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Use of Artificial Neural Networks for Modelling the Drape Behaviour of Woollen Fabrics Treated with Dry Finishing Processes

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Abstract
The relationship between fabric drape, low stress mechanical properties and finishing processes is relatively complex. This paper demonstrates the possibility of using artificial neural networks to identify the fabric drape of woollen fabrics treated with different dry finishing processes (stenter, decatising, superfinish, formula, KADE strong/weak - autoclave decatizing). The mechanical and surface properties of woollen fabrics were measured by both the KES-FB and FAST systems, and then the results obtained were applied to artificial neural network (ANN) modelling. ANN models were compared by verifying the Mean Square Error (MSE) and Correlation coefficient (R-value). The results indicated that each model is capable of making quantitatively accurate drape behaviour predictions for wool fabrics (R_{min} = 0.92, MSE_{min} = 0).

Key words: *artificial neural network, fabric drape, KES, FAST, wool fabrics, finishing processes.*

Introduction

Fabric handle corresponding to psychological perception of a fabric's character, such as soft, stiff, rough, rigid, prickle, etc. is related to the fabric's mechanical and physical properties. Subjective estimation of fabric handle is not enough nor an accurate way of comparing fabric quality since experts' feelings and expressions in terms of subjective sensations are different. In an attempt to quantitatively assess handle, two measurement systems, namely the Kawabata Evaluation System for Fabrics (KES-FB) [1] and Fabric Assurance by Simple Testing (FAST) [2] have been developed. These two systems give objective evaluation of fabric handle related to the mechanical and physical properties of textile surfaces, mainly tensile, shear, bending, compression, surface and extension properties.

In wool fabrics, the frictional properties and related surface properties are important components of fabric handle, and they are improved by different combinations of wet and dry finishing processes. Decatising is a normal dry finishing step applied in various forms for many wool and wool blend fabrics. High pressure decatising is an effective mechanical softening treatment that leads to an increase in the surface smoothness and handle properties of wool fabrics, thus resulting in lustrous, soft and smooth handle. In this process wool fabric is interleaved with a cotton or cotton/synthetic wrapper, at a regain usually between 5 and 15%, and wound into a batch on a hollow perforated cylinder in an autoclave (pressure vessel) with steam greater than atmospheric pressure. The direction of steam flow can usually be varied from outside-to-inside or alternatively inside-to-outside, with both cohesive and permanent set being introduced into the fabric. After purging with steam to remove air, the roll is steamed under pressure for up to five minutes at temperatures between 105 and 130 °C. The fabric and wrapper are then cooled by drawing air at ambient temperature through the roll. The amount of permanent set introduced depends on the fabric pH, the time of the treatment, the temperature and relative humidity of the steam and the regain of the fabric. In the semi-decatising process, wool fabric is wound onto a perforated drum between interleaving cotton blankets. Steam is sent through the perforated drum for several minutes to ensure moisture and heat. The controlling time, pressure, heat, moisture and cooling result in effective mechanical softening and better surface properties like a luxurious, soft and smooth handle [3 - 4]. Superfinish and Formula are kinds of decatising processes in which the fabric is processed continuously. The difference between the decatising process and those processes is that in the decatising machine the fabric passes through the cylinder and felt, whereas in Formula and Superfinish it passes through the cylinder and continuous silicon tape. In the Formula process, the pressure applied is higher than in Superfinish. KADE, on the other hand, is a discontinuos process in which the fabric is processed on an auto-clave, also known as autoclave decatizing. Here the fabric is wrapped in a cotton blend fabric and processed with steam on two sides. The strength (strength and weakness) depends on the amount of pressure applied. For the selection criteria of fabrics in the apparel industry, another important factor is fabric drape. It plays a significant role in the aesthetic appearance of a fabric by satisfying the relation with the fabric's mechanical properties. The relationship between fabric drape and low stress mechanical properties (bending, rigidity, formability, tensile and shear properties and compressibility) is relatively complex [5]. Many researchers have discussed the relationship between the drape coefficient and mechanical properties. For instance, Tokmak et al. analysed the mechanical properties of wool and wool-blended fabrics using FAST, KES-FB and Cusick's drape meter. They investigated both the relationship between the drape ratio, KES-F bending and shear values, and between FAST bending and shear values [6]. Shyr et al. proposed a new dynamic drape automatic measuring system and by using it, they compared the relationship between the fabric drape coefficient and sixteen physical properties of woven fabrics based on the KES-FB system [7]. Pattanayak et al. predicted the drape profile of cotton fabrics using an artificial neural network from the mechanical properties of fabrics that were measured by the KES-FB system [8]. Additionally Jedda et. al., focused on this relation by taking into account the results of the FAST measurement system [9].

Accurate modelling of the drape behaviour of fabric is extremely difficult with conventional analytical solutions since it requires rigorous mathematical nonlinear

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equations. From a textile point of view, to know the effect of some production parameters in various textile applications, neural network models are used since they have proved to be useful tools for many prediction-related problems [10 - 11]. For instance, to determine the hairiness of polyester-viscose blended yarns, an artificial neural network model was set up based on various process parameters. [12]. For the dyeing of fabrics, in order to find appropriate dyes for achieving the colour required, artificial neural network models were used in [13]. To identify the thermal resistance of textile fabrics, two different back-propagation artificial neural network architectures were compared in [14]. In another study, ANN models were used to predict the sewing process. Stitch type, seam density, sewing needle type and sewing yarn type were used as inputs of ANN models to predict the seam strength and seam elongation at break [15]. In spinning, the leveling action point in drawframes was investigated by taking into account the feeding speed and tension as well as break draft parameters using an ANN [16]. In all those studies, results showed that the Artifical Neural Network (ANN) algorithms provided more accurate predictions.

Due to this fact, in this research the application of the artificial neural network approach for modelling the drape behavior of woollen fabrics treated with dry finishing processes, which has not been previously discussed in literature using intelligent techniques, was explored. In the study, wool fabrics were treated with different finishing processes such as shearing, stenter, decatising, superfinish, and KADE strong and weak in a different order, and then the fabrics' mechanical and surface properties were measured by both the KES-FB and FAST systems. The processing of fabrics was carried out on an industrial scale using real-scale production machinery. Shearing took place on a shear machine with a spiral knife at 1500 revolutions per minute. The drying temperature during the fabric drying process (stenter) was 160 to 180 °C. Superfinish was performed using a belt pressing machine at a temperature of 145 °C. Autoclave decatizing (KADE) was carried out within a closed system (KD) where the fabric was wrapped together with a satin wrapper on a perforated cylinder through which steaming took place under different conditions. During the experiments, although the treatment parameters (temperature, pressure, velocity) for each treatment stayed almost at the same values, the sequences and number of treatments were varied in order to analyse the prediction capabilities of models with respect to KES-FB and FAST measurement results. Thus the properties obtained at the end of KES-FB and FAST measurements such as the tensile, shear, bending, compression and surface properties were used as input parameters of ANN models, which were then analysed and compared to predict the drape behaviour of wool fabrics. Based on the results of the ANN models developed, the models proved capable of drape prediction using both KES and FAST measurements. In other words, although the two measuring systems KES-FB and FAST show differences in the determination of the mechanical, surface and dimensional properties of the fabrics, which include tensile, shear, bending, compression, surface friction and relaxation shrinkage, with this research they all showed that the prediction capability of an ANN for the drape behaviour of woollen fabrics subjected different dry finishing processes is possible.

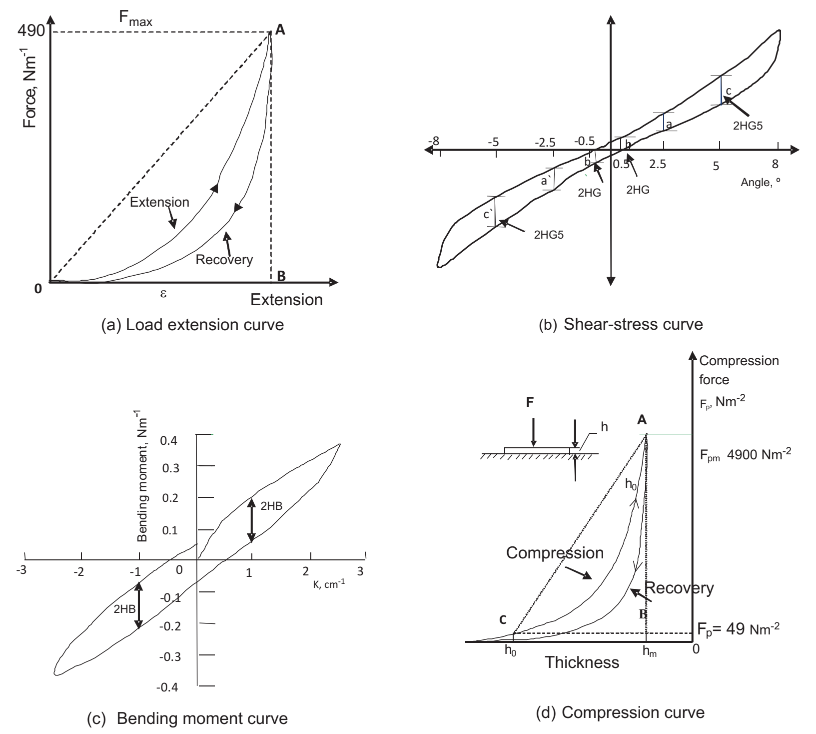
Description of the physical model

Fabric drape, which is related to a fabric's mechanical and physical properties, is considerably influenced by the factors of bending, shear and extension, formability, thickness and weight. *The bending behaviour of fabric* depends on the inside friction of fibres in the yarn. The number of interlacing points in a fabric is one of the most important factors that define bending rigidity. The more interlacing points there are on the surface of fabric the more it can be bent. The bending rigidity of fabrics is also directly connected to their thickness and weight as well. It is known that fabric shows a decrease in the fabric drape coefficient with increasing bending rigidity. The *shear properties* of fabric depend on its constructional parameters, such as the weave, yarn and linear density. The shear properties also depend on friction arising between yarns because of the resistance of the yarn to rotation during shear deformation. Furthermore friction forces also arise because of the crisscrossing of warp and weft threads. Fabrics with high yarn density are stiffer because there is lower sliding between warp and weft threads than in fabrics with low yarn density. Fabrics with lower shear rigidity mean that the impact of shear properties (shear rigidity) on fabric draping is less prominent. The *extensional properties* of fabrics are mostly influenced by their constructional parameters and the properties of weft and warp threads. Extension properties do not have a high influence on fabric drape, especially if they are measured in a low loading area. The *formability of fabric* could be defined as the ability of the shell fabric part to reform to dimensional forms. In most cases it depends on how easily the flat surface of the fabric could be re-formed. Furthermore it is a criterion of the ability of shell fabric to adapt to three dimensionally shaped garments [17]. Fabric formability depends on the constructional parameters i.e. fibre structure, yarn structure, fabric geometry (weave, density, thickness) and the technology of fabric production [18]. Increasing the density of threads of some weaves results in an increase in the interlacing points. The more interlacing points in a limited area of fabric, the more rigid the shell fabric is, because the threads are tightly connected to each other. On the other hand, fewer interlacing points enables more free space between the threads, and as a result the fabric is less rigid, and therefore formability is higher. Fabric with a high value of formability has lower ability to re-form into a 3D shape, consequently this means that the drape coefficient is high. F*abric thickness***,** which in itself depends on yarn fineness and densit, as well as on the fabric weave, has an influence on the *fabric weight* by surface area. As fabric draping is a function of the weight of the fabric, higher fabric weight obviously means a higher draping coefficient. Even slight changes in fabric thickness can exhibit a considerable impact on fabric rigidity, and with it on the draping coefficient [17, 19 - 22].

Based on the parameters briefly explained above, to predict the drapeability of fabric is not easy since its drape is unstable and the drape shape changes easily minute by minute, acting on the force of draped fabrics. Additionally textile material has nonlinear mechanical properties and with different dry finishing procedures it will become more complicated to predict its behaviour in relation to drapeability. Besides this, during the production of fabric, the fabric is exposed to different kinds of strain such as tensile, pressure, shear and bending. Therefore, in our study, in order to

***Table 1.** KES-FB parameters.*

Parameters		Description	Unit
Tensile	LT	Linearity in extension (Higher value, stiff feeling)	
	WT	Tensile energy (Lower value, hard extension)	Nm^{-1}
	RT	Resilience (Lower value, inelastic)	%
	EM	Tensile strain (Extensibility of the fabric)	%
Bending	B	Bending stiffness (Higher value, stiffer fabric)	10^{-4}Nm^2/m
	2HB	Bending hysteresis (Higher value. inelastic)	10^{-2}Nm/m
Shearing	G	Shear rigidity (Higher value, stiffer fabric)	Nm^{-1}/·°
	2HG	Shear hysteresis (Higher value, inelastic)	Nm^{-1}
	2HG5	Shear hysteresis at 5° shear angle (Higher value, inelastic and wrinkle problems)	Nm^{-1}
Compression	LC	Linearity in compression (Higher value, hand feeling)	
	WC	Compression energy (Lower value, hard feeling)	Nm/m^2
	RC	Resilience (Lower value, inelastic)	%
Surface	MIU	Mean frictional coefficient (Too high or too low, yield unusual surface feeling)	
	MMD	Surface frictional roughness (Higher value, hard feeling)	
	SMD	Surface geometrical roughness (too high or too low, unusual feeling of surface)	µm
Thickness	T	Fabric thickness	**mm**
Weight	W	Fabric weight per unit area	mg cm^{-2}



(a) Load extension curve

(b) Shear-stress curve

(c) Bending moment curve

(d) Compression curve

***Figure 1.** Tensile, shear, bending and compression curves obtained by KES-FB.*

evaluate the drape behaviour of woolen fabrics treated with different dry finishing processes, the FAST and KES-FB measuring systems were used to realise the mechanical, surface and dimensional properties of the treated fabrics prior to drape prediction in terms of tensile, shear, bending, compression, surface friction and relaxation shrinkage. Thus these properties were used as inputs for modelling the ANN architecture to predict the treated fabric's drape. Since the two measuring systems show differences in the determination of these properties, they might cause variations in the drape prediction of ANN models. Therefore the properties obtained from the KES-FB and FAST measuring systems are firstly clarified below to explain parametric inputs of the physical model for the ANN architecture.

The KES-FB system measures the following fabric properties: tensile, shearing, compression, surface thickness and weight at low load conditions. This low load condition is used to simulate the action of fingers pulling the fabric during handling evaluation [23]. The parameters that can be measured using KES-F instruments are listed in ***Table 1***.

For tensile and shearing properties, fabric is tested under an extension load between 0 and a maximum force of 4.90 N cm^{-1}. Fabric is released until it returns to its original length and a load extension curve is obtained, as seen ***Figure 1.a***. The tensile energy can then be estimated based on the area under the load extension curve, as seen in ***Figure 1.a***.

For shear properties, the sample is sheared at an 8° angle along the longer side of the fabric under a constant tension of 0.091 N cm^{-1}. From the graph of shear stress-strain seen in ***Figure 1.b***, shear stiffness (G) can be measured based on the slope of the shear force-shear strain curve. Besides this, the hysteresis at 0.5 degrees (2HG) and that at 5 degrees (2HG5) are calculated.

For measuring the bending property, the fabric is bent between curvatures -2.5 and 2.5 cm^{-1}, and a bending curve including the bending rigidity (B) and moment of hysteresis (2HB) is obtained, as seen in ***Figure 1.c***. Bending rigidity can be measured by taking the slope of the bending curve.

For the compression property, the fabric is placed between two plates and during the application of pressure up to a value of 0.49 N cm^{-2}, the fabric thickness is monitored. The pressure is released in order to observe the recovery process of the fabric. Due to this process, a graph of load and extension is plotted in order to calculate the LC: Linearity of the compression thickness curve, WC: Compres-

***Table 2.** Fabric properties calculated from FAST measurements.*

Properties	Calculated from
Bending rigidity	Bending length
	Mass per unit area
Shear rigidity	Bias extensibility
Formability	Bending rigidity
	Extensibility at low loads
Finish stability	Fabric surface thickness
	Relaxed surface thickness
Surface thickness	Thickness at 2 cm^2 and 100 cm^2
	Released surface thickness
	Released thickness at 2 cm^2 and 100 cm^2

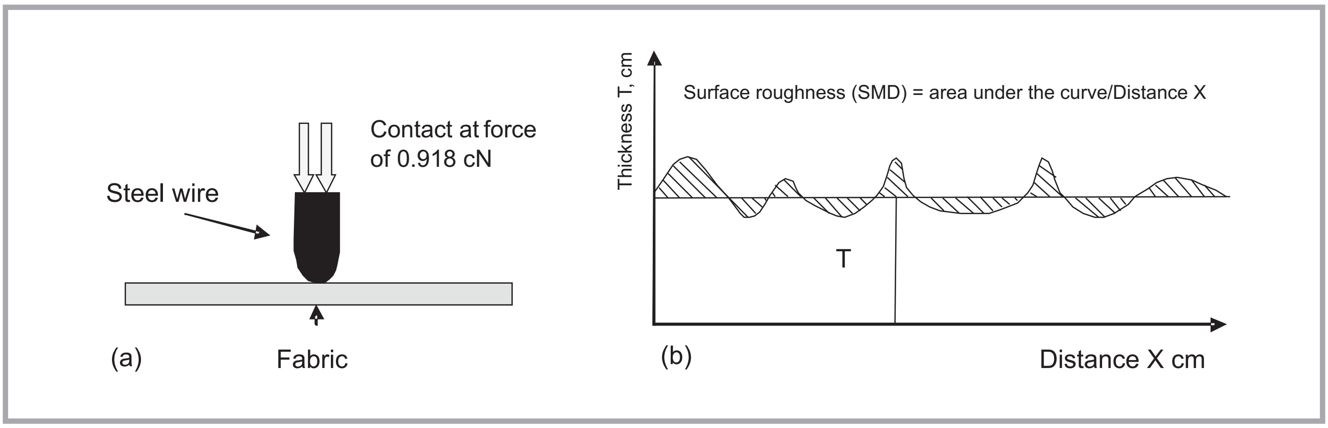


***Figure 2.** Surface roughness measurement (a) and graph (b) by KES-FB.*

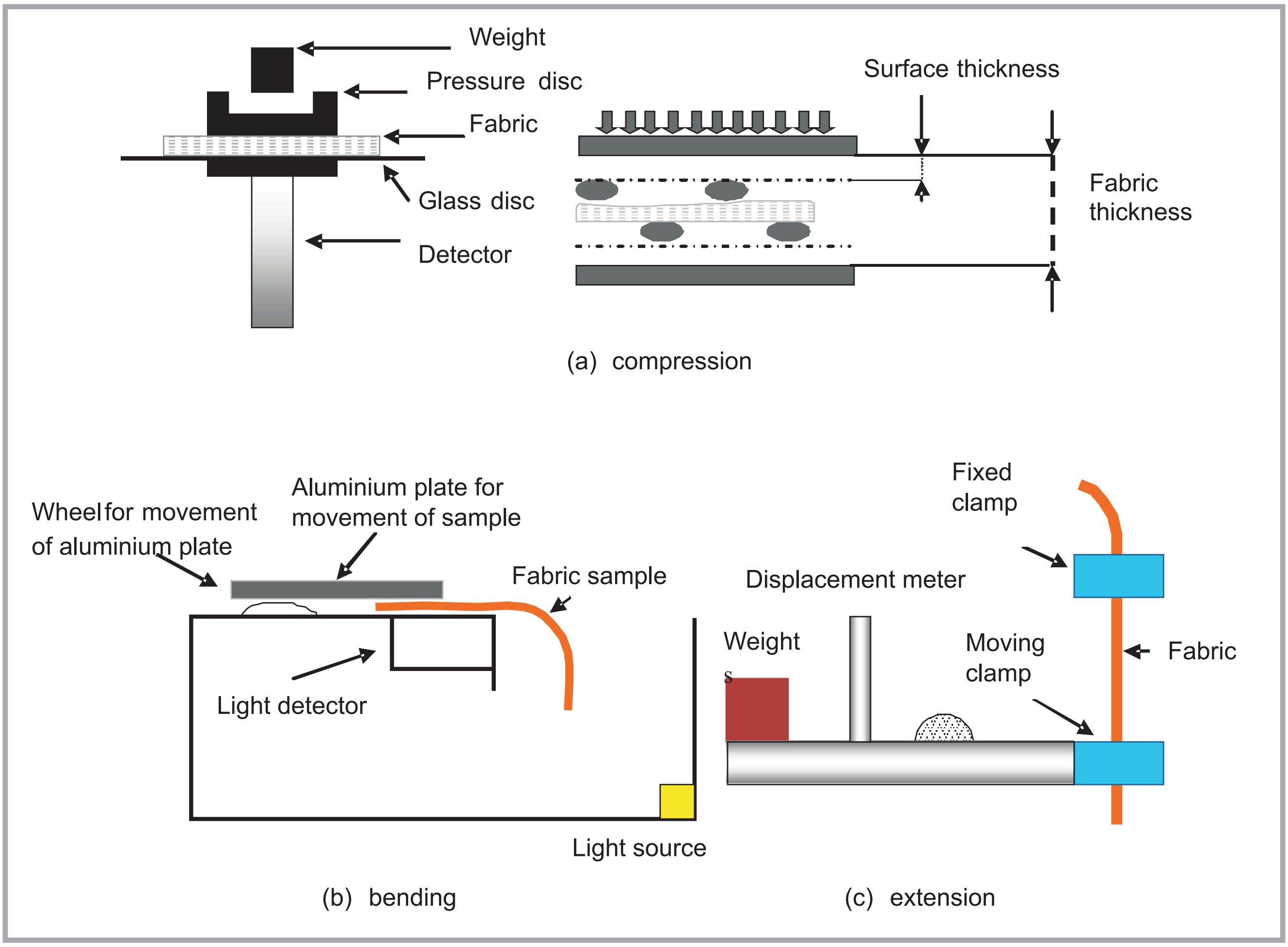


***Figure 3.** Schematic diagram of compression, bending and extension in the FAST measuring system.*

sion energy. and RC: Compression resilience, as shown in ***Figure 1.d***.

For the surface property, U-shaped steel wire that has a diameter of 0.5 mm is used as shown in ***Figure 2.a***. Due to the movement of this wire, the surface roughness is monitored as shown in ***Figure 2.b***. Based on this movement, the surface roughness (SMD), mean deviation of the coefficient of friction (MMD) and the mean value of the coefficient of friction (MIU) are determined.

The FAST system measures the following fabric properties: bending, shearing, formability, surface thickness and finish stability, as summarised in ***Table 2***.

The thickness of the fabric is measured by a compression meter, seen in ***Figure 3.a***, at two predetermined loads, which are 0.0196 and 0.98 N cm^{-2}, whereas the bending property is measured by bending equipment based on the cantilever bending principle shown in ***Figure 3.b*** [24, 25]. The bending length is determined according to the edge of the fabric detected using photocells. The bending rigidity is calculated based on the bending length and fabric weight. The extensibility of the fabric is measured by extension equipment,

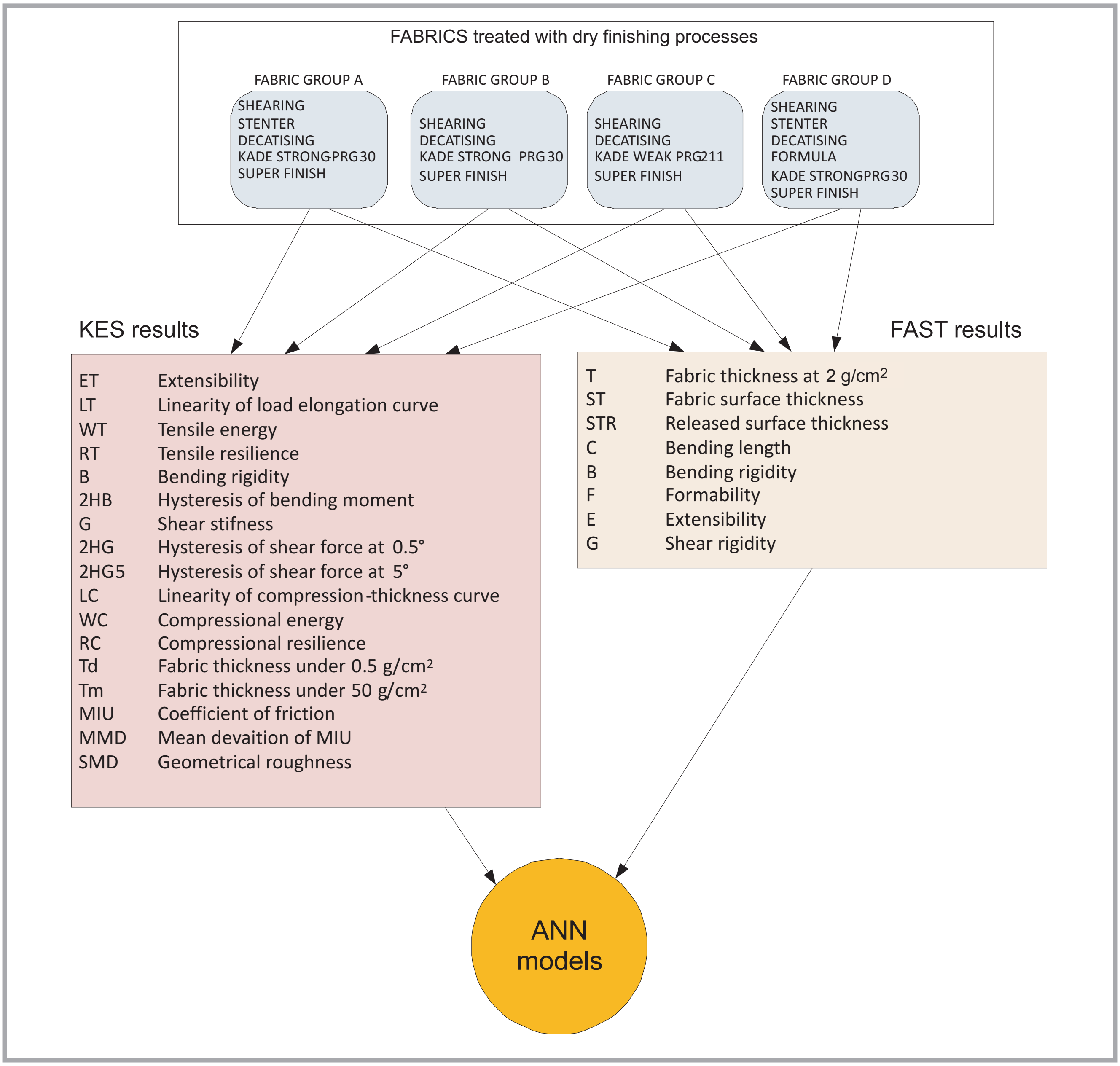


Figure 4. *Physical model for constructing ANN Architecture.*

seen ***Figure 3.c***, in the warp and weft directions under three predetermined loads: 0.049, 0.196 and 0.98 Ncm^{-1}. These loads are to imitate the values of deformation which usually occur during the process of making up. Meanwhile, in the bias direction the extensibility is measured at only 0.049 Ncm^{-1} loads, where the shear extensibility as well as shear rigidity are calculated. All these values are then used to calculate the fabric formability. Dimensional stability is a method to measure the amount of relaxation shrinkage and hygral expansion and is mostly suitable for determining the dimensional stability of wool fabrics.

To sum up, as described above, the two measuring systems, KES-FB and FAST, show differences in the determination of mechanical, surface and dimensional properties, which include tensile, shear, bending, compression, surface friction and relaxation shrinkage. Therefore for our study it is intended to compare the properties obtained from the KES-FB and FAST measuring systems for ANN models in relation to the drape prediction of fabrics subjected to drying finishing processes. Accordingly parametric inputs of the physical model for the ANN architecture include KES and FAST measurement results of fabrics subjected to drying finishing processes, namely shearing, stenter, decatizing, superfinish, and KADE strong and weak, shown in ***Figure 4***. Information based on the drying finishing processes are presented in the section 'Experimental method and data collection'.

Artificial neural network models

In order to predict the drape behaviour of woollen fabrics treated with different dry finishing processes, the steps shown in ***Figure 5*** were used for modelling the ANN architecture.

The ANN models designed have mainly separate inputs of KES and FAST results, with some of them also including

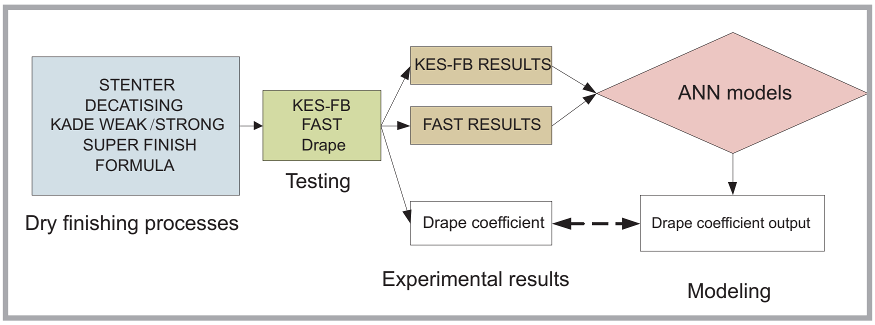


__Figure 5.__ Steps taken in research for modelling the ANN architecture of wool fabrics subjected to dry finishing processes.

the weight of the samples. Besides this models contain one hidden layer and one output vector (drape coefficient) (see ***Figure 6***). In a simple ANN, interconnections of neurons are supported by the scalar weight *w* along with biases in order to form the output vector [26]. As seen in ***Figure 6***, typical ANN models used for this study consist of three layers: the input layer, one hidden layer and the output layer. The first and third models were designed to measure the prediction capability of KES and FAST results for the drape behaviour, respectively. However, in the second and fourth model, in addition to KES and FAST results, the weights of the samples were also considered in order to assess if the weight is an important parameter for the prediction models or not, despite the fact that it is used to determine some of the properties obtained by FAST and KES measurements. Therefore it is also attempted to analyse separately in order to see the effect on the drape prediction capability of the models in addition to the FAST and KES measurement results usually obtained.

In the networks, information along neurons is transferred through links characterised by the weights using a transfer function. An external bias is applied to each neuron to increase the activation of the transfer function. The process starts with the randomly assigned weight functions (*w*) and continues by minimising the error function. The error between the network output and actual output was calculated using the mean square error (mse). The mse can be obtained using

$$\mathrm{mse} = \frac{1}{n}\sum_{k=1}^{n}[a(k) - p(k)]^2 \qquad (1)$$

where *a* is the actual output, *p* the output predicted from the neural network model, and *n* is the number of input vectors.

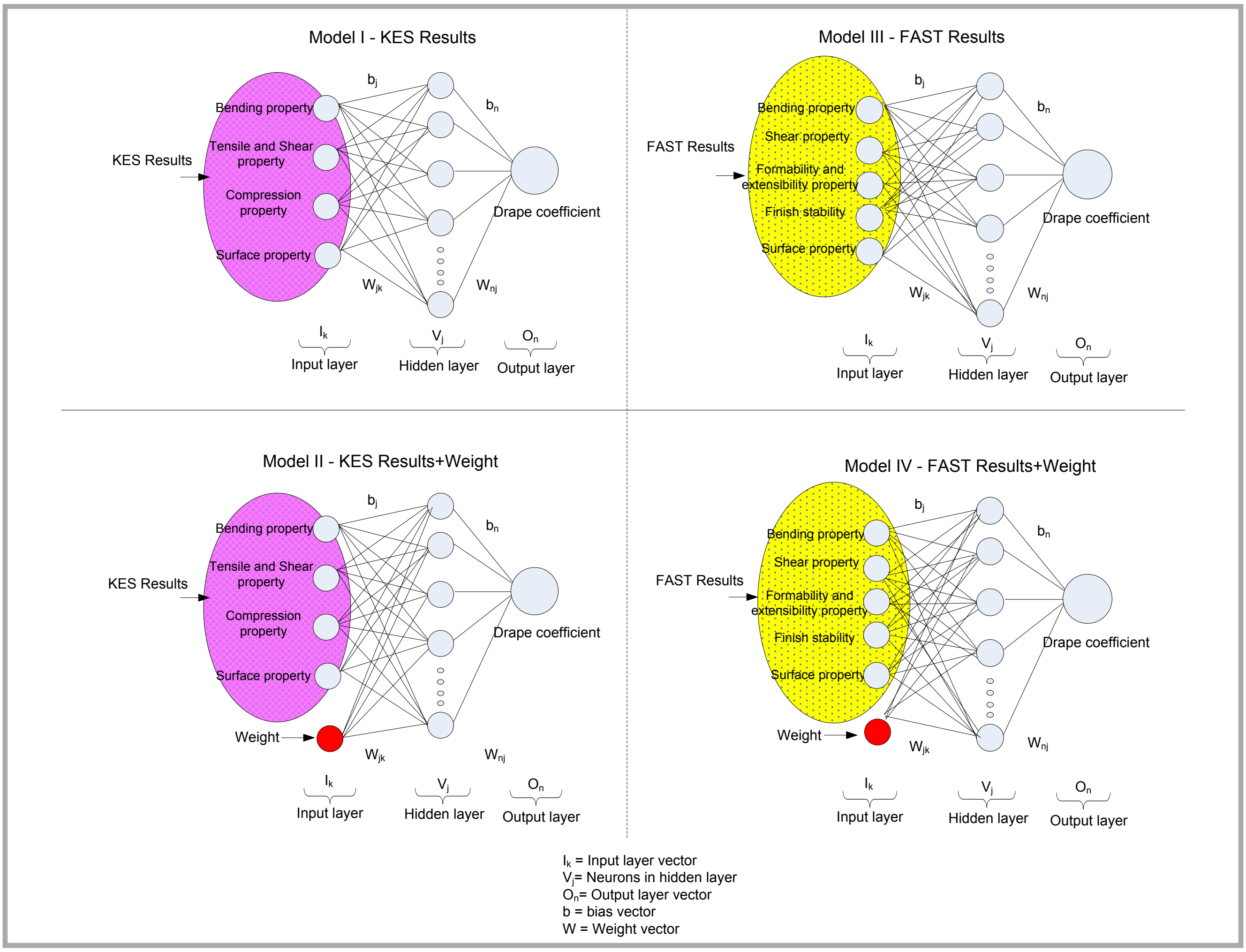


__Figure 6.__ ANN models developed to predict the drape behaviour of wool fabrics: model I-using KES results, model II-using KES and weight results, model III-using FAST results, model IV-using FAST and weight results.

Back propagation

In the network, in order to minimise the error between the actual input and training output, back propagation was used. One iteration example of back-propagation is given as follows

$$y_{k+1} = y_k - \varphi_k g_k \tag{2}$$

where y_k is the vector of current weights and biases, g_k the current gradient, and φ_k is the learning rate.

Due to various studies, it was established that neural networks with one hidden layer are suitable for the majority of applications, and that the second hidden layer can improve the performance of the network if there is a complex relationship between input and output parameters [27]. For the present study, a network of three layers with one hidden layer was used. In order to show the performance of the model, sigmoid transfer function 'sigmoid'(3) and tangent hyperbolic function 'tanh'(4) were both tried; [26]

$$F(x) = \frac{1}{1 + e^{-x}} \tag{3}$$

$$F(x) = \frac{e^{x} - e^{-x}}{e^{x} + e^{-x}} \tag{4}$$

The network was scaled by normalising the mean and standard deviation and was trained with *1000* training *epochs* and *five runs.*

Table 3. *Finishing processes applied to fabrics and their parameters.*

Fabric group	Finishing process & order	Processing temperature, °C	Processing pressure, MPa	Processing velocity
A	SHEARING			1500 m/min
	STENTER	180	NA	28 m/min
	DECATISING	140	0.4	18 m/min
	KADE WEAK PRG 211	95	0.04	60 s
	SUPER FINISH	145	10.0	20 m/min
B	SHEARING			1500 m/min
	DECATISING	140	0.4	18 m/min
	KADE STRONG PRG 30	110	0.1	150 s
	SUPER FINISH	145	10.0	20 m/min
C	SHEARING			1500 m/min
	DECATISING	140	0.4	18 m/min
	KADE WEAK PRG 211	95	0.04	60 s
	SUPER FINISH	145	10.0	20 m/min
D	SHEARING			1500 m/min
	STENTER	160	NA	30 m/min
	DECATISING	140	0.4	18 m/min
	FORMULA	155	12.0	6 m/min
	KADE STRONG-PRG 30	110	0.1	150 s
	SUPER FINISH	145	10.0	20 m/min

Table 4. *Summary of fabric properties measured.*

Symbol		Measured fabric property	Min	Max
	W	Fabric weight	153.2	165.6
KES System	ET	Extensibility	2.28	3.43
	LT	Linearity of load elongation curve	0.512	0.656
	WT	Tensile energy	3.55	4.4
	RT	Tensile resilience	76.14	86.05
	B	Bending rigidity	0.0182	0.0847
	2HB	Hysteresis of bending moment	0.009	0.0397
	G	Shear stifness	0.44	0.99
	2HG	Hysteresis of shear force at 0,5°	0.2	1.15
	2HG5	Hysteresis of shear force at 5°	0.65	2.25
	LC	Linearity of compression-thickness curve	0.232	0.308
	WC	Compressional energy	0.059	0.21
	RC	Compressional resilience	61.11	67.37
	Td	Fabric thickness under 0.5 g/cm2	0.175	0.527
	Tm	Fabric thickness under 50 g/cm2	0.075	0.361
	MIU	Coefficient of friction	1.232	1.783
	MMD	Mean devaition of MIU	1.328	7.967
	SMD	Geometrical roughness	5.906	11.39
FAST System	T	Fabric thickness at 2gr/cm2	0.274	0.568
	ST	Fabric surface thickness	0.057	0.197
	STR	Released surface thickness	0.059	0.203
	C	Bending length	13.8	17.3
	B	Bending rigidity	4.0	8.4
	F	Formability	0.16	0.47
	E	Extensibility	2.1	3.8
	G	Shear rigidity	20.5	70.3

Experimental method and data collection

For this research, a total of 64 samples of 100% wool fabrics were taken, of which 50 (approx. 80%) were used for training and 14 for testing of the network. In all samples, the weft yarn count was 20 tex and the warp yarn count 22 tex. There were a total of four different weave sets: plain, twill, sateen and warp ribs. All fabrics were firstly subjected to shearing and then different finishing processes (stenter, decatizing, superfinish, formula, and KADE strong and weak) in a different sequence. Finishing processes were applied to the fabrics in a sequence,the parameters of which are summarised in ***Table 3***.

After the production, all the fabrics were firstly placed on a flat surface for at least 24 hours prior to testing under standard atmospheric conditions (65 ± 2% RH, 20 ± 2 °C). The mechanical properties of the samples were measured by both the Kawabata Evaluation System (KES) and Fabric Assurance by Simple Testing (FAST) system. The drape parameters of these fabrics were measured according to ASTM BS 5058.

These systems are designed to measure key mechanical properties of fabrics: KES-FB1, KES-FB2, KES-FB3 and KES-FB4 measure tensile and shear, pure bending, compression and surface properties of fabrics, whereas SiroFAST-1, SiroFAST-2, SiroFAST-3 and SiroFAST-4 measure compression, bending, extension and dimensional stability, respectively. In our research, the KES and FAST properties of the fabrics measured, which were used as inputs of ANN models, are summarised in ***Table 4***.

Results and discussion

After setting up the network model with relevant data as mentioned above, the network efficiency was tested by increasing the number of neurons and by changing the transfer function. Initially a network was created with two neurons and a single hidden layer, then manually the number of neurons was increased. Performances of the ANN models were measured by the mean square error *(MSE)* and correlation coefficients (*R*-value). For ANN network testing, the fabric specifications,given in ***Table 5*** were used.

The results of four models including the hyperbolic tangent activation function *(tanh)* and sigmoid activation function *(sigmoid)* with different neurons are shown in ***Table 6***, and a comparison of transfer functions with respect to the number of neurons for model I is given in ***Figure 7***. According to ***Table 6***, it was found that the *tanh* function presented better performance results than the sigmoid function, with lower mean square errors. As seen from the table, the MSE of the sigmoid function is generally observed at around 0.009, while the *tanh* is observed within the range of 0.004 and 0.008 in the ANN models. Actually this result also matches the literature. The hyperbolic tangent activation function for neurons of hidden layers was proved to provide the best performance in ANNs mentioned in previous studies [27]. Furthermore it is clear that the MSE of the ANN models with the tanh function changes according to the number of neurons. On the other hand, changing the number of neurons does not present any significant effect on the MSE of the ANN models with the sigmoid function (see ***Table 6***). Considering these results, the networks (Model I - IV) including tanh functions were optimised with five (MSE_5 = 0.0046), eight (MSE_8 = 0.0051), nine (MSE_9 = 0.0064) and twelve neurons (MSE_{12} = 0.0048), respectively.

The next step was to perform an analysis of the network response with respect to the actual output. The prediction capabilities of four neural network models are shown in ***Figure 8 - 11***, respectively. These figures were drawn to assess the over fitting phenomenon of models, which can ensure information about the accuracy of predictions. As is seen from the figures, the models did not over fit the data and were able to generalise on unseen/test data well.

The prediction performances of the neural network models are summarised in ***Table*** *7*. Both of the models developed using FAST and KES results were capable of making quantitatively accurate drape behaviour predictions. All of the models were able to achieve a good fit to the drape coefficients measured, as evidenced by the high mean R values, ranging from 0.92 to 0.94. Whilst providing an insight into possible relationships between the independent input parameters of KES and FAST results, it can be concluded that models with these parameters predicted the drape coefficients of the samples well; however it is necessary to stress that these findings corresponded to the range of material properties and processing conditions investigated. The results in ***Table 7*** also suggested that the removal of the weight of samples as inputs

Table 5. *Test set of fabric specifications.*

Sample no	Fabric group	Weave type	Finishing process	Drape coefficient
1	A	Warp ribs	AFTER SUPER FINISH	0.36
2	D	Warp ribs	AFTER STENTER	0.33
3	A	Twill	AFTER STENTER	0.45
4	C	Warp ribs	AFTER DECATISING	0.50
5	B	Warp ribs	AFTER DECATISING	0.49
6	A	Plain	AFTER KADE STRONG-PRG 30	0.36
7	D	Plain	AFTER SUPER FINISH	0.33
8	D	Twill	AFTER DECATISING	0.51
9	D	Warp ribs	AFTER KADE STRONG-PRG 30	0.36
10	B	Warp ribs	AFTER KADE STRONG PRG 30	0.36
11	A	Sateen	AFTER DECATISING	0.45
12	C	Warp ribs	AFTER KADE WEAK PRG 211	0.43
13	D	Warp ribs	AFTER FORMULA	0.37
14	C	Sateen	AFTER SUPER FINISH	0.45

Table 6. *Performance of ANN models with the sigmoid and tanh functions according to the number of neurons.*

No. of Neurons	Model I		Model II		Model III		Model IV	
	Minimum MSE		Minimum MSE		Minimum MSE		Minimum MSE	
	Tanh	Sigmoid	Tanh	Sigmoid	Tanh	Sigmoid	Tanh	Sigmoid
2	0.0048	0.0095	0.0061	0.0093	0.0068	0.0092	0.0077	0.0093
3	0.0047	0.0094	0.0062	0.0092	0.0080	0.0093	0.0061	0.0093
4	0.0051	0.0094	0.0058	0.0092	0.0068	0.0094	0.0064	0.0093
5	**0.0046**	0.0094	0.0077	0.0092	0.0068	0.0094	0.0055	0.0093
6	0.0049	0.0094	0.0055	0.0092	0.0071	0.0095	0.0065	0.0093
7	0.0052	0.0094	0.0056	0.0092	0.0065	0.0095	0.0066	0.0094
8	0.0060	0.0094	**0.0051**	0.0070	0.0066	0.0094	0.0050	0.0094
9	0.0060	0.0094	0.0057	0.0091	**0.0064**	0.0094	0.0060	0.0094
10	0.0057	0.0094	0.0063	0.0092	0.0066	0.0095	0.0052	0.0094
11	0.0060	0.0094	0.0060	0.0092	0.0072	0.0095	0.0052	0.0095
12	0.0059	0.0094	0.0060	0.0091	0.0068	0.0095	**0.0048**	0.0095
13	0.0059	0.0094	0.0059	0.0092	0.0064	0.0095	0.0059	0.0094
14	0.0064	0.0094	0.0066	0.0092	0.0066	0.0095	0.0052	0.0095
15	0.0063	0.0094	0.0080	0.0092	0.0065	0.0096	0.0060	0.0095

Table 7. *Prediction performances of four neural network model.*

	Model I	Model II	Model III	Model IV
MSE	0.000	0.000	0.001	0.002
NMSE	0.208	0.243	0.358	0.428
MAE	0.025	0.028	0.032	0.035
Min Abs Error	0.005	0.011	0.002	0.003
Max Abs Error	0.050	0.050	0.059	0.063
R	0.940	0.929	0.933	0.920

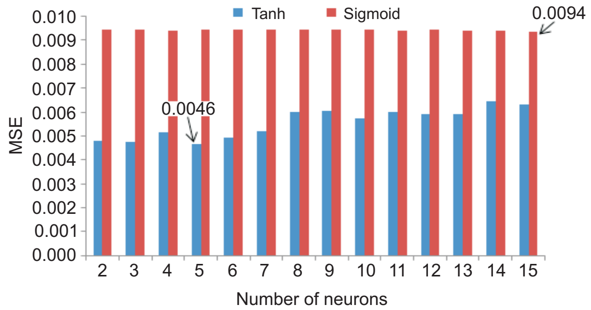


Figure 7.

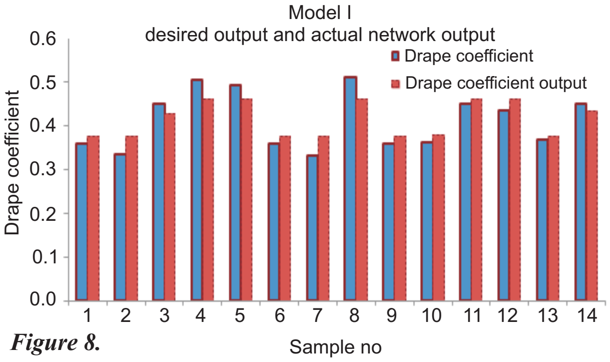


Figure 8.

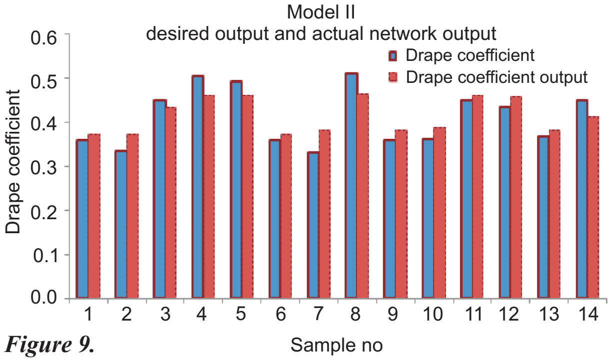


Figure 9.

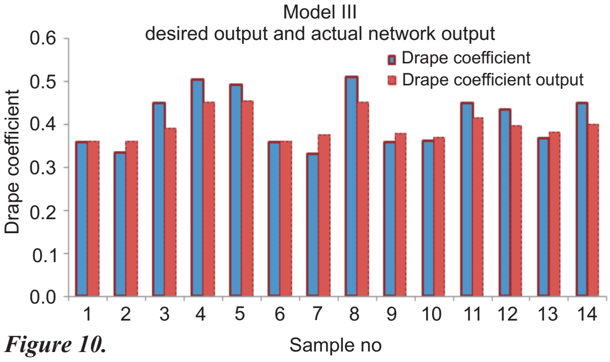


Figure 10.

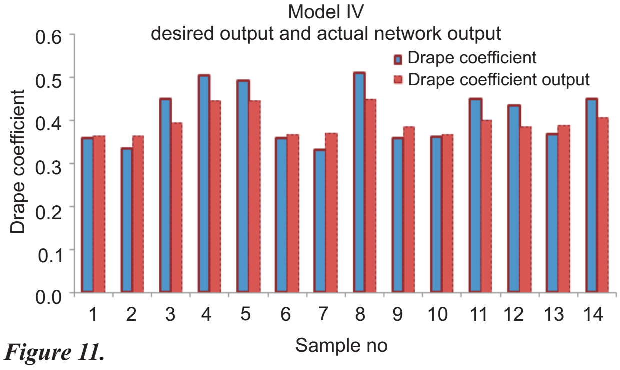


Figure 11.

Figure 7. *Comparison of transfer functions with respect to the mean square error (MSE) versus the number of neurons for model I.*

Figure 8. *Prediction capability of the neural network model with the tanh function including 5 neurons.*

Figure 9. *Prediction capability of the neural network model with the tanh function including 8 neurons.*

Figure 10. *Prediction capability of the neural network model with the tanh function including 9 neurons.*

Figure 11. *Prediction capability of the neural network model with the tanh function including 12 neurons.*

was not unlikely to significantly reduce the performance of the model.

Conclusions

In this study, an ANN technique was used in order to predict the drape behaviour of woolen fabrics treated with different finishing processes (stenter, decatizing, superfinish, formula, KADE strong and weak) in a different sequence. A procedure was presented for creating ANN models from the mechanical and surface properties of treated fabrics measured using the KES-FB and FAST systems. The FAST and KES-FB measuring systems were used to realise the mechanical, surface and dimensional properties of the treated fabrics prior to drape prediction in terms of tensile, shear, bending, compression, surface friction and relaxation shrinkage. Mechanical, surface and dimensional properties of the treated fabrics were used as inputs of ANN models in order to determine the relationship between the results and the drape. The success of neuron numbers in the hidden layer of the modelling structure and comparison of transfer functions were also studied. In the models, the hyperbolic tangent activation function (*tanh*) presented better performance results than the sigmoid activation function (*sigmoid*), with lower mean square errors. Higher values of correlation coefficients (changing between R = 0.94 and R = 0.92) and lower MSE (changing between 0 and 0.002) values showed that the models were capable of making quantitatively accurate drape behaviour predictions for woolen fabrics. In addition, increasing the number or changing the sequence of dry finishing processes does not have any significant effect on the prediction performance of the ANN models developed for woolen fabrics. Although the fabric is exposed to different kinds of strain such as tensile, pressure, shear and bending during the dry finishing processes, it is found that the models developed can accurately predict the drape behaviour of each group of fabric. Moreover this study exhibited that fabric drape could be predicted with high accuracy for woolen fabrics treated with finishing processes. Thus it can be concluded that the use of an artificial neural network model developed by using either KES or FAST results can be used as an analytical tool to improve the processing parameters of woollen fabrics.

The next step of this research will be to determine the effect of the finishing process order on the drape behaviour of woolen fabrics using artificial neural networks. Additionally, as a future work, the ANN models developed can also be tested using different kinds of fabric types of woollen fabrics to predict drape performance.

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