a circular fabric specimen through a nozzle. They reported that different testing variables, like presence of supporting plate, extraction speed and shape of the specimen, have significant effect on peak extraction force, whereas the number of pass does not have any specific effect on the extraction behaviour of fabric. Chemical finishing results in the reduction in extraction force and traverse-at-peak extraction force. In another work, artificial neural network (ANN) has been used to predict fabric hand stiffness by using fabric surface and mechanical parameters[8]. The study reveals that subjective hand property, stiffness and objective measured property, and bending rigidity have strong correlation. Grover *et al.*[9] reported that the handle force correlates significantly and positively with fabric weight (W), bending modulus (B) and bending hysteresis (2HB). In another paper, the fabric hand was assessed for 145 fabrics by several methods including quantitative method using a nozzle[10]. Sülar and Okur[11] have studied 71 suiting fabrics and observed relationship between fabric handle parameters and pulling force of extraction method.

In this study, an attempt has been made to evaluate the handle of different types of fabrics by using nozzle extraction method and to correlate the results with that of KES method. An attempt has also been made to predict the shear force and bending rigidity by using artificial neural network (ANN) with the input parameters of extraction and radial force obtained from nozzle extraction method.

2 Materials and Methods

2.1 Materials

Fifteen different woven samples were collected from the industry and categorized into suiting and shirting fabrics. For the ANN modelling, 15 additional fabrics were used to enhance the database. Before testing, the fabric samples were conditioned in standard atmospheric condition of 27°C ± 2°C and 65% RH ± 2% for 24 h. The fabric construction properties are given in the Table 1.

2.2 Methods

To test the fabrics in the nozzle extraction instrument Fig. 1, samples were cut in to circular shape with diameter of 250 mm and attached to sample holder of the instrument. The samples were then drawn through a specially designed nozzle made of iron (27 mm inner diameter, 40 mm outer diameter, 40 mm in length) at a speed of 200 mm/min. Utmost care was taken so that the fabric samples are free from wrinkles and crease. As the clamp with which the connecting pin is attached moves upward, it extracts the fabric specimens through the nozzle. The forces required for extracting the fabric specimens through the nozzle, in terms of extraction force and radial forces, change as more and more of the fabric was introduced in the nozzle. The fabric specimen gets folded, sheared, rubbed, compressed and bent during extraction. The extraction and radial forces can be recorded by the instrument. The same procedure was followed for all fabric samples and results are summarised in Table 2.

Table 1—Fabric construction parameters

Sample code	Ends per inch	Warp count, Ne	Picks per inch	Weft count Ne
Su1	45	28	45	36
Su2	111	34	86	20
Su3	74	20	70	20
Su4	66	18	56	16
Su5	76	15	60	15
Su6	101	16	83	16
Su7	60	15	58	15
Su8	50	22	45	22
Su9	60	9	50	9
Su10	68	8	50	8
Su11	60	9	34	8
Su12	60	12	42	12
Su13	84	20	65	20
Su14	60	15	40	15
Su15	81	20	55	11

Various tests were also conducted for measuring the fabric thickness, bending length, bending rigidity, shear force, compression energy, mass per unit area, and fabric construction as per the standard testing methods. Bending, shear and compression characteristics of fabrics were measured using KES-F instruments.

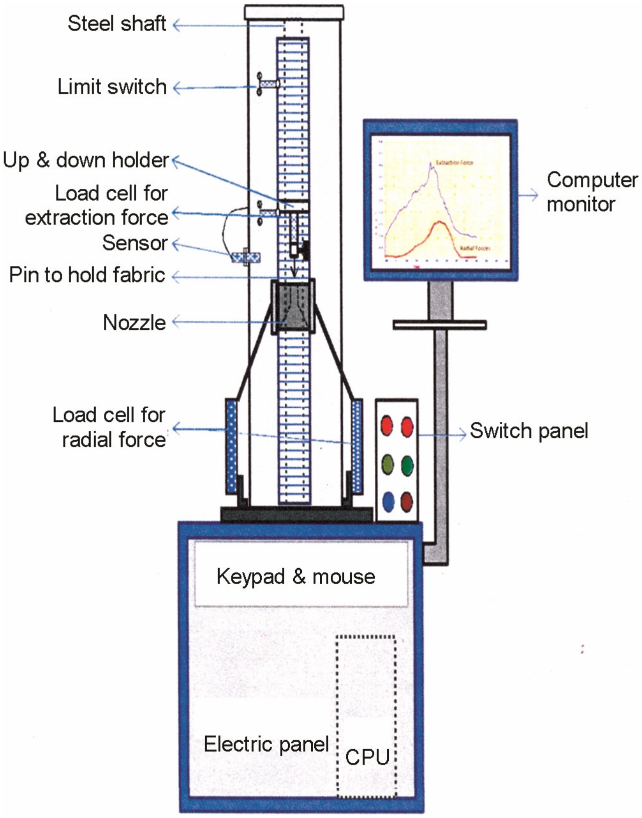

Fig. 1—Schematic diagram of computerized fabric feel tester

2.2.1 Prediction of Low Stress Mechanical Properties

Construction of a proper network structure and optimization of learning parameters greatly influence the prediction performance of ANN model. The important structural parameters to be decided are the number of hidden layers and the number of nodes in each of the hidden layers[12-14]. Only one hidden layer has been used in this investigation, as it is capable of handling nonlinear relationship between inputs and outputs. Transfer function in the hidden and output layers was log-sigmoid as shown below:

$$f(Z) = \frac{1}{(1 + e^{-Z})}$$

where Z is the weighted sum of inputs to a node; and $f(Z)$, the transformed output from that node.

The number of nodes in the input layer of ANN was 2 as there were 2 input parameters, namely radial force and extraction force. The schematic representation of the ANN structure is shown in Fig. 2. The number of nodes in the output layer was only one as either

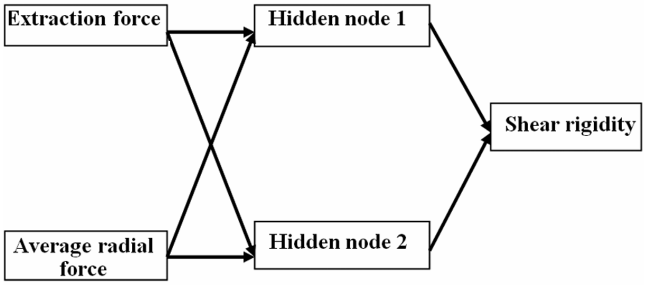

Fig. 2—Schematic diagram of ANN model

Table 2—Fabric properties measured by nozzle extraction method and KES-F

Fabric code	Extraction force, kgf	Average radial force, kgf	Shear force gf/cm.deg	Bending rigidity gf.cm^2/cm	Compression energy, gf.cm/cm^2	Mass / unit area, mg/cm^2
Su1	1.11	0.041	0.69	0.047	0.091	15.2
Su2	1.11	0.038	0.77	0.066	0.036	17.5
Su3	1.19	0.340	0.76	0.060	0.050	18.6
Su4	1.39	0.049	0.98	0.076	0.295	22.2
Su5	1.41	0.041	0.82	0.115	0.153	23.4
Su6	1.21	0.036	0.60	0.100	0.183	23.9
Su7	1.78	0.275	1.55	0.105	0.167	25.1
Su8	1.72	0.056	1.39	0.113	0.139	27.0
Su9	1.95	0.156	0.38	0.305	0.219	27.5
Su10	2.13	0.205	1.52	0.148	0.382	28.6
Su11	2.19	0.222	1.50	0.166	0.427	29.0
Su12	2.21	0.398	1.69	0.144	0.329	34.4
Su13	2.48	0.309	2.59	0.157	0.182	35.8
Su14	2.58	0.427	3.37	0.196	0.352	37.6
Su15	2.83	0.571	2.72	0.254	0.274	38.2

bending rigidity or shear rigidity was predicted at a time. As ANN requires large number of experimental data for training, 15 additional samples were added in the training database. Total number of available data sets for ANN training was 30, out of which 25 data sets were used for training and remaining 5 data sets were used for validation of ANN model. Training of ANN was done using back-propagation algorithm. The number of nodes in the hidden layer and learning parameters (learning rate and momentum) were optimised by trial and error method. It was found that one hidden layer with two nodes is giving best prediction performance in terms of error % and correlation coefficient. Learning rate was optimized at 0.3. Different fits/equations, namely linear, quadratic and power functions, have been used to have least errors.

3 Results and Discussion

The extraction force is a combination of fabric resistance to bending, compression, shear, extension and sliding. The forces involved in the initial deformations are related to the bending and the shear stiffness of the fabric. As the test progresses, forces due to compression play a larger role as the fabric specimen is squeezed to the dimension of the ring. Fabric friction with the inner surface of the nozzle and the extensibility of the fabric also affect the withdrawal force. The greater the fabric resistance to bending, shear, compression and sliding, the higher will be the final withdrawal force. The forces generated will not only depend on fabric properties but also on nozzle size and sample size. The fabric resistance to deformation may be numerically assessed in several ways, such as the force values at the fixed extension, the extension values at a fixed force, and area under the curve to a given point. In this instrument, the maximum withdrawal force is taken as a measure to 'fabric handle' and refer to it as 'handle force'.

3.1 Correlation of Extraction Force with Shear Force and Bending Rigidity

Table 2 shows the results of extraction and radial force obtained through nozzle extraction instrument. It also shows the shear force, bending rigidity, compression energy, and mass per unit area obtained from KES-F. The correlation of extraction force with shear force and bending rigidity is shown in Figs 3 (a) & (b). It reveals that shear force and bending rigidity have good coefficient of determination (R^2) of 0.78 and 0.74 respectively with extraction force, i.e. higher extraction force in the nozzle extraction system gives higher shear force and bending rigidity in KES-F method of evaluation. Table 1 shows that the higher extraction force is observed for the fabrics having

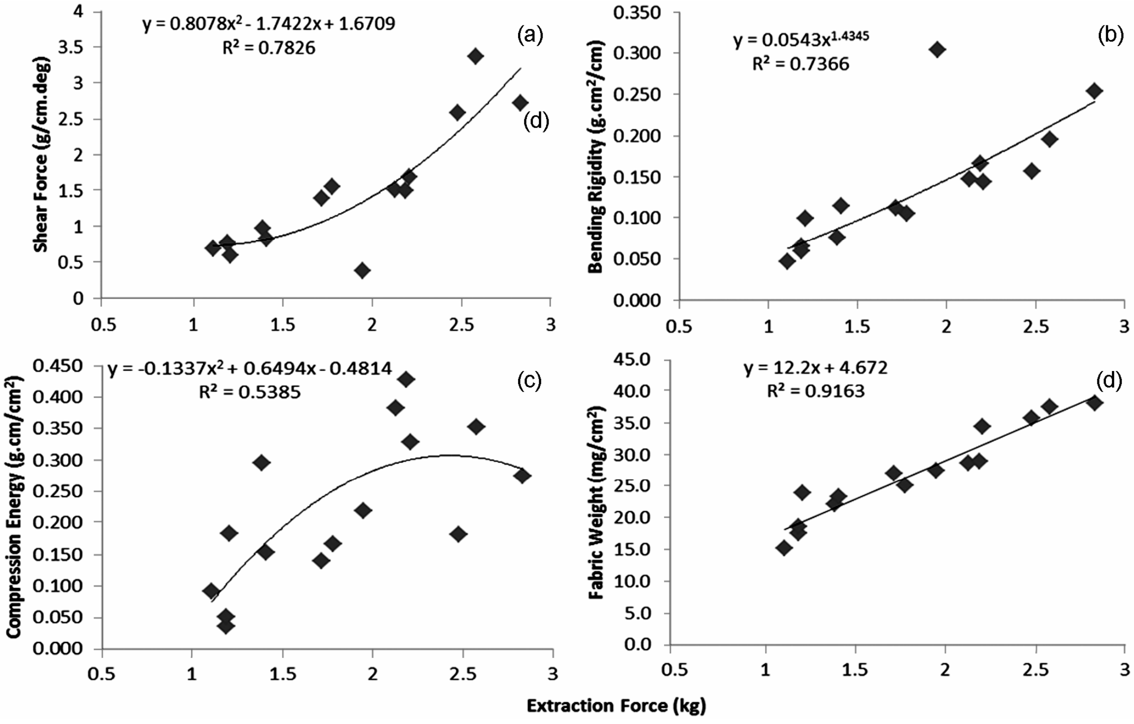

Fig. 3—Correlation between the extraction force and fabric properties

higher mass per unit area, which results in higher shear force between the yarns in the fabric, when it is pulled through nozzle.

3.2 Correlation of Extraction Force with Compression Energy and Fabric Weight

KES-F results (Table 2) of compression energy and fabric weight are correlated with extraction force of nozzle extraction system and it is shown in the Figs 3 (c) and (d) respectively. The figures show that the extraction force has coefficient of determination of 0.54 and 0.92 with compression energy and fabric weight respectively. The less correlation with compression energy may be due to the difference in the measuring principle of two systems. In KES-F, the compression energy is measured by applying standard pressure on the fabric, which is kept on the base, but in the nozzle extraction system the fabric is extracted through cylindrical nozzle in which the fabric is squeezed through the nozzle during extraction. So, the compression force applied on the fabric is different in both the systems which results in less correlation. A linear relationship is observed between the extraction force and the mass per unit area. In general, it is observed that the increase in mass per unit area also results in the increase in bending rigidity. The heavier fabric may give higher resistance for pulling or extraction through the nozzle due to higher surface contact and friction with the inner cylindrical surface of the nozzle due to its higher bending rigidity. So, extraction force increases with increase in mass per unit area of the fabric.

3.3 Correlation of Radial Force with Shear Force and Bending Rigidity

Figures 4 (a) and (b) show the correlations between average radial force obtained from nozzle extraction system and shear force as well as bending rigidity respectively obtained from KES-F system. The radial force has coefficient of determination of 0.58 and 0.33 with shear force and bending rigidity respectively. The radial force acts in radial direction (or in side wards) when the fabric is pulled through nozzle. As compared to extraction force, it is always less for suiting fabrics. So, impact of radial force on shear and bending of fabric is less as compared to extraction force. Shear force and bending rigidity do not affect the radial force significantly as they do for extraction force.

3.4 Correlation of Radial Force with Compression Energy and Fabric Weight

The correlation results between average radial force and compression energy and fabric weight of KES-F are shown in Figs 4 (c) and (d). It reveals that radial force has coefficient of determination of 0.21 with compression energy and 0.56 with fabric weight. In nozzle extraction there is no rigid support or base and the fabric itself bears all the compression force applied due to the squeezing operation through the nozzle. Due to the difference in measuring principles of these instruments, radial force has very less correlation with the compression energy. The radial force has better correlation with fabric weight and it is due to more amount of material in the nozzle for heavier fabric during extraction through nozzle.

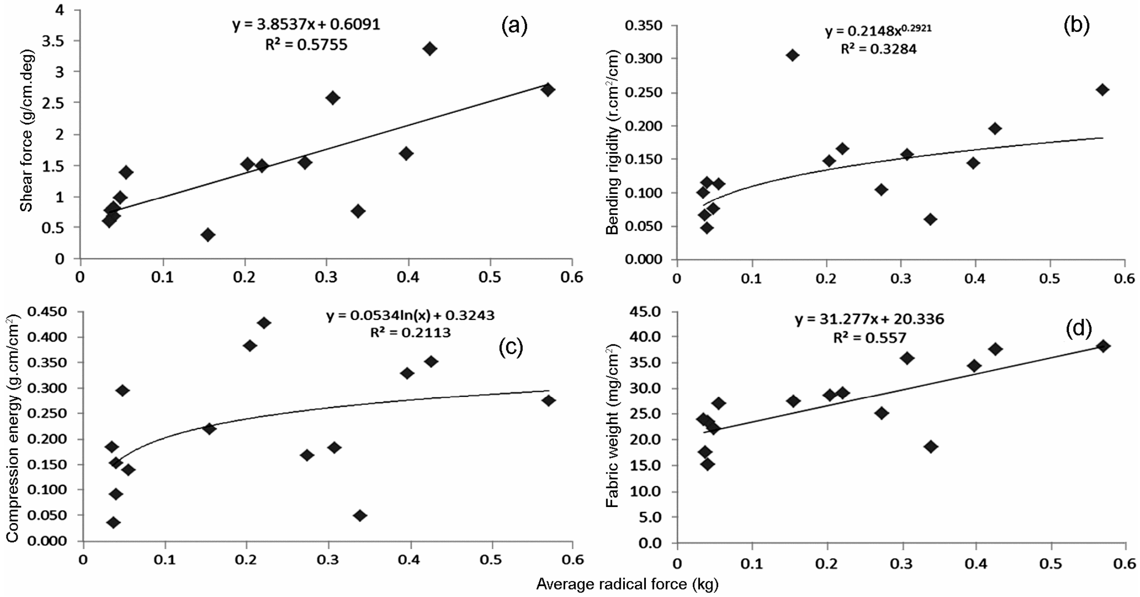

Fig. 4—Correlation between the average radial force and fabric properties

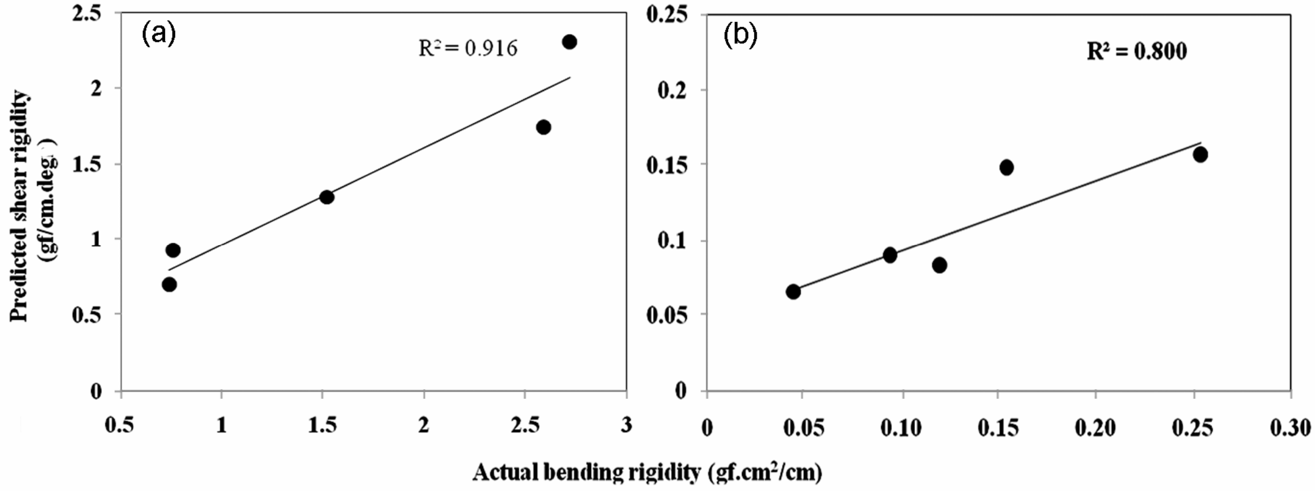

Fig. 5—Prediction of shear rigidity and bending rigidity using ANN model

3.5 Prediction of Shear and Bending Rigidity by ANN Model

Linear regression equations were also developed to predict the fabric shear and bending rigidities obtained from KES by using extraction and average radial forces as the inputs. The relationships are given below:

$$G = -0.535 + 0.888 \times EF + 1.081 \times RF$$
$$B = -0.026 + 0.097 \times EF - 0.013 \times RF$$

where G is the shear rigidity (gf/cm.deg); B, the bending rigidity (gf.cm^2/cm); EF, the extraction force (kgf); and RF, the average radial force (kgf).

The extraction force is found to be statistically significant (p<0.000) for shear and bending rigidities. However, the average radial force is statistically significant for shear rigidity (p=0.058) but not for bending rigidity (p=0.829). The prediction accuracy of regression model is shown in Table 3. As the correlation coefficients are modest (0.80 and 0.68 for shear and bending rigidity respectively) and mean absolute prediction errors are quite high (41.60 and 32.20 for shear and bending rigidity respectively), ANN models are tried to handle the nonlinearity of relationship and to cope with the noisy experimental data. From Table 3, it is noted that the prediction performance of ANN model is much better even in the unseen testing data sets. Correlation coefficients are 0.926 and 0.89 for shear and bending rigidity respectively and mean absolute prediction errors are 13.15 and 24.96 for shear and bending rigidity respectively. Figures 5 (a) and (b) show the actual and predicted values of shear and bending rigidities respectively.

Table 3—Prediction results by regression and ANN models

Fabric property	Statistical parameter	Regression model	ANN model
Shear rigidity gf/cm.deg	Correlation coefficient	0.80	0.926
	Mean absolute error ,%	41.60	13.15
Bending rigidity gf.cm^2/cm	Correlation coefficient	0.68	0.89
	Mean absolute error, %	32.20	24.96

4 Conclusion

The computerized fabric feel tester based on nozzle extraction principle was used to study the fabric feel through measuring extraction and radial forces. Then the extraction and average radial forces are correlated with the KES-F results and the later is also predicted by ANN model using the formers as inputs. The following inferences can be drawn from this study:

4.1 The extraction force obtained from nozzle extraction instrument has good correlation with KES-F parameters. The coefficient of determinations (R^2) is quite high for shear force (78%), bending rigidity (74%), and weight per unit area (92%). But compression energy has low correlation with extraction force which can be attributed to the differences in measurement principles in two equipments.

4.2 The average radial force has lower correlation with KES-F parameters compared to that of extraction force. This is due to the fact that radial force is an indirect value obtained because of extraction force.

4.3 The KES-F parameters, namely shear and bending rigidities, can be predicted by ANN model using extraction force and average radial force as an input parameters. Fabric extraction and radial forces obtained through nozzle extraction instrument can be used to predict fabric handle/feel value.

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