Research Article

A research on the investigation of physical properties of polyester/cotton fabrics

Abstract

The aim of this study is to reach closer results to the actual measurements by using artificial neural networks in evaluating the properties of single and double layer woven fabrics that affect the end user. The variation of the most important parameters such as breaking strength, weight, thickness, tearing strength properties to meet the end user's needs depending on the yarn count and the weaving type was investigated. In the fabrics produced in this study, cotton yarn was used as weft yarn in three different numbers and 90 denier polyester yarns were used as warp yarn. Plain, twill, panama, warp rips and satin were used as weaving type. Fabrics were weaved in three different weft frequencies. Evaluations using artificial neural networks were found to give closer results to the actual measurements.

Keywords: cotton, comfort, breaking strength, tear strength, thickness, weight

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Introduction

Comfort properties of the fabrics come out as the first consideration of the user after their color factor with the developing technology and the consciousness of users. Production of the functional products compatible with the movements and daily life of users has become very important. Cotton materials are the best evaluated products in terms of comfort. Parameters that affect the comfort characteristics of fabrics have been studied by many researchers.[1–9] The clothing comfort depending on these parameters is evaluated within the clothing physiology.[10–12]

The aim of the science of clothing physiology is to create rules for clothing design and production which will not affect the comfort and working efficiency of the person negatively and even contribute to the healing, taking into consideration the fashion and sales parameters.[10] Clothing comfort is defined as the user's feeling of being physically and psychologically comfortable within the current working conditions of user.[10,13–15]

Different techniques such as correlation analysis, regression analysis, factor analysis, artificial neural networks, and fuzzy logic were used to analyze the comfort of clothes.[10] Correlation analysis determines the relationship and direction between variables. In regression analysis, the function of relationship can be determined by considering dependent and independent variables.[10,16] Factor analysis is a technique that allows obtaining a small number of but independent variable sets by combining moderately or highly related variables with each other. It is thus possible to reduce many variables to a few clusters or sizes.[10] The multiple logic system that determines the realization rates of daily living variables is expressed as fuzzy logic. In fuzzy logic, infinite number of propositions can be made. In fuzzy logic, infinite number of gray between black and white is evaluated.[10,17]

It is difficult to estimate comfort with these statistical methods, which are used due to nonlinear relations between comfort and fabric parameters. This non-linear relationship is explained by Pontrelli. In his study, Pontrelli has declared that comfortable feeling is due to the invisible parameters such as environmental factors depending on the relationship between environment and fabric characteristics, psychological and physiological factors depending on purpose and appearance of fabrics as well as the user's experience and expectations.[18] In order to overcome this restriction, the relationship between fabric structures and comfort properties is evaluated with artificial neural network. Artificial neural networks are systems that can learn using examples and determine the reaction to environmental effects.

Artificial neural networks are used in learning, associating, classifying, generalizing, characterizing and optimizing operations similar to those that the human brain can do.[10] Detailed information on the basic principles of artificial neural networks and their work has been given in many articles.[19]

The human nervous system in the working system of artificial neural networks is taken into consideration and three layers (input, intermediate, and output) are introduced into the network. The measured parameters form the input layer and are used to train the system. The intermediate layer is the part of training itself and is used to obtain output. The output layer expresses the outputs that are reached through the input parameters considered.[10,20]

Artificial neural networks have advantages such as short-time application and self-training according to new situations. Artificial neural networks can be classified as forward-feed, back-feed, and forward-feed-back artificial neural networks.[10,21,22] It is preferred to use forward feed-back propagation neural networks, when the comfort characteristics are determined.

Wong et al. reported that artificial neural networks, which can be used in evaluating the comfort of clothes, are fast, flexible and predictive techniques in terms of self-training ability and also estimation of sensory comfort.[10,23]

In his study, Tokarska used artificial neural networks to evaluate permeability of fabrics depending on some constructional parameters such as fabric density and twisting parameters of warp and weft yarns. As a result, he stated that the input parameters affected air permeability.[24] In a study, thermal conductivity and thermal absorbency

parameters were estimated to determine the effect of raw material and knitting construction on comfort properties by using artificial neural networks.[25] In another study, weaving construction type, densities and counts of warp and weft yarns, weight and thickness data were used as input material and two artificial neural networks were used in estimating the thermal resistances of the fabric.[22] Majumdar used artificial neural network to estimate of thermal conductivity of bamboo and cotton fabrics. Fabric knitting structure, yarn count, ratio of raw material, fabric thickness and weight were used as input parameters in the artificial neural networks.[10,26] Park et al. used seven mechanical parameters measured with KES-F system as input parameters, and artificial neural network was used to estimate tactile sensation of users.[10,27] Yaman et al. used artificial neural network in the hand evaluation of the bulky materials. Friction, compression, thermal properties both wet and dry forms and also wettability properties of disposable diapers were used as input parameters in their study.[19] The effect of the plasma treatment on the comfort characteristics of the fabric has also been examined and it has been shown that the surface properties of the fabric determine the comfort parameters.[28]

In this study, artificial neural networks were used to estimate the breaking and tearing behaviors of fabrics by using the yarn number, frequency, weight and thickness parameters of single and double layered fabrics with different constructions woven from polyester/cotton yarns by considering the cost factor and the speed required by the age.

Materials and methods

Ne 16/1, 20/1 and 30/1 100% cotton yarns were used as weft yarns while 90 denier 100% polyester yarns were used as warp yarns in the fabrics produced in this study. All fabrics were weaved in 160cm reed width and with 160/2 reed number. The fabrics were weaved as single and double layer fabrics by using plain, twill, rips, panama and satin weavings. Fabrics were produced at weft frequencies of 20-60 wire/cm depending on the type of weaving and yarn counts. The fabric widths were measured after 24hours from the end of the weaving process. The technical characteristics of the fabrics produced in this study are given in Tables 1-5.

Table 1 Properties of the plain fabrics

		Single-layered (weaving factor:0.5)			Double-layered (weaving Factor:)		
	Code	**P101**	**P102**	**P103**	**P201**	**P202**	**P203**
Ne 16	Width	158	159	158.8	153	155	156.5
	Warp Fre	32.4	32.2	32.9	33.5	33	32.7
	Weft Fre	25	22	19	39.4	34.9	30.5
	Code	**P104**	**P105**	**P106**	**P204**	**P205**	**P206**
Ne 20	Width	157.5	157	158	152	153	156
	Warp Fre	32.5	32.6	32.4	33.7	33.5	32.8
	Weft Fre	26	28	23	44.1	34.9	23.2
	Code	**P107**	**P108**	**P109**	**P207**	**P208**	**P209**
Ne 30	Width	156.5	157.5	157.5	150	152	154
	Warp Fre	32.7	32.5	32.5	34.1	33.7	33.3
	Weft Fre	32	29	26	52	41.9	32.7

Table 2 Properties of twill fabrics

		Single-layered (Weaving factor:0.5)			Double-layered (Weaving factor:)		
	Code	**T101**	**T102**	**T103**	**T201**	**T202**	**T203**
Ne 16	Width	155.5	155	156	155	155.2	156
	Warp Fre	32.9	33	32.8	33	33	32.8
	Weft Fre	30	27.5	24.2	50.5	40.4	30.5
	Code	**T104**	**T105**	**T106**	**T204**	**T205**	**T206**
Ne 20	Width	153	156	156,5	154	154.5	155
	Warp Fre	33.5	32.8	32.7	33.3	33.1	33
	Weft Fre	36	33	30	56	45.9	36.3
	Code	**T107**	**T108**	**T109**	**T207**	**T208**	**T209**
Ne 30	Width	153	153	153.5	154	154.3	155
	Warp Fre	33.5	33.5	33.4	33.3	33.2	33
	Weft Fre	44	40.8	37.1	68.7	55	41.5

Table 3 Properties of panama fabrics

		Single-layered (Weaving factor:0.5)			Double-layered (Weaving factor:)		
	Code	P101	P102	P103	P201	P202	P203
Ne 16	Width	156	156	157	150	153	155
	Warp Fre	32.8	32.8	32.6	34.1	33.5	45
	Weft Fre	29.7	26.9	24.3	61	45	30
	Code	P104	P105	P106	P204	P205	P206
Ne 20	Width	155.5	156	157	150	152	154
	Warp Fre	32.9	32.8	32.6	34.1	33.7	33.3
	Weft Fre	32.7	29.7	26.9	67.1	50.5	32.7
	Code	P107	P108	P109	P207	P208	P209
Ne 30	Width	153	153	154	152	153.5	154.5
	Warp Fre	33.5	33.5	33.3	33.7	33.4	33.1
	Weft Fre	41.9	39	36.2	81.6	61	41.9

Table 4 Properties of rips fabrics

		Single-layered (Weaving factor:0.5)			Double-layered (Weaving factor:)		
	Code	R101	R102	R103	R201	R202	R203
Ne 16	Width	158	158.5	158.5	156	157	157
	Warp Fre	32.3	32.3	33.3	32.8	32.6	32.6
	Weft Fre	27.5	24.3	20.9	57	44.1	31
	Code	R104	R105	R106	R204	R205	R206
Ne 20	Width	158.2	158.5	158.8	156	157	157
	Warp Fre	32.4	32.3	32.2	32.8	32.6	32.6
	Weft Fre	30.7	27.5	24.9	60.3	52	37.1
	Code	R107	R108	R109	R207	R208	R209
Ne 30	Width	157	157.3	158	154	156	157
	Warp Fre	32.6	32.6	32.4	33.3	32.8	32.6
	Weft Fre	37.1	34.4	31.5	78	57	37.1

Table 5 Properties of satin fabrics

		Single-layered (Weaving factor:0.5)			Double-layered (Weaving factor:)		
	Code	S101	S102	S103	S201	S202	S203
Ne 16	Width	154	153.5	153.2	151	152	153
	Warp Fre	33.3	33.4	33.4	32.9	33.7	33.5
	Weft Fre	28.2	31.1	34.4	56.5	45	34.4
	Code	S104	S105	S106	S204	S205	S206
Ne 20	Width	155	155.6	156	150	152	153
	Warp Fre	33	32.9	32.8	34.1	33.7	33.5
	Weft Fre	31.9	35.9	39	61.1	47.1	39
	Code	S107	S108	S109	S207	S208	S209
Ne 30	Width	154.5	154.6	155	152	153.6	154
	Warp Fre	33.1	33.1	33	33.7	33.3	33.3
	Weft Fre	39	42.5	47	74.4	61.1	47.1

Physical and comfort tests were conducted at 20±2°C temperature and 65±5% relative humidity. The frequencies of the fabrics were counted by threading from samples cut to contain at least 100 yarns in the amount of frequency using the Method a specified in TS 250 EN 1049-2. Thickness measurement was performed with a hand type thickness gauge at three different points of the fabric and the average of the obtained values was taken. Thickness measurement was made with 3 repetitions. In the determination of the weights of the fabrics, 15x 15cm² pieces were cut from 3 different parts to represent all samples. The pneumatically operated square meter cutter cuts 100cm² of the sample and weighed it on a digital precision scale. Fabric tensile strength was measured according to TS EN ISO 13934-1, three samples were taken on both sides (in the weft and warp direction) to include different weft and warp threads on the fabric. Samples were taken from the edges of the samples to a thickness of 50mm. After setting the speed of the elongation rate constant (CRE) device to 100mm/min and the distance between jaws to 200mm, the samples were tested with pre-stress of 2-5N. The data was automatically retrieved from the device. Tear strength test was fulfilled according to TS EN ISO 13937-2. Three samples were taken in both directions (in the weft and warp direction) to include different weft and warp threads. The specimens were subjected to a tear test after the elongation rate constant (CRE) was set to 100mm/min at a distance of 100mm from the jaws. The data was automatically retrieved from the device.

The weaving factor values of the fabrics are calculated according to the following formula, which we derived from the weaving factor formula given in the literature.[28] The calculated weaving factors were evaluated as input parameters in this study and used in artificial neural networks. Artificial neural networks were performed to estimate breaking and tearing strength of the fabrics by using weft and warp density, weft yarn number, weaving type and weaving factor as input parameters.

Results

The weights and thicknesses of the woven fabrics were measured as indicated in the material section and are shown in Figures 1-3.
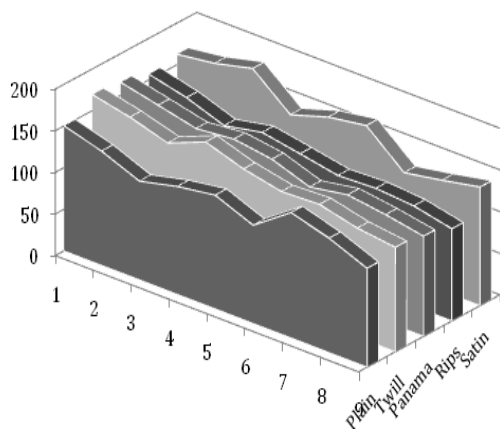

Figure 1 Weight values of the single-layered fabrics (g/m²).

It has been observed that the weights of fabrics produced in the work increased with the increase of warp and weft frequency and decreased with the increase of weft yarn number. It has been observed that the number of fabric types and number of fabric layers play a role in the change of fabric thickness. It is seen that the most important

parameter in the change of the fabric width is the connection type in the fabric braid. Amount of connection type in fabric constructions are given in Table 6.
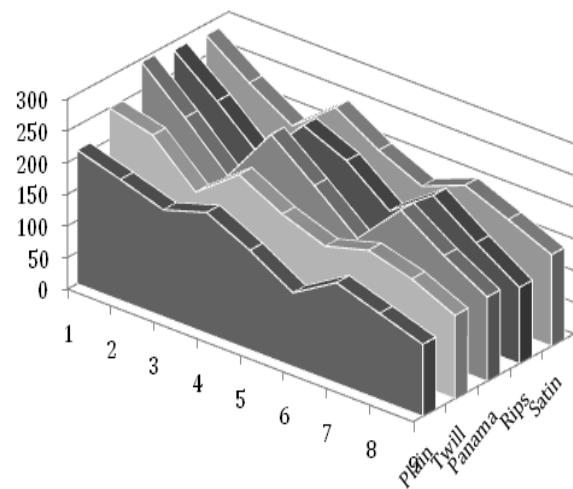

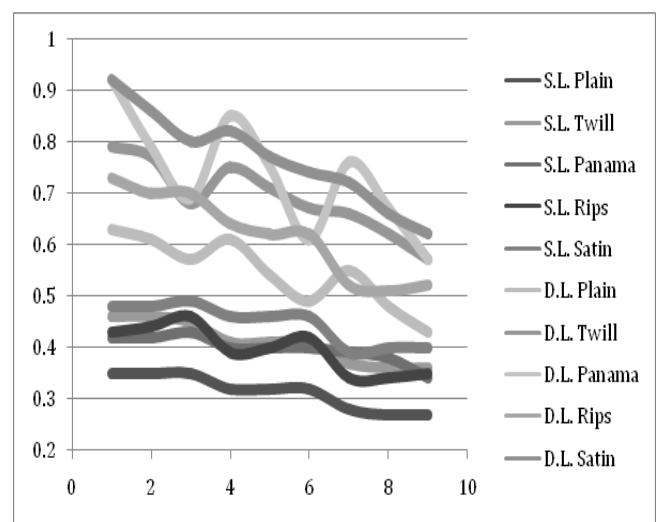**Figure 2** Weight values of the double-layered fabrics (g/m²).

Figure 3 Thickness values of the single and double layered fabrics (mm).

It is observed that the most important parameters in changing the fabric width are the weft density, the number of fabric layers, and the type 1 and type 2 connection quantities. Fabric width stretch is larger in the fabrics having more type 5 connection than having more type 1 connection'. For this reason, the fabrics having lowest width are plain fabrics, while the fabrics that have the largest fabric width are rips.

The tensile strengths in the weft and warp direction of the fabrics weaved in the study are shown in Figure 4 & 5), and the tearing strengths are shown in Figure 6 & 7.

In the regression analysis, it was seen that the weft tensile strength of both single and double-layered fabrics was affected negatively by the weft yarn numbers while being affected from the weft density in the positive direction. It was determined that the effect of the weaving factor on the fabric tensile strength was negligibly small. The reason why there was no change in the warp tensile strengths was that the same warp set was used in all fabrics.

Table 6 Amount of the connection type in the fabrics (%)

Connection	Single-layered					Double-layered				
	Plain	Twill	Panama	Rips	Satin	Plain	Twill	Panama	Rips	Satin
Type 1	100	25	25	-	20	25	64	31.3	25	65
Type 2	-	50	-	-	80	50	25	37.5	50	30
Type 3	-	25	25	50	-	25	11	29.6	25	5
Type 4	-	-	25	-	-	-	-	-	-	-
Type 5	-	-	25	50	-	-	-	1.6	-	-
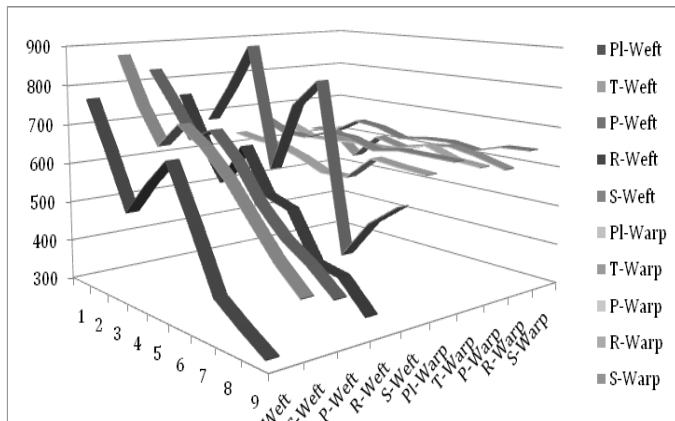
Figure 4 Warp and weft direction tensile strength of single-layered fabrics (N).
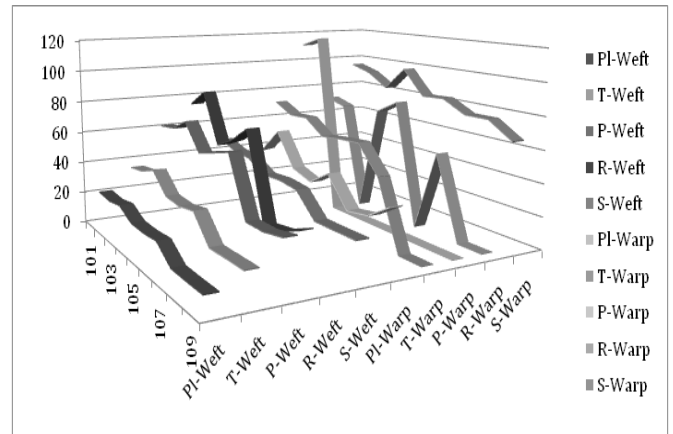
Figure 6 Warp and weft direction tearing strength of single-layered fabrics (N).
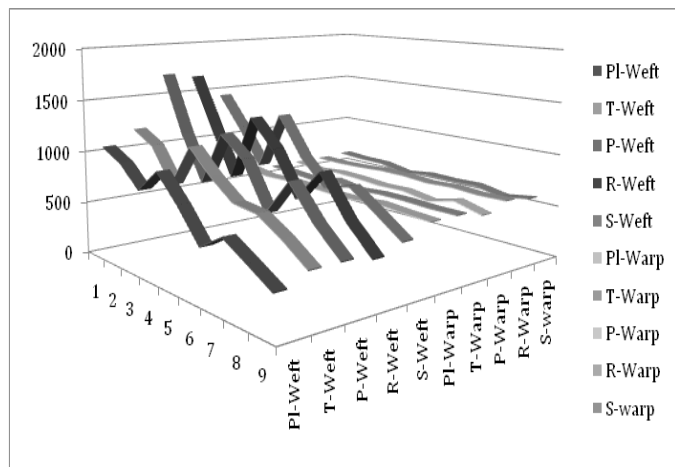
Figure 5 Warp and weft direction tensile strength of double-layered fabrics (N).
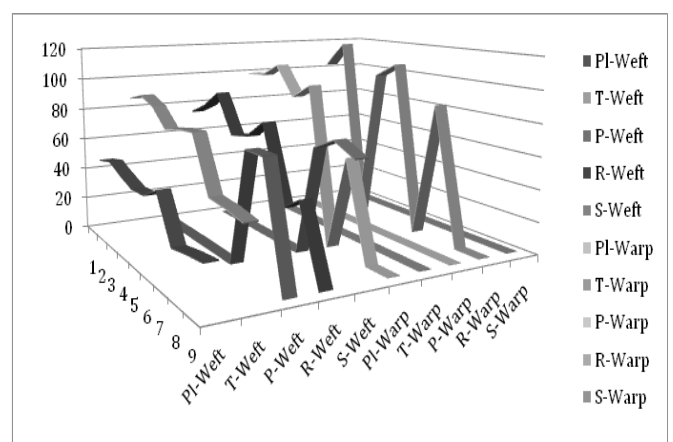
Figure 7 Warp and weft direction tearing strength of double-layered fabrics (N).

The change in warp tensile strength values arises only from differences in fabric width due to weaving type. The statistical evaluation showed that the weft tearing strength was influenced by the fabric layer number, weft yarn number, weft connection type, and weft and warp frequency. The higher type 5 and type 1 connection type affects the weft tearing strength positively. In type 5 and type 1 connection, the weft yarn has been held between two warp yarns and they have become closer to each other, which makes tearing more difficult. As the number of fabric layers increases, the tearing of the weft yarns will have become more difficult because of the increase in the bunch formation ratio. Weft yarn number and weft frequency parameters affect the negative direction.

The reason why weft tearing was not occur in double-layered panama fabrics was the overlaying of a large number of weft threads due to the low threading frequency.

Artificial neural networks application

Artificial neural networks were applied by taking the yarn number, weft frequency, warp frequency and fabric layer number parameters as input parameters and weight, thickness, tensile strength and tearing strength as output parameters. The sigmoid transfer function,

$$f(x) = \frac{1}{1+e^{-x}}$$, was used in the study. Separate artificial neural

network procedures have been run for weight, thickness, tensile and tearing strength.

Evaluation of fabrics weight and thicknesses parameters with artificial neural networks: While weft yarn number, weft and warp density, number of layer and weaving factor were used as input parameters, thickness and weight values measured were used as output parameters to evaluate fabric weight and thickness with artificial neural networks.

The sigmoid algorithm was used in the hidden layer for artificial neural networks in this study. The structure of the applied artificial neural networks is shown in Figure 8. Relationship between measured and calculated with artificial neural networks is shown in Figures 9 & 10 for fabric weight and thickness, respectively.

The square root of the error squares (RMSE) values, calculated as formula $RMSE = \sqrt{\dfrac{\sum_{i=1}^{n}\left(x_H - x_{\ddot{O}}\right)}{N}}$, and are given in Table 7. As you seen in Table 7, the fabric weight and thickness values calculated using artificial neural networks were close to real/measured values at $R^2=0.9946$ and $R^2=0.9916$, respectively.

Because the calculated RMSE values are very low, it can be said that the weight and thickness parameters calculated with artificial neural networks reflect the actual measurement results.
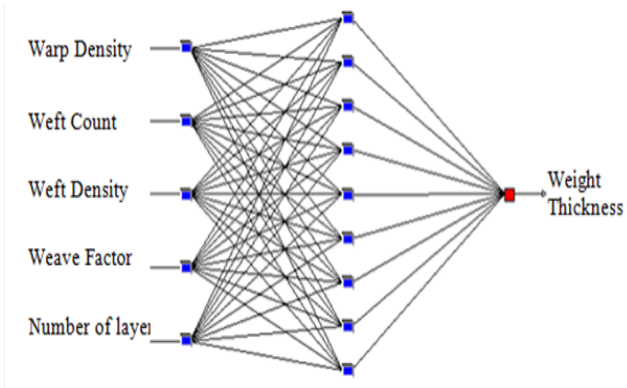

Figure 8 Artificial neural networks model for fabric weight and thickness (MLP 5:5-9-1:1).
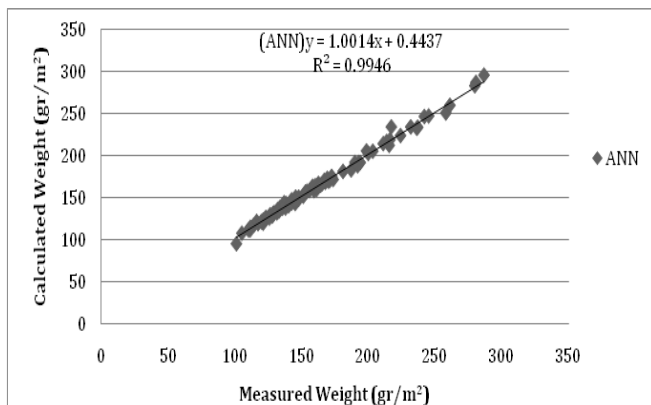

Figure 9 Relationship weight values between measured and calculated with artificial neural networks.

Evaluation of tensile strength parameter with artificial neural networks: While weft yarn number, weft and warp density, weaving factor, thickness and weight were used as input parameters, tensile strength both warp and weft direction measured were used as output parameters to evaluate fabric tensile strength properties with artificial neural networks.

Table 7 Calculated RMSE values for fabric weight and thickness

	Weight	Thickness
Artificial Neural Networks	3.300043	0.021592
Lineer Regression	12.32627	0.049799

The sigmoid algorithm was used in the hidden layer for artificial neural networks in this study. The structure of the applied artificial neural networks is shown in Figure 11. Relationship between measured and calculated with artificial neural networks is shown in Figure 12.
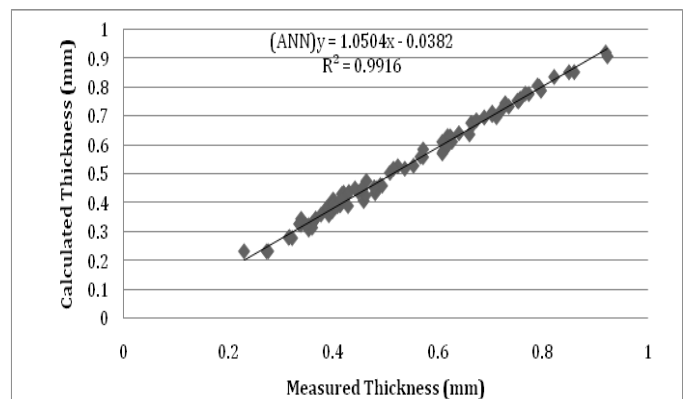

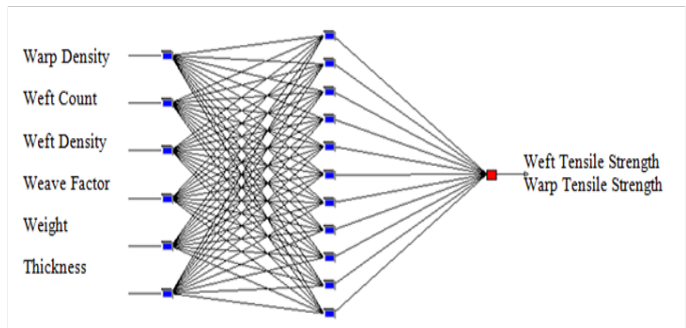**Figure 10** Relationship thickness values between measured and calculated with artificial neural networks.

Figure 11 Artificial neural networks model for warp and weft tensile strength (MLP 6:6-11-1:1).
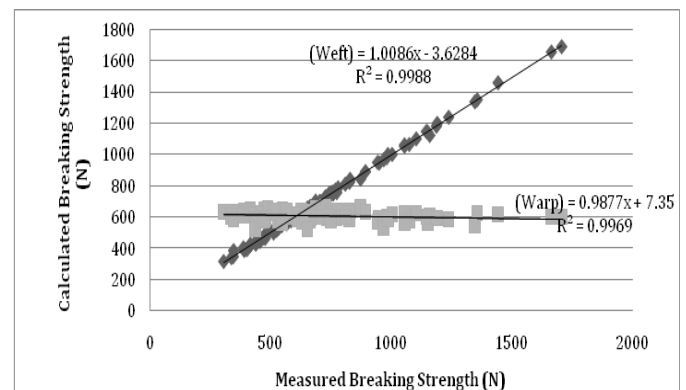

Figure 12 Warp and weft tensile strength values calculated with artificial neural networks (N).

The RMSE values for both warp and weft tensile strength are given in Table 8. As you seen in Table 8, the fabric tensile strength values calculated both weft and warp directions by using artificial neural networks were close to real/measured values at R^2=0.9988 and R^2=0.9969, respectively.

Because the calculated RMSE values are very low, it can be said that tensile strength parameters calculated with artificial neural networks reflect the actual measurement results.

Table 8 The RMSE values calculated for warp and weft tensile strength

	Weft direction	Warp direction
Artificial Neural Networks	10.85848	1.597895
Lineer Regression	91.53256	19.12542

Evaluation of tearing strength parameter with artificial neural networks: While weft yarn number, weft and warp density, weaving factor, thickness and number of layer were used as input parameters, tearing strength both warp and weft direction measured were used as output parameters to evaluate fabric tearing strength properties with artificial neural networks.

The sigmoid algorithm was used in the hidden layer for artificial neural networks in this study. The structure of the applied artificial neural networks is shown in Figure 13. Relationship between measured and calculated with artificial neural networks is shown in Figure 14.
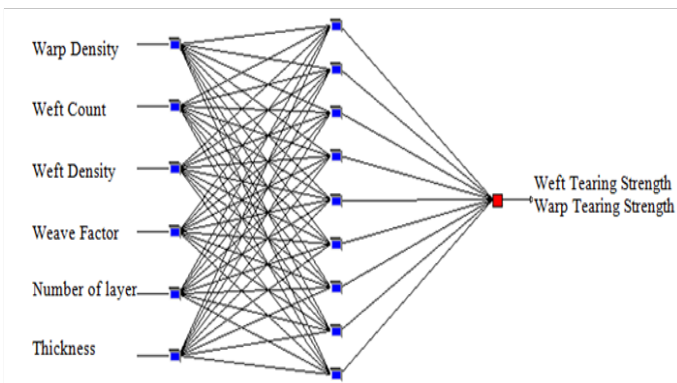

Figure 13 Artificial neural networks model for warp and weft tensile strength (MLP 6:6-9-1:1).
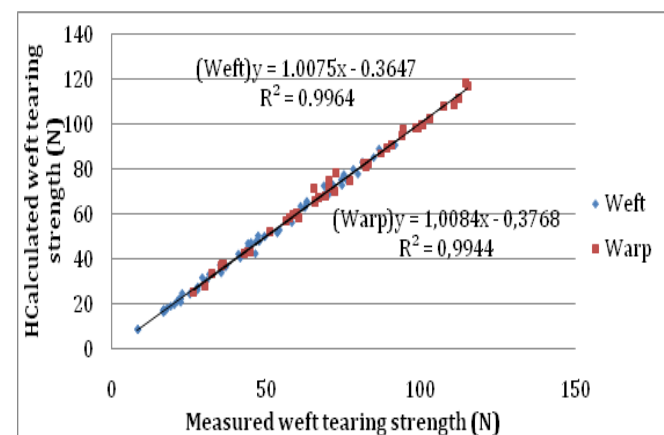

Figure 14 Warp and weft tearing strength values calculated with artificial neural networks (N).

The RMSE values for both warp and weft tearing strength are given in Table 9. As you seen in Table 9, the fabric tearing strength values calculated both weft and warp directions by using artificial neural networks were close to real/measured values at R^2=0.9964 and R^2=0.9944, respectively.

Because the calculated RMSE values are very low, it can be said that tensile strength parameters calculated with artificial neural networks reflect the actual measurement results.

Table 9 The RMSE values calculated for warp and weft direction

	Weft direction	Warp direction
Artificial Neural Networks	1.412265	1.921667
Lineer Regression	10.19919	9.177846

Discussion

a. It is seen that the fabric density values affect the fabric weight in the positive direction while the yarn counts affect the negative direction.

b. It is seen that the most important parameter in the change of the fabric width is the connection type in the fabric braid.

c. The most important parameter for fabric width is the count of type 5 connection.

d. The most important parameters for tensile strength is weft density. On the other hand, weaving factor can be neglect for this parameter because of very small effect.

e. It is seen that the counts of type 5, type 1 connection and layers of the fabrics affect tearing strength of the all fabrics positively.

f. The fabric weight, fabric width, tensile and tearing strength values calculated with artificial neural networks were found to be closer to real values.

Acknowledgments

Conflict of interest

Author declares there is no conflict of interest in publishing the article.

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