Predicting the seam efficiency of sewn blended fabrics using ANN and linear regression models

Najwa Ali Abu Nassif
Fashion Design Department, Design and Art College, King Abdul Aziz University, Jeddah, kingdom of Saudi

Abstract:
In most cases, quality of sewn apparel products is characterized by seam performance. The durability of the seam is mainly defined by its efficiency along the seam line; therefore it is one of the most important characteristics to obtain the desired seam quality. Throughout this study, seam efficiencies of woven blended fabrics were predicted using two different methodologies, i.e. ANN and regression methods. ANN with four neurons input layer, 15 neuron hidden layer and output layer with one neuron focusing on the seam efficiency was used and compared to regression line. The input variables in both predictive modes were polyester ratios, sewing needle size, stitch density and sewing thread count. The findings of this work revealed that ANN predictive model is outperformed the multiple linear regression one with lower vales of RMSE and MBE and high R^2 values.

Keywords:
Seam Efficiency
Predicting
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Artificial Neural Networks
Regression Analysis.

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1. Introduction
In general, the seams were found to be the essential requirements in manufacturing of apparels. In general, seam quality has a great influence on apparel products. Seam strength, seam efficiency and its elongation and puckering, seam boldness … etc. are the main characteristics of the seam quality.

Efficiency of the seams determines its durability along the seam line. It also plays a vital role for obtaining the required quality. Durability is indicated as satisfactory seam functional properties. Thus an efficient seam should be more durable than the weak ones [1-3].

A strength apparatus is used to measure the seam efficiency by many researchers according to ASTM 1683-04 [4-7]. In this test method, the quotient of seam strength and fabric tensile strength is used to evaluate the seam efficiency. This test method yields an accurate measure of seam efficiency and thus it is widely accepted. Stitch density, sewing thread linear density, sewing needle size and seam type are the most influential parameters on seam quality, which have been investigated by many researchers [5-10]

Numerous papers explained and predicted the tensile properties of woven and knitted fabrics [10-17]. Weave structure, constituent yarn densities, constituent yarn counts and final finishing processes are the key parameters influencing fabrics' tensile properties.

Prediction of woven fabrics' seam efficiency via ANN and regression models is the main objective of this study. The Polyester ratio, sewing needle size, stitch density and sewing thread linear density were used as input (independent) variables and seam efficiency was considered as output (dependent) variable.

2: Experimental work

2-1: Materials
During this experimental study, three different cotton polyester blended fabrics were woven with different polyester ratios in the weft yarns, namely 0%, 35% and 55% respectively. These woven fabrics were sewn using a plain seam, i.e. SSA with three different stitch densities, three different sewing needle sizes and three sewing yarn counts. Therefore, a total of 81 samples were produced in this study in order to measure their seam efficiencies. The characteristics of woven fabrics samples used in this study were presented in table 1. Whereas the used seam parameters to sew these fabrics were introduced in table2. The plies spun polyester yarn with different linear densities were used as sewing threads and their characteristics were listed in table 3. The general view of the plain seam used to sew the cotton polyester woven blended fabrics in the weft direction was depicted in figure1.

Table 1: Characteristics of cotton: polyester woven fabrics

Polyester ratio	Warp count	Weft count	Ends/inch	PPI	Weave structure
0% (100 %cotton fabric)	20 (Ne)	20 (Ne)	80	60 ppi	Plain 1/1
35% (blended fabric)					
55% (blended fabric)					

Table 2: Seam parameters

Sewing needle count	Stitch density/ 10 cm	Sewing thread count (tex)
11	30	30
14	40	50
16	50	80

Table 3: Tensile characteristics of sewing threads used in this study

Sewing thread count (tex)	Twist direction Ply/Single	Tensile strength cN	Breaking extension %
30	Z/S	1000	20.9
50	Z/S	18000	22.1
80	Z/S	2400	24.2

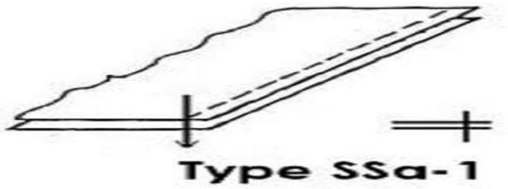

Figure 1: General view of plain seam (seam of type SSa-1) used in this study

2-2: Determination of seam and fabric tensile strength

Tensile strength in the weft way direction of the blended woven fabrics was determined using the Instron tensile apparatus of model 4411 according to ASTM D-5034. The measured samples were cut and raveled to be in the size of 20 cm (in weft direction) × 5 cm (in warp direction). The tensile strength of ten samples were taken and averaged.

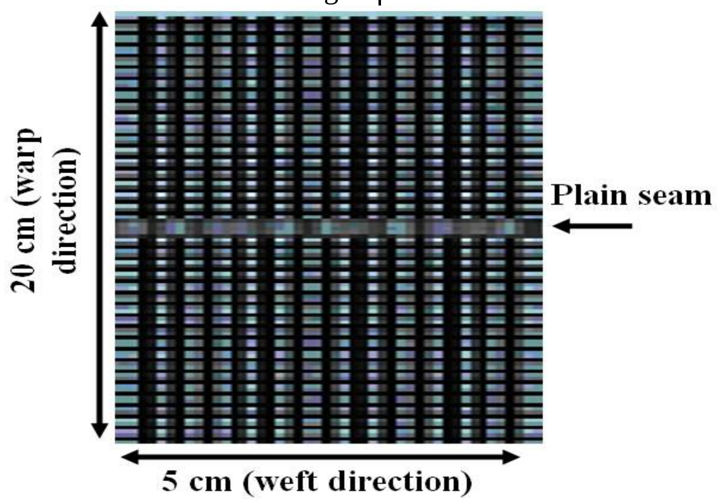

Figure 2: Specimen used to measure seam strength

The tensile strength of the seam was measured the same tensile testing apparatus using a raveled sample in warp direction and with size 5cm in the weft and 20 cm in the warp direction. The sample was cut from the middle and sewn using SSa seam as shown in figure 2.

For each sample, the seam efficiency, %, from the test data was calculated in accordance with ASTM standard D 1683-04 as follows:

$$\textbf{Seam strength (\%)} = \frac{\textbf{Seam tensile strength}}{\textbf{weft way fabric tensile strength}} \times \textbf{100}$$

For each specimen, five readings of seam efficiencies were calculated and averaged.

2-3: Identifying number of neuron in hidden layer

So as to optimize hidden layer neurons' number, the relation between ANN performance, namely MSE and neuron numbers was calculated, investigated and depicted as shown in figure 3. It can be noticed from this figure that the means square error (MSE) decreases significantly with the increasing of neuron numbers from 1 to 15, while it decreases very slightly with further increasing in the number of neuron from 15 to 20. Thus, the neural network performance will be better and will be able to model the experimental data of sewing efficiency when the hidden layer neuron numbers approximates 15 neurons. It is worthy noted that higher number of neurons will complicate the neural network and it will take a long time to be trained. Therefore twenty neurons associated with the hidden layer were excluded and the 15 neurons will be chosen for modeling seam efficiency of sewn blended woven fabrics.

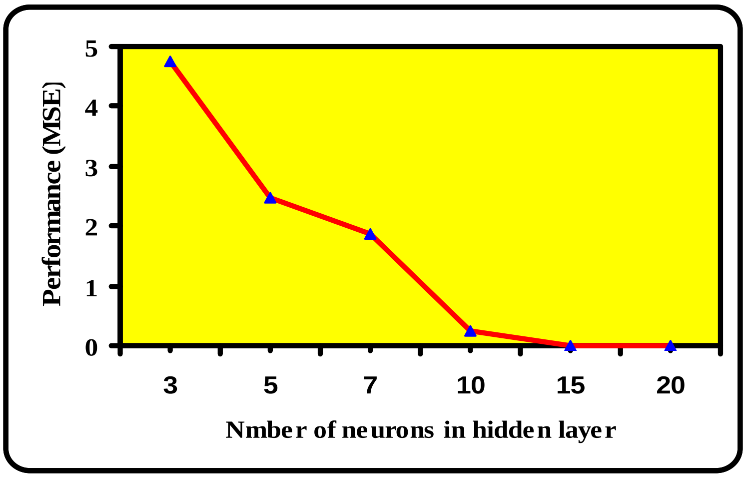

Figure 3: Performance of artificial neural network versus hidden layer neurons' number

2-4: Architecture, learning and performance of ANN

Pursuant to the hidden layer neurons number that have been optimized as shown in the previous figure, the construction of used neural network in this study includes 4 neurons in input layer represent needle size, polyester ratio, stitch density and sewing thread count, 15 neurons associated with the hidden layer and only one neuron accompanied output layer represents seam efficiency. The general view of artificial neural network architecture that has been used throughout this study was demonstrated in figure 4.

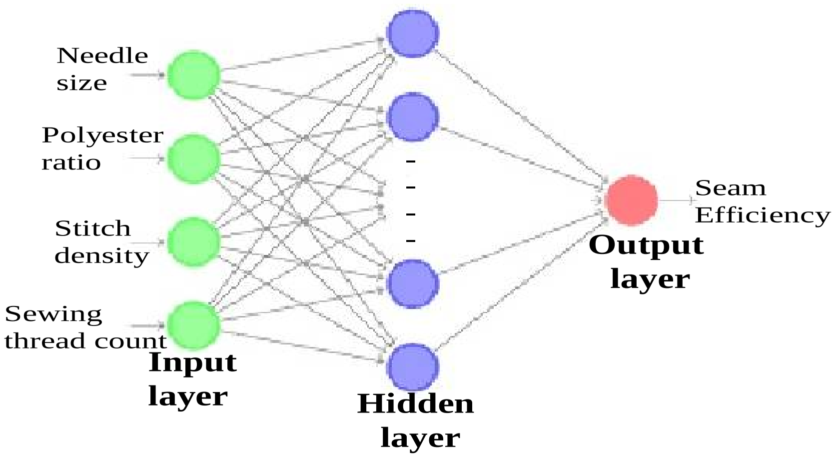

Figure 4: Architecture of the used artificial neural network

Before learning, the eighty one individual experimental data (values of seam efficiencies) were divided as follows: 70% of the whole data were randomly chosen for training; 15% were

assigned for testing the neural network and the remaining data were selected for validating performance of ANN model.
The following sigmoid transfer function was used to learning the ANN:

$$\textbf{Sigmoid- } f(x) = 1/(1+e^{-x})$$

The training parameters of ANN were listed in table 4.

Table 4. Parameters of ANN training.

Parameters of ANN	Value
Input nodes' number	**4**
Hidden nodes' number	**15**
Output nodes's number	**1**
Type of learning rule	**Levenberg–Marquardt**
Epochs'numbers	**1000**
Error target	**0.001**
Marquardt adjustment	**0.001**
Minimum performance gradient	**0.000001**
Learning rate (lr)	**0.35**

To evaluate the ANN model, the predicted output values from this model was calculated and the error from the experimental results was also determined. The error values were used to judge the ANN and predicted moles' performance. The RMSE, coefficient of determination and MBE are the statistical parameters which have been chosen to assess both of predictive models

2-4: Statistical analysis

In order to disclose the significance influence of seam parameters and polyester blending ratio on the efficiency of the seam, the Analysis of variance (ANOVA) was conducted. The values of significance level range $0.05 \leq \alpha \leq 0.01$ was used to assess the influence of the independent variables. The percent contribution of each variable on the effect on seam efficiency was also determined.
A predictive model of seam efficiency at different seam parameters was derived in the form of multiple linear one. The multiple linear regression models that correlate seam efficiency with the independent variables, i.e. needle size, sewing thread linear density, polyester ratio and stitch densities has the following regression line.

$$\textbf{Seam efficiency, \% } = 90.2 - 1.4\,X1 - 0.13\,X2 + 0.09\,X3 + 0.19\,X4$$

Where, X1, X2, X3 and X4 are sewing needle size, polyester ratio, stitch density and sewing thread linear density.
The performance parameters used to assess the ANN and predictive regression models are the same.

3- Results and discussion

Throughout this study, three ANN layers that consist of 4 neurons, 15 neurons and 1 neuron for input, hidden and output layers respectively affecting the seam efficiency of sewn blended fabrics were chosen. The experimental data of four inputs and one target, part of which was listed in table 5 are in accordance with the neural network learning model.

Table 5. Some learning data of back propagation ANN

Sample No.	Input variables				Seam efficiency
	Needle size	Polyester ratio	Stitch density	Sewing thread count	
1	11	0	40	80	93
2	11	35	30	50	85
3	11	35	50	30	83
4	11	55	30	80	83
5	14	0	30	30	78
6	14	0	40	80	90
7	14	35	30	50	82

8	14	35	50	30	82
9	14	55	50	50	79
10	16	0	40	30	75
11	16	0	50	80	89
12	16	35	40	50	78
13	16	55	30	30	67
14	16	55	40	80	78

As seen from regression model above and the results of ANOVA listed in table 6, sewing needle size and polyester ratio negatively and profoundly affected seam efficiency of polyester woven fabrics. Also it was proven that remaining independent variables positively and significantly affected the efficiency of the sewn seams. It was also proved that sewing needle size accounted for 47% of the effects on the seam efficiency, whereas polyester ratio, stitch density and sewing thread count accounted for 47%, 11% and 63% respectively of the effects on seam efficiency.

The actual and predicted values of seam efficiency using artificial neural network and regression models and their performances were listed in tables 7 and 8 and figures 5 and 6 respectively. From the results, it can be noticed that ANN outperformed the regression analysis with lower RMSE, MBE and higher R^2 values. The root mean square errors associated with ANN and regression models were 1.48 and 2.63 respectively, while the mean bias errors were 1.16 and 2.1 for ANN and regression models respectively. The coefficient of determination of the predicted model using ANN fitted the experimental data very well more that its corresponding regression model. The values of the coefficient of determinations were 0.96 and 0.83 for ANN and regression models respectively. Therefore, it can be conclude that ANN predictive model outperformed and fits the data very well in comparison with regression model.

Table 6. Results of the analysis of variance for seam efficiency

Variation	SS	Df	MS	F	P	% contribution
Needle size	720.3	2	360.2	64.36	0.000	47
Polyester ratio	716.2	2	358.1	64	0.000	47
Stitch density	114.2	2	57.1	10.21	0.0001	11
Sewing thread count	1284.8	2	642.4	114.8	0.000	63
Error	402.9	72	5.6			
Total	3238.4	80				

Table 7. Seam efficiency predicted by multiple regression and ANN models.

Actual value	Multiple linear regression		Artificial neural network (ANN)	
	Predicted value	Absolute error (%)	Predicted value	Absolute error (%)
90	86.88604	3.460	89.75116	0.276
93	93.5605	0.603	93.12252	0.132
94	94.43087	0.458	94.0657	0.070
90	88.12382	2.085	89.52891	0.523
83	80.19108	3.384	82.47854	0.628
84	79.71041	5.107	83.3295	0.798
83	84.38409	1.668	82.6469	0.425
91	90.18818	0.892	91.68554	0.753
82	78.94741	3.723	82.48515	0.592
69	72.24955	4.709	68.82004	0.261
69	72.63926	5.274	68.95729	0.062
67	69.64024	3.941	66.72436	0.411
79	80.1841	1.499	78.39136	0.770

From table 7 it can be observed that the absolute error ranges between 0.6 and 5.3 for regression model, whereas for ANN model the absolute error ranges between 0.07 and 0.8. This results confirms the above results which indicates the higher performance associated with the predictive ANN model compared to regression one.

The predicted outputs using ANN and multi linear regression models versus the actual values of seam efficiency were presented in figures 5 and 6.

Table 8. Comparison of prediction performance of linear regression, logarithmic regression and ANN models for seam efficiency.

	Statistical parameters		
	R^2	MBE	RMSE
Linear regression	0.83	2.106418	2.63496
ANN	0.96	1.159114	1.486759

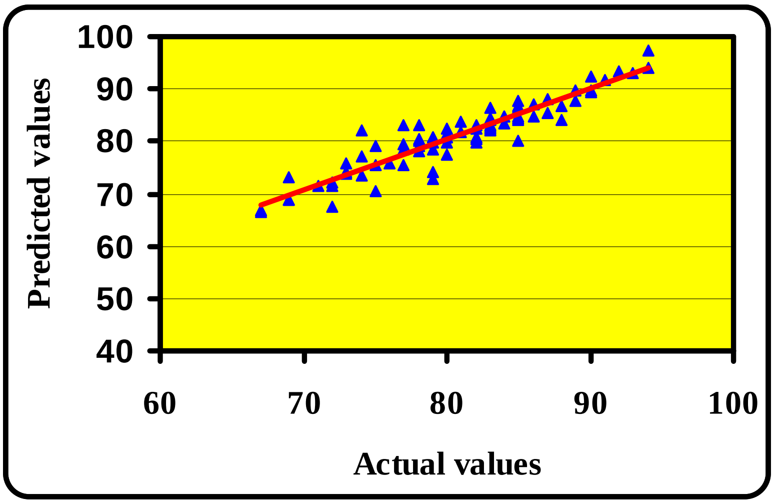

Figure 5: Actual values against the predicted ones using ANN for seam efficiency

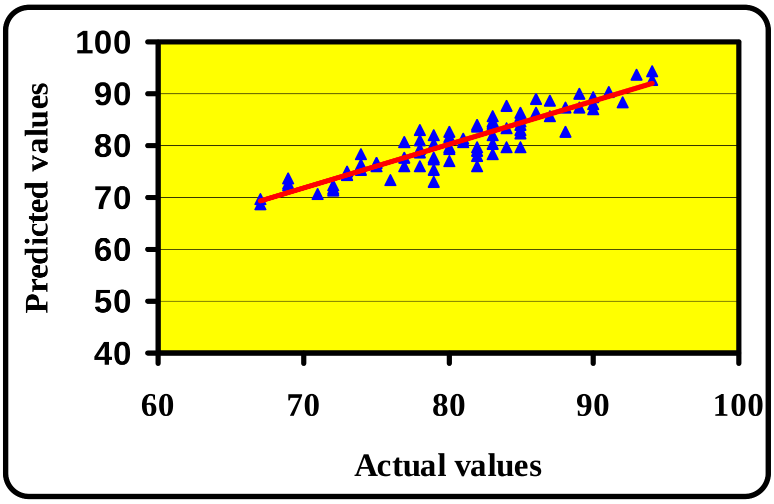

Figure 6: Actual versus predicted values using linear regression for seam efficiency

From these figures it can be noticed that the experimental data predicted using multi linear regression model are largely scattered around their regression line more than those predicted using ANN model. It was also shown that the trend of the measured values reproduced using ANN model is better than the regression one. Thus ANN model has the more ability to predict seam efficiency than regression model. It was also showed that the correlation coefficient between actual values and predicted ones for seam efficiencies were 0.982 and 0.919 for ANN and regression predictive models which assures the above results.

Conclusion

To conclude, seam efficiency of sewn fabrics at different levels of needle size, polyester ratio, stitch density and sewing thread count was predicted using ANN and regression models. The comparison between the two predictive models was compared in terms of RMSE, MBE and R2 values. The conclusions of this study were as follows:

- Seam efficiency was significantly affected by polyester ratio, sewing needle size, stitch density and sewing thread count. It was found that sewing thread count and polyester ratio accounted the high ratio of the effects on seam efficiency.
- Artificial neural network predicted model was found to be outperformed the regression model with lower values of RMSE and MBE and higher value of the coefficient of determination.
- The values of RMSE, MBE and R2 associated with ANN model were 1.48, 1.16 and 0.96 respectively. While in the case of linear regression model the associated values were 2.6, 2.1 and 0.83 for RMSE, MBE and R^2 respectively.
- The percentage absolute errors for the experimental data predicted by ANN model were lower than those predicted by regression line which confirms the superiority of predictive Ann model compared to regression model.
- It was also conclude that actual seam efficiency values tracked the predicted ones very well with high value of the coefficient of correlation in the case of ANN model compared to regression one.
- Finally, we can say that artificial neural networks can be used effectively with high precision and accurate to predict the seam efficiency compared to regression model.

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