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Prediction of Fabric Stiffness Based on Fabric Construction

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Abstract: This research presents a statistical tool to predict fabric stiffness based on fabric construction to avoid material waste, effort and time consuming in laboratories testing. Three different blended material of fabric were used that made from wool and polyester with different percentages of material yarns, counts and type (single/ply) of weft yarn, and fabric weave pattern (plain, twill and satin). Quantitative and qualitative variables were used in prediction by applying regression analysis and Artificial Neural Network (ANN) with a suitable coding system for different variables. Three independent models were derived to predict fabric stiffness by using regression analysis and compared to ANN model. Model (3) is the best prediction tool depending on regression analysis to predict fabric stiffness due to higher interpretation of the relation between variables used in prediction of fabric stiffness. Whereas, ANN achieved higher performance of validation (MSE = 7.41E-05) and total value of (R^2= 0.967) when comparing to regression analysis model.

Keywords: Regression analysis, Artificial Neural Network (ANN), Worsted fabric, Prediction performance, Correlation.

1. Introduction

In the textile industry, much research has been conducted on automated textile testing to monitor the quality of textile products because it has a significant role in lucrative profits in the global market. Testing of textile products could be divided into three sections; full automated measurement (digital devices), semi-automated evaluation and subjective evaluation. Testing which depends on human evaluation or semi-automated evaluation has an error in assessment. Moreover, textile testing means a waste of materials and time, hence more cost. Therefore a lot of researches directed to obtain objective methods to measure different properties of textiles. Consequently, fabric stiffness is an effective property that defines the final use of textile products and most laboratories depend on semi-objective evaluation methods in fabric stiffness assessment such as cantilever stiffness equipment. Most of researches in textile testing depended on numerical variables in fabric construction to predict different properties of fabric. Although, fabric weave structure is a specification that has a large proportion to affect fabric properties, most of researches avoided qualitative variables to predict fabric properties. According to research studies, regression analysis is an effective tool to predict fabric properties and has multiple applications in the textile industry. It is used to predict fabric features from other fabric construction such as fiber properties, yarn properties and fabric properties. Moreover, correlation between different factors of fabric construction was investigated. Most of these factors that used to predict fabric features are numerical variables such as fiber length, yarn strength or fabric weight and avoid using significant qualitative fabric factors such as fabric weave structure [1].

The previous literature shows that multiple regression analysis has numerous applications in textile industry such as; Hager A., and Hassan A. [2] used regression analysis to study contribution between hairiness of yarns and some properties of fiber such as; length of fibers (mm) and its strength (gm/tex), fiber micronair, percentage of short fiber, elongation percentage and the index of uniformity. The regression models were significant and explained a high variation in percentage of yarn hairiness using based on fiber properties. Halim, F et al., [3] studied the effect counts of yarns, knit designs and lengths of stitches on the depth of stripes that leads to attractive fabric and added extra values for the products. 100% cotton samples with dyed yarns were used and the study was divided into three sections according to the proposed values of variables; yarn counts, fabric structure and stitch length. Results conducted linear regression formula to predict depth of striped based on the studied numerical variables.

Moreover, Tang, X. et al., [4] measured the acoustic absorption properties of 24 kinds of woven fabrics with different structural. The relationship between acoustic behavior and various numerical physical parameters was studied by using multiple regression analysis such as perforation ratio and air permeability. Results showed that the regression models could well predict the acoustic absorption properties of woven fabrics. Shanbeh, M., et al., [5] applied multiple linear regression analysis and correlation analysis to study shear rigidity of fabrics which is based on the effects of weft density, count of weft yarn, and fiber type. Statistical methods such as multiple linear regression analysis and correlation analysis were also applied. Multiple linear regression results indicated to poor shear behavior in woven fabrics with cotton weft yarns. The results displayed that there is a high correlation between shear rigidity and cover factor of fabrics.

Wang, C., et al., [6] investigated the mechanical properties, gas permeability, thermal conductivity of bamboo fibers/ reinforced polypropylene BF/PP needle punched non-woven fabrics. Regression analysis was used to predict properties of composites produced based on needle punched non-woven fabrics. The results showed that shear strength and thermal conductivity of the BF reinforced PP composites have a linear relationship to the thermal conductivity of non-woven fabrics through a linear fitting. In addition, it was concluded that the prediction tool is an effective technical guide to produce the non-woven fabrics and their composites in the automotive industry.

Alsayed, M., et al., [7] used regression analysis to predict air permeability property of fabric based on the number of filaments in yarn cross-section, weave density, and fabric weave structure. Three different structures of woven fabric were used; satin, twill, and plain as qualitative variables. Satisfactory results of prediction were concluded avoiding of using the qualitative variables with regression analysis. Independent models of regression analysis were applied for every type of fabric weave structure. Mustafa E. [8] proposed a prediction tool for fabric pilling grades based regression analysis based on count of weft yarns, type of material and fabric structure. In addition, Çelik, H. İ. [9] depended on image processing to get porosity ratios of air-laid nonwoven fabric samples. The research tried to obtain numerical value of porosity based on applying image processing. Then applying regression analysis to predict air permeability based on porosity, thickness and fabric weight.

In addition, some of recent researchers conducted comparisons between results of regression analysis and Artificial Neural Networks (ANN) to predict different properties of fabrics. ANN is a powerful statistical tool to predict fabric properties and explain the complicated relationships between different variables in the textile industry. ANN and regression analysis were used to predict fabric tensile strength and air permeability based on numerical parameters of woven fabrics such as; count and density of weft yarns [10]. Majumdar et al. [11] and Malik and Arain [12] applied different statistical tools based on weft and yarn parameters to predict fabric tensile strength of woven fabrics that made from blended cotton fabrics.

Regarding the fabric stiffness, Yüksekkaya, M. E. [13] et al., investigated the relationship between fabric stiffness and diameters of warp and filling yarns, fabric modulus, and synthetic fabrics density. The fabric stiffness increased according to increasing of yarn diameters and fabric modulus by using the least squared method. Also, Elkateb, S. N. [14] based on blended cotton polyester fabrics to predict fabric mechanical properties using different numerical fabric factors such as; tensile strength, bending rigidity and elongation percentage in weft and warp directions by comparing between regression analysis and artificial neural network. In addition, Shirley cantilever test for fabric stiffness testing which is according to (ASTM: D1388-2002) [15], depends on human to adjust the fabric specimen to reach the required angle that has defined in the test procedure, Elder, H. M. [16] considered the test as an objective method to measure fabric stiffness. Also, Sun, M. N. [17] proposed a new tester to fabric stiffness has the same principle of the cantilever test that depends on more steps and calculations that lead to more error during testing and there is a shortage to predict fabric stiffness for blended wool fabrics. Therefore, this research tried to assign the fabric stiffness by an accurate statistical tool to avoid human error, and time and material consuming by using multiple regression analysis and artificial neural network. In addition, the current research based on dummy variables for qualitative variables such as type of yarn (single or ply) and fabric structure to numerical ones to suit regression analysis and ANN calculations [18]. Therefore, a suitable coding system was established for fabric weave structure and other fabric factors used in prediction.

2. Experimental Work

Table (1) displays factors studied of fabric samples that were manufactured on Rapier and Picanol machines, and were divided into three models according to the material of the weft yarn. Four different weft yarn count (twist factor=3.8), three values of picks per inch (except material (2) has 2 only two values of picks / inch) and two fabric weave patterns for each material have been chosen for this experiment. The materials of weft yarns were; 40/60% blended of polyester/wool fibers (Material 1 – M1), 65/35% blended of polyester/viscose fibers (Material 2 – M2) and 40/40/20% blended of polyester/acrylic/viscose fibers (Material 3 – M3). Weft yarns (Ne 50/2, 48/2, 40/2, 32/2) were used. Warp yarns (Ne 32/2) were made from blended of 40/60% of polyester/ wool fibers (Material 1 – M1) and were constant for the three materials of weft yarns during fabric manufacturing. The weft yarn counts were coded according to the equivalent yarn count and Three different patterns; satin (4H), twill (2/2) and plain (1/1) were manufactured and their codes were (-1, 0, 1) respectively.

Table 1. Factors studied in models (1, 2 and 3)

Model	**Material type**	**Weft yarn (Ne)**				**Picks per inch**			**Fabric pattern**	
Model (1)	M 1	18/1	25/1	32/2	40/2	44	47	50	Plain (1)	Satin (-1)
Model (2)	M 2	25/1	32/2	40/2	50/2	44	----	50	Plain (1)	Twill (0)
Model (3)	M 3	25/1	32/2	40/2	48/2	44	47	50	Twill (0)	Satin (-1)

Fabric stiffness was measured according to ASTM: D1388 - 2002 [15] by Peirce cantilever method. Values of R^2, Mean Square error (MSE) and error value of prediction were calculated to compare between performance results of models. Coefficient of correlation explains to what extent dependent variable is based on independent variables. R - squared displays how the independent variables have the ability to explain variations of the dependent variable. MSE measures the quality of an estimator and the difference of average squared between actual and predicted values [1]. In addition, the error of prediction equals the difference between actual and predicted values. State of yarn (single/ply) is considered as a dummy variable so (0 and 1) were expressed on (single and ply) respectively in equation derivation. SPSS software is used to analyze data of three models to predict fabric stiffness. According to the specifications in table (1), sixteen fabric samples were produced for each material. The Levenberg-Marquardt algorithm is used with the "trainlm" training function to obtain an accurate ANN to predict fabric stiffness. It is consisted of three layers; input layer, hidden layer with seven neurons, an output layer. The performance indication of the neural was the MSE to conduct a comparison with the regression analysis model [19].

4. Results and discussion

Results present four different models; three ones are established according to material of weft yarn by using the multiple regression analysis. The fourth model is the ANN that depends on all data of table (2); fabric factors are the input of the neural and fabric stiffness is the output. Table (2) shows codes of fabric factors that used to predict fabric stiffness.

4.1. Model (1):

The regression equation (1) that predicts fabric stiffness includes weft yarn count, state of weft yarn (single/ply), picks per inch and fabric pattern but count of weft yarn and picks per inch are insignificant factors according to their P-values, (proposed significance level: $P \leq 0.05$ at 95%, so the equation (2) neglects these insignificant factors model (1).

$$\text{Fabric Stiffness} = -0.003 - (0.002*\text{Yarn count}) + (0.04*\text{Yarn state}) + (0.001*\text{Picks per inch}) + (0.016*\text{Fabric pattern}) \ldots\ldots\text{Equation (1)}$$

Table 2. Codes of models (1, 2 and 3)

Model	Sample	Weft (Ne)	Yarn state	Picks per inch	Fabric pattern	Stiffness (gm.cm)
Model (1)	1 M1	25	0	44	1	0.017
	2 M1	25	0	50	1	0.025
	3 M1	25	0	44	-1	0.019
	4 M1	25	0	50	-1	0.021
	5 M1	16	1	44	1	0.101
	6 M1	16	1	50	1	0.126
	7 M1	16	1	44	-1	0.045
	8 M1	16	1	50	-1	0.051
	9 M1	18	0	47	1	0.030
	10 M1	18	0	50	1	0.034
	11 M1	18	0	47	-1	0.022
	12 M1	18	0	50	-1	0.025
	13 M1	20	1	47	1	0.085
	14 M1	20	1	50	1	0.098
	15 M1	20	1	47	-1	0.041
	16 M1	20	1	50	-1	0.044
Model (2)	1 M2	25	0	44	1	0.017
	2 M2	25	0	50	1	0.034
	3 M2	25	0	44	0	0.013
	4 M2	25	0	50	0	0.020
	5 M2	25	1	44	1	0.046
	6 M2	25	1	50	1	0.072
	7 M2	25	1	44	0	0.028
	8 M2	25	1	50	0	0.038
	9 M2	20	1	44	1	0.073
	10 M2	20	1	50	1	0.096
	11 M2	20	1	44	0	0.038
	12 M2	20	1	50	0	0.043
	13 M2	16	1	47	1	0.092
	14 M2	16	1	50	1	0.121
	15 M2	16	1	47	0	0.043
	16 M2	16	1	50	0	0.052

Material Type	Sample	Weft (Ne)	Yarn state	Picks per inch	Fabric pattern	Stiffness (gm.cm)
Model (3)	1 M3	25	0	44	-1	0.018
	2 M3	25	0	50	-1	0.023
	3 M3	25	0	44	0	0.023
	4 M3	25	0	50	0	0.037
	5 M3	24	1	47	-1	0.029
	6 M3	24	1	50	-1	0.033
	7 M3	24	1	47	0	0.033
	8 M3	24	1	50	0	0.038
	9 M3	20	1	44	-1	0.038
	10 M3	20	1	50	-1	0.042
	11 M3	20	1	44	0	0.046
	12 M3	20	1	50	0	0.054
	13 M3	16	1	47	-1	0.043
	14 M3	16	1	50	-1	0.056
	15 M3	16	1	47	0	0.057
	16 M3	16	1	50	0	0.065

Equation (2) that expresses on model (1) displays that the R^2 value of total model, is about (0.78) and (MSE = 0.0002). This means that only 78% of the whole variance data can be described by the model, and 22% of the total variation cannot be explained.

Fabric stiffness = 0.024 + (0.05*Yarn state) + (0.016*Fabric pattern)…………Equation (2)

Table (3) shows the correlation coefficients between fabric stiffness, state of weft yarn (single / ply) and fabric pattern. Coefficient of correlation of yarn state has a high relation with fabric state (single (0)/ ply (1)) and this confirms that the fabric stiffness increases in the state of plied yarns because of less mobility between fibers when comparing to single yarns.

Table 3. Correlation between fabric stiffness and fabric factors

Factor	Stiffness
Yarn state	0.75
Fabric pattern	0.47

Table (4) compares between predicted and actual fabric stiffness of model (1). The values of error illustrate that this model is non-effective statistical tool to predict fabric stiffness and the relation between these factors should be studied by another technique to get more explanation.

4.2. Model (2)

Equation (3) relates between the proposed factors that was stated in table (1); count of weft yarn, weft yarn state (single or ply), picks per inch and fabric pattern whereas (R^2 = 0.87 and MSE = 0.0001).

Fabric stiffness = -0.048 - (0.003*Yarn count) + (0.025*Yarn state) + (0.003*Picks per inch) + (0.035* Fabric pattern)……………………………………………………………….Equation (3)

Table 4. Results of model (1)

Sample	Actual	Predicted	Error
1 M1	0.017	0.040	-0.023
2 M1	0.025	0.040	-0.015
3 M1	0.019	0.009	0.010
4 M1	0.021	0.009	0.013
5 M1	0.101	0.089	0.012
6 M1	0.126	0.089	0.036
7 M1	0.045	0.058	-0.014
8 M1	0.051	0.058	-0.008
9 M1	0.030	0.040	-0.010
10 M1	0.034	0.040	-0.005
11 M1	0.022	0.009	0.014
12 M1	0.025	0.009	0.016
13 M1	0.085	0.089	-0.004
14 M1	0.098	0.089	0.009
15 M1	0.041	0.058	-0.017
16 M1	0.044	0.058	-0.014

Table (5) shows that count of weft yarn, its state (single/ply) and fabric pattern have the same value of coefficient of correlation (0.6) approximately, i.e., they have a moderate effect on fabric stiffness prediction. Although state of weft yarn, picks per inch and fabric pattern have a positive correlation to fabric stiffness, weft yarn count has a negative correlation. It can be concluded that an increase in weft yarn count (Ne) leads to lower values of fabric stiffness due to high flexibility of finer yarns.

Table 5. Correlation between fabric stiffness and fabric factors

Factor	Stiffness
Yarn Count	-0.63
Yarn state	0.59
Fabric pattern	0.58
Picks per inch	0.35

Table (6) displays values of error between actual and predicted fabric stiffness. Results show that model (2) is not acceptable to predict fabric stiffness due to higher values of errors and it is suggested that applying ANN in model (4) to get more explanation of relations between fabric factors and fabric stiffness.

4.3. Model 3

Equation (4) relates between fabric stiffness, count of weft yarn, weft yarn state (single/ply), picks per inch and fabric pattern but yarn state is insignificant factor according P-value (0.142) therefore it is neglected in equation (5).

Fabric stiffness = 0.032 - (0.003*Yarn count) + (0.004*State of yarn) + (0.001*Picks per inch) + (0.01*Fabric pattern)……………………………………………………………….. Equation (4)

Equation (5) relates between fabric stiffness, weft yarn count, picks per inch and fabric pattern and it explains about 94% of variables (R2 = 0.939) and MSE equals (1.06E-05).

Fabric stiffness = 0.038 - (0.003*Yarn count) + (0.001*Picks per inch) + (0.009*Fabric pattern) ……………………………………………………………………………Equation (5)

Table 6. Results of model (2)

Sample	Actual	Predicted	Error
1 M2	0.017	0.030	-0.013
2 M2	0.034	0.047	-0.013
3 M2	0.013	-0.004	0.017
4 M2	0.020	0.012	0.008
5 M2	0.046	0.055	-0.010
6 M2	0.072	0.072	0.000
7 M2	0.028	0.021	0.007
8 M2	0.038	0.037	0.001
9 M2	0.073	0.071	0.002
10 M2	0.096	0.087	0.009
11 M2	0.038	0.036	0.002
12 M2	0.043	0.052	-0.009
13 M2	0.092	0.091	0.001
14 M2	0.121	0.099	0.022
15 M2	0.043	0.056	-0.013
16 M2	0.052	0.065	-0.013

Table (7) shows that weft yarn count has the highest value of coefficient of correlation compared to picks per inch and fabric pattern.

Table 7. Correlation between fabric stiffness and fabric factors

Factor	Stiffness
Weft count	-0.86
Pick per inch	0.37
Fabric pattern	0.34

Table (8) shows that model (3) is an acceptable tool to predict fabric stiffness from proposed factors that affecting fabric pattern because all values of error are closed to (0) that indicate to a high performance of prediction model.

Table (9) displays that model (3) is the best model of prediction performance by applying regression analysis to predict fabric stiffness. It gets high percentage of explanation between fabric factors and fabric stiffness that means higher values of R-Squared (0.939) and (MSE = 1.06E-05).

Table 8. Results of model (3)

Sample	Actual	Pre-dicted	Error
1 M3	0.018	0.018	0.000
2 M3	0.023	0.027	-0.004
3 M3	0.023	0.027	-0.004
4 M3	0.037	0.036	0.001
5 M3	0.029	0.026	0.003
6 M3	0.033	0.030	0.003
7 M3	0.033	0.035	-0.002
8 M3	0.038	0.039	-0.001
9 M3	0.038	0.033	0.005
10 M3	0.042	0.042	-0.001
11 M3	0.046	0.042	0.004
12 M3	0.054	0.051	0.003
13 M3	0.043	0.050	-0.007
14 M3	0.056	0.055	0.001
15 M3	0.057	0.059	-0.002
16 M3	0.065	0.064	0.001

4.4. Model 4

Model (4) is based on ANN to predict fabric stiffness from all data of fabric factors (48 samples) that were stated in table (2) to get more effective statistical tool for prediction. The neural network consists of an input layer (weft yarn material, count and state of weft yarn and fabric pattern), 10 hidden layers and an output layer (fabric stiffness) as it is shown in figure (1).

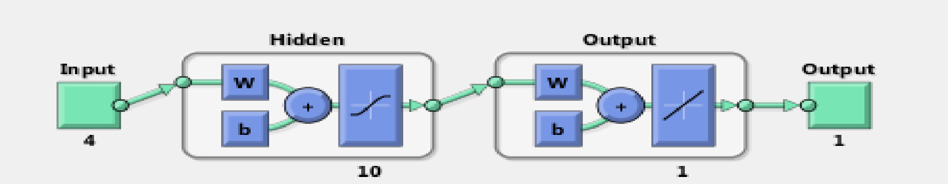

Figure 1. Artificial Neural Network Components

The data of neural network were divided into three sections for training, validation and testing to confirm the performance efficiency of the neural network.

Table 9. Results of models (1, 2, 3 and 4)

Model	R-Squared	MSE
Model (1)	0.78	0.0002
Model (2)	0.87	0.0001
Model (3)	0.939	1.06E-05

Table (10) displays the results of training, validation and testing of the ANN. Values of MSE are less than 1 and R- squared is closed to 1 which means that ANN is a robust tool to predict fabric stiffness when compared to models 1, 2 and 3.

Table 10. Results of ANN

	MSE	**R-Squared**
Training	1.756E-5	0.974
Validation	7.412E-5	0.934
Testing	2.588E-5	0.983

Figure (2) shows the results of ANN performance which indicate to the value of MSE. The best validation performance is about 7.41E-05 at epoch 6 and MSE of testing is closed to 10E-05 at epoch 12.

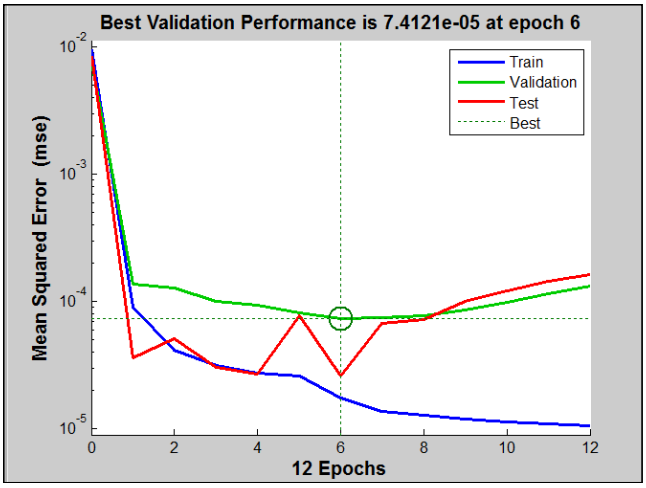

Figure 2. Performance results of ANN

Figure (3) shows the relations between fabric results of fabric stiffness and targets values of ANN trials to get the highest performance of prediction. The total value of R-squared of the ANN equals (0.967) and this value is more satisfied when compared to the models (1, 2 and 3) of regression analysis.

5. Conclusion

Multiple regression analysis and Artificial Neural Network can be used to predict fabric stiffness based on quantitative or qualitative variables by using dummy variables for qualitative ones. Although model (1 and 2) recorded acceptable values for R-squared and MSE, results of error values are not acceptable. Model (3) is the best one of regression analysis models to predict fabric stiffness based on count of weft yarn, weft state (single/ply), picks per inch and fabric pattern when considering values of error. Weft yarn state is the significant factor affects prediction of fabric stiffness in model (1) whereas the yarn count is the effective one in models (2 and 3) based on values of coefficient of correlation. ANN is a powerful prediction tool to relate between different fabric factors and fabric properties when comparing to regression analysis in textile industry. The mean square error is quite closed to (0) and total coefficient of correlation of ANN is closed to (1), therefore results of ANN is acceptable to predict fabric stiffness based on material type, count and state of weft yarn, and fabric pattern.

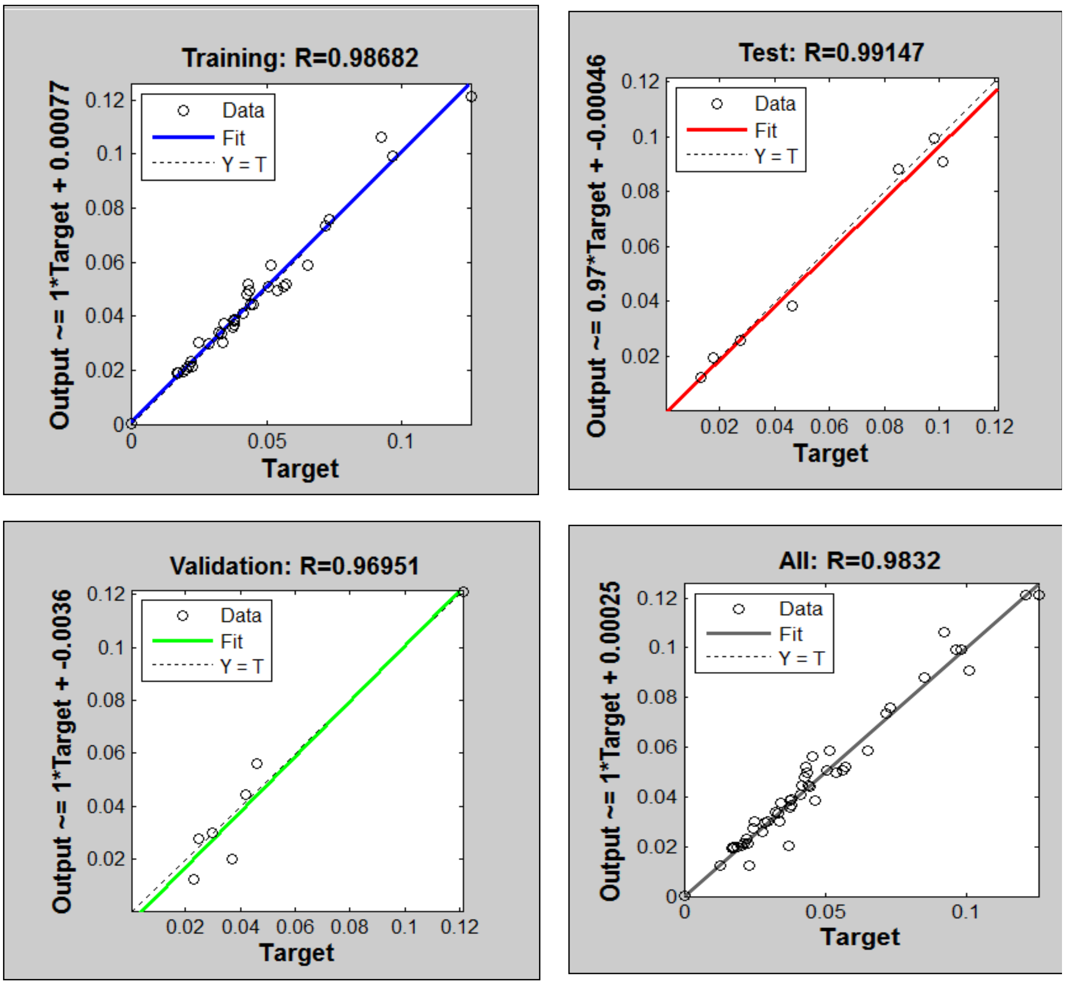

Figure 3. Coeffcient of correlation values of model (4)

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