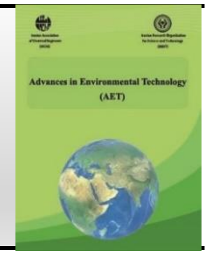
Advances in Environmental Technology 1 (2019) 35-45

Advances in Environmental Technology

journal homepage: http://aet.irost.ir



Green technology used in finishing process study of wrinkled cotton fabric by radial basis function (Experimental and modeling analysis)

Mir Saed Hesarian[a,*], Jafar Tavoosi[b]

[a] *Faculty of Textile Engineering, Urmia University of Technology, Urmia, Iran.*

[b] *Department of Electrical Engineering, Faculty of Engineering, Ilam University, Ilam, Iran.*

ARTICLE INFO

Article history:
Received 24 July 2019
Received in revised form
5 December 2019
Accepted 9 December 2019

Keywords:
Green technology
Cellulose chain
Wrinkle development
Anti-wrinkle finishing
Neural network

ABSTRACT

The wrinkling of cotton fabric is an important factor that affects a garment's appearance. This paper evaluated the use of a non-toxic green anti-wrinkle material in the finishing process to address this issue. For this purpose, the chemical structure of the wrinkled cotton sample was evaluated and treated with a scouring and anti-creasing finishing material. Due to the environmental issues created by the toxic material used as finishes, the type of anti-wrinkle material used in this study had the least possible environmental impact. The mechanism of this anti-crease finishing was based on the crosslinking of cellulose molecular chains. This process limited the chain movements made by wrinkling. Accordingly, the effect of the mentioned mechanism and structural parameters such as the thickness, weight, density of the weft yarn, and linear density of the weft yarn (Ne) were evaluated. The wrinkle degree of the samples was analyzed by using a radial basis function neural network (RBFN). This RBFN modeled the relationships between the degree of wrinkling in the fabrics and the mentioned parameters, especially the anti-crease finishing of the samples. The simulation results confirmed the effectiveness of the proposed method.

1. Introduction

After repeated home laundering, one of the factors that influences garment quality is the ability of fabrics to recover from induced wrinkles [1]. Since the garment's appearance is an important factor for customers, clothing manufacturers pay considerable attention to this property. Viscoelastic properties have an important role in the forming of wrinkles. All fabrics have a different wrinkle property. The resistance of wool and silk to wrinkling is good. The cellulose chains of cotton and viscose easily wrinkle [2]. Cellulose is the important compound in cotton fibers (Nearly 90%). Bast fibers such as flax, jute, and kenaf consist of about 75% cellulose. The cellulose in cotton fibers have a high molecular weight, and its structure is crystalline with amorphous regions [3]. During the scouring or wearing of cotton cloths, humidity and water absorption affects the molecular chains of the cellulose and leads to their movement in amorphous regions. After the movements of the chains, the cellulose molecules get a new arrangement in the chain structure, and the hydrogen groups in the adjacent positions create new hydrogen bonds [3]. Thus, the crosslinking of the chains in the cellulous structure was used for this problem. As a result, the chains were consolidated by crosslinking with the finishers [3,4]. The cross-linkers used in the finishing process can be divided into the following groups: chemical agents with a formaldehyde base and those agents free of formaldehyde. The first chemical agents introduced were based on the N-methylol groups. These groups are known as urea-formaldehyde [5,6]. Their important components are urea and formaldehyde. Another reactive group used for the crosslinking of cellulose chains is melamine-formaldehyde. This product has groups of N-methylol. The number of these groups is 3 to 6. The crosslinking property of melamine-formaldehyde is high. The molarity of melamine and formaldehyde determines the kind of product, respectively. Trimethylol melamine has 3 groups of N-methylol, and hexamethylol melamine has 6 groups

*Corresponding author. Tel: +98 4433728180
E-mail address: s.hesarian@uut.ac.ir
DOI: 10.22104/aet.2019.3730.1183

[7-9]. With more interest in the study of green technology and its environmental concerns [10-13], other methods should be developed. Today, computational intelligence has infiltrated many sciences [14-16]. The reason for this is certainly the high power of this knowledge in the approximation of functions, modeling, and so on. In the textile and chemical industries, too, computational intelligence has been very influential [17-19]. For this reason, an RBF network was used in this investigation for modeling the condition of the wrinkled fabric. This study did not use a formaldehyde chemical-based finisher because it is problematic for the health of humans and the environment. Instead, a non-toxic material was used as the finisher in the finishing process. The wrinkle degree of the fabric is dependent on the type of material, yarn and fabric structural characteristics, and finish treatment. Therefore, the effects of these factors on the wrinkle property of the fabric samples in this study were evaluated by a projected profile light line method [1]. In present study, new neural network modeling are developed for the analysis of the relationship between the above-mentioned parameters and the wrinkle degree of the samples. It was observed that the wrinkle development of the fabrics had a good relationship with these parameters, especially the anti-crease finishing of the samples.

2. Material and methods

2.1. Material

In this paper, 40 samples of cotton fabric were developed with different linear densities of the weft yarn, weight per square meter, thickness of fabric, and weft densities that are shown in Table1.

2.2. Test method and wrinkle assessment of samples

The AATCC128 (2000) standard was used to prepare the samples [10]. The wrinkle grade of the fabrics were analyzed and determined by an objective test method developed by M.S. Hesarian [1]. In this method, the wrinkle grade was measured via the light line method. For analyzing the effect of the measurement angle on the judgment of the fabric wrinkle degree, an objective measurement was executed for each sample at different angles (0°, 45°, 90°, 180°, 270°) between the warp direction of the wrinkled sample and the X axis direction.

In this research, the angle is defined as the angle between the warp direction of the wrinkled sample and the X axis direction. In the 3D position of the fabric sample (Fig. 1), the warp direction of the sample is the same with the X axis.

2.2.1. Preparation of samples

In this study, the samples were prepared objectively according to the AATCC128 method. For this purpose, the specimens were prepared at 150×280 mm. Then, a 3.5 kg weight was placed on the samples for 20 minutes. Finally, the wrinkle degree of the samples was evaluated objectively after a 24 hour recovery period. The standard atmosphere before the experiment was 65% RH and 20° C for 24 hours.

2.2.2. RBF Network-Based Classifier

In multi-layer perceptrons, the hidden neurons are based on linear basis function (LBF) nodes. Another type of hidden neurons is the radial basis function (RBF) neurons, which is the building block of the RBF neural networks. In an RBF network, each neuron in the hidden layer is composed of a radial basis function that also serves as an activation function. The weighting parameters in an RBF network are the centers and the widths of these neurons. The output functions are the linear combination of these radial basis functions. A more general form of the RBF networks is the elliptical basis function (EBF) networks, where the hidden neurons compute the Mahalanobis distance between the centers and the input vectors. It has been shown that RBF networks have the same asymptotic approximation power as multi-layer perceptrons, see Fig.2.

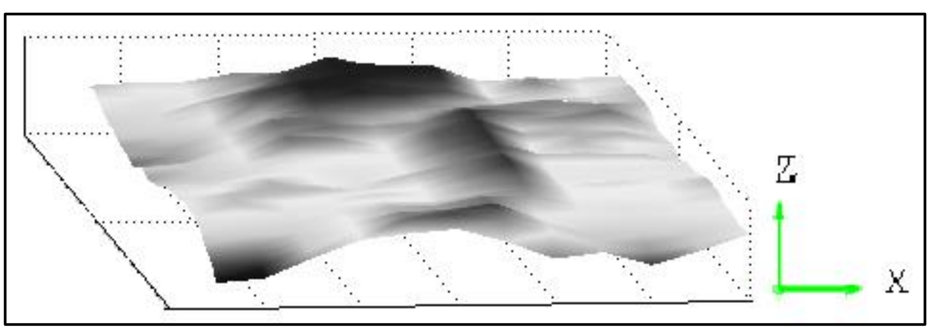


Fig.1. 3D position of wrinkled fabric respective to X axis

Table 1. The cotton fabric samples developed in this research

	Material	Thickness (mm)	Weft Density (yard/cm)	Linear density of Weft yarn (Ne)	Weight (g/m²)
1	Staple Cotton	0.31	32	18.87	155
2	Staple Cotton	0.31	34	18.83	160
3	Staple Cotton	0.33	37	18.86	169
4	Staple Cotton	0.33	33	25.22	136
5	Staple Cotton	0.33	35	25.12	146
6	Staple Cotton	0.29	37	25.10	150
7	Staple Cotton	0.30	34	30.43	139
8	Staple Cotton	0.29	36	30.32	124
9	Staple Cotton	0.32	38	30.23	126
10	Staple Cotton	0.32	34	18.92	160
11	Staple Cotton	0.32	36	21.55	164
12	Staple Cotton	0.33	38	21.60	171
13	Staple Cotton	0.33	34	25.16	142
14	Staple Cotton	0.33	37	25.14	147
15	Staple Cotton	0.29	39	25.03	153
16	Staple Cotton	0.29	33	30.31	120
17	Staple Cotton	0.28	36	30.42	125
18	Staple Cotton	0.31	38	30.05	128
19	Staple Cotton	0.30	32	21.95	153
20	Staple Cotton	0.30	34	19.15	160
21	Staple Cotton	0.32	37	19.00	165
22	Staple Cotton	0.32	33	25.66	138
23	Staple Cotton	0.32	35	25.60	143
24	Staple Cotton	0.27	38	25.44	149
25	Staple Cotton	0.27	33	30.86	117
26	Staple Cotton	0.29	35	30.23	122
27	Staple Cotton	0.29	37	30.31	127
28	Staple Cotton	0.29	33	21.37	151
29	Staple Cotton	0.31	37	18.68	164
30	Staple Cotton	0.34	39	18.70	167
31	Staple Cotton	0.33	34	25.05	133
32	Staple Cotton	0.31	36	24.88	144
33	Staple Cotton	0.32	38	25.18	150
34	Staple Cotton	0.29	33	30.24	120
35	Staple Cotton	0.29	37	30.15	126
36	Staple Cotton	0.29	39	30.14	131
37	Staple Cotton	0.34	33	21.53	155
38	Staple Cotton	0.35	35	19	164
39	Staple Cotton	0.34	38	21.56	167
40	Staple Cotton	0.32	36	25.12	134

To apply RBF/EBF networks for pattern classification, each class is assigned a group of hidden units, and each group is trained independently using the data from the corresponding class. Fig. 2 depicts the architecture of an RBF/EBF network with *D* inputs, *M* basis functions (hidden nodes), and *K* outputs. The input layer distributes the D-dimensional input patterns, x_t, to the hidden layer. Each hidden unit is a Gaussian basis function of the form

$$\phi_j(x_t) = \exp\left\{-\frac{1}{2\gamma_j}(x_t-\mu_j)^T\Sigma_j^{-1}(x_t-\mu_j)\right\} \quad j=1,\ldots,M \tag{1}$$

where μ_j and Σ_j are the mean vector and covariance matrix of the *j-th* basis function, respectively, and γ_j is a smoothing parameter controlling the spread of the *j*-th basis function. The *k*-th output is a linear weighted sum of the basis functions' output, i.e,

$$y_k(x_t) = \omega_{k0} + \sum_{j=1}^{M}\omega_{kj}\phi_j(x_t) \quad t=1,\ldots,N \text{ and } k=1,\ldots,K \tag{2}$$

where x_t is the *t-th* input vector and ω_{k0} is a bias term.

In matrix form, (2) can be written as $Y=\Phi W$ where Y is an $N\times K$ matrix, Φ an $N\times(M+1)$ matrix, and W is an $(M+1)\times K$ matrix. The weight matrix W is the least squares solution of the matrix equation

$$\Phi W = D \tag{3}$$

where D is an $N\times K$ target matrix containing the desired output vectors in the rows. As Φ is not a square matrix, one reliable way to solve (3) is to use the technique of singular value decomposition.

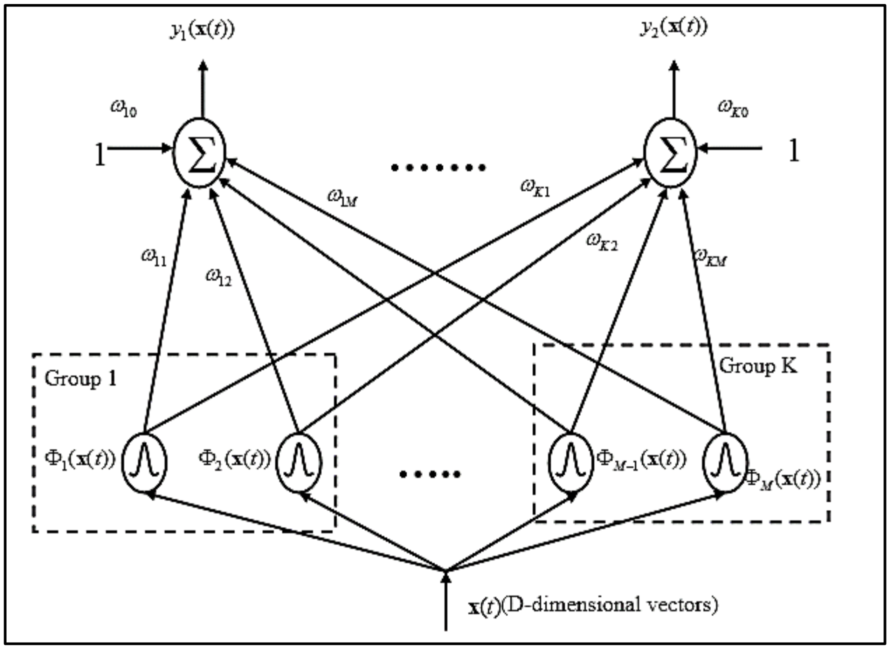


Fig. 2. Architecture of a K-output RBF network

In this approach, the matrix Φ is decomposed into the product $U\Lambda V^T$, where U is an $N\times(M+1)$ column-orthogonal matrix, Λ is an $(M+1)\times(M+1)$ diagonal matrix containing the singular values, and V is an $(M+1)\times(M+1)$ orthogonal matrix. The weight vectors $\{w_k\}_{k=1}^{K}$ are given by

$$w_k = V\Lambda^{-1}U^T d_k \tag{4}$$

where d_k is the *k*-th column of D. For an over-determined system, singular value decomposition gives a solution that is the best approximation in the least squares sense. See [20] for more information regarding the RBF network. It should be noted that in this paper, the RBF network is used for modeling. In the procedure, the input-output data on the fabric properties are first experimentally extracted and then used to train the RBF network. Finally, the obtained model is validated with the actual fabric system data. A variety of work has been done on the use of neural networks in the textile industry, some of which are discussed in the following studies. In [21], a neural network application in yarn, fabric, nonwoven, and cloth defect detection and categorization was reviewed. Its application in textiles and clothing industries involved the interaction of a large number of variables. Because of the high degree of variability in raw materials, multistage processing, and a lack of precise control on process parameters, the relation between such variables and the product properties relied on human knowledge, but humans cannot remember all the details of the process-related data over the years [22]. In [23], artificial neural networks (ANNs) were used to predict the thermal resistance of wetted fabrics. For this aim, two different architectures were experienced, and a high regression coefficient between the predicted (training and testing) and observed thermal resistance values were obtained from both models. The obtained regression coefficient values were over 90% for both models. Thus, it can be said that ANNs could be used for successfully predicting the thermal resistance of wetted fabrics.

2.3. Finishing Treatments

The fabric samples were treated with scouring and the green anti-wrinkle finish. To address the environmental concerns, this study used polycarboxylic acid as the finisher in the anti-wrinkling finishing bath. This material was supplied by the Henan Kaicheng New Materials Co., Ltd. This process affected the wrinkle degree of the fabric by resisting the chains of cellulose molecular against the movements. The samples were scoured at 96°C for two hours. An anti-wrinkle treatment was used from polycarboxylic acid (BTCA (1,2,3,4-butane tetra-carboxylic acid)) as the finisher; then, the samples were dried at 105°C. The time of the condensation process was 2 min in 135°C.

3. Results and discussion

A wrinkle is the collection of the creases and folds that are made on the fabric under the forces and surrounding settings such as the thermal and humidity conditions. During the scouring or wearing of cotton cloths, humidity and water absorption affects the molecular chains of the cellulose and leads to their movement in the amorphous regions. After the movements of the chains, the cellulose molecules are newly arranged in the chain structure, and the hydrogen groups in adjacent positions create new hydrogen bonds. These new chain arrangements make a collection of creases and folds as a wrinkle on the fabric.

The AATCC128 test method was used for determining the value and intensity of the wrinkle of fabrics as the wrinkle grade. In this method, there are five reference samples: reference 1 has the maximum wrinkle, and reference 5 has the minimum wrinkle. The wrinkled fabric sample is compared with this reference, which determines the wrinkle grade of the sample. As a result, the wrinkle grade is inverse with the wrinkle. Therefore, by increasing of the wrinkle grade, the wrinkle of the fabric decreased. According to above description, the results of wrinkle grade measurements by the light line method [1] are presented in Table 2. The first to fourth columns of Table 2 are characteristic of the samples. Fig. 3 shows the samples of the wrinkled cotton fabric after the scouring and anti-wrinkling finishing process. According to this figure, the wrinkle grade of the sample decreased after the anti-wrinkling finishing process. As shown in Fig. 3 (c), the cotton fabric finished with an agent material of polycarboxylic acid can easily recover to its original flat appearance under blowing steam. However, according to Figure 3(b), the cotton fabric not treated with polycarboxylic acid does not have enough wrinkle resistance and therefore, cannot recover to a flat shape under blowing steam.

Table 2. Values of the structural parameters and wrinkle grade of samples

	Material	Thickness (mm)	Weft Density (yarn/cm)	Linear density of Weft yarn (Ne)	Weight (g/m²)	Wrinkle Grade (after scouring)	Wrinkle Grade (After Finishing)
1	Staple Cotton	0.31	32	18.87	155	2.00	3.00
2	Staple Cotton	0.31	34	18.83	160	1.90	2.89
3	Staple Cotton	0.33	37	18.86	169	1.79	2.71
4	Staple Cotton	0.33	33	25.22	136	1.72	2.96
5	Staple Cotton	0.33	35	25.12	146	1.69	2.79
6	Staple Cotton	0.29	37	25.10	150	1.59	2.68
7	Staple Cotton	0.30	34	30.43	139	1.91	2.91
8	Staple Cotton	0.29	36	30.32	124	1.62	2.72
9	Staple Cotton	0.32	38	30.23	126	1.62	2.60
10	Staple Cotton	0.32	34	18.92	160	1.75	2.83
11	Staple Cotton	0.32	36	21.55	164	1.69	2.66
12	Staple Cotton	0.33	38	21.60	171	1.65	2.70
13	Staple Cotton	0.33	34	25.16	142	1.87	2.93
14	Staple Cotton	0.33	37	25.14	147	1.67	2.72
15	Staple Cotton	0.29	39	25.03	153	1.48	2.52
16	Staple Cotton	0.29	33	30.31	120	1.65	2.85
17	Staple Cotton	0.28	36	30.42	125	1.51	2.50
18	Staple Cotton	0.31	38	30.05	158	1.80	2.79
19	Staple Cotton	0.30	32	21.95	153	1.90	2.95
20	Staple Cotton	0.30	34	19.15	160	1.92	2.93
21	Staple Cotton	0.32	37	19.00	165	1.74	2.70
22	Staple Cotton	0.32	33	25.66	138	1.72	2.8
23	Staple Cotton	0.32	35	25.60	143	1.78	2.74
24	Staple Cotton	0.27	38	25.44	149	1.44	2.5
25	Staple Cotton	0.27	33	30.86	117	1.45	2.55
26	Staple Cotton	0.29	35	30.23	122	1.71	2.76
27	Staple Cotton	0.29	37	30.31	127	1.55	2.61
28	Staple Cotton	0.29	33	21.37	151	1.94	2.90
29	Staple Cotton	0.31	37	18.68	164	1.88	2.91
30	Staple Cotton	0.34	39	18.70	167	2.95	3
31	Staple Cotton	0.33	34	25.05	133	1.79	2.84
32	Staple Cotton	0.31	36	24.88	154	1.89	2.94
33	Staple Cotton	0.32	38	25.18	150	1.79	2.80
34	Staple Cotton	0.29	33	30.24	120	1.78	2.81
35	Staple Cotton	0.29	37	30.15	126	1.50	2.59
36	Staple Cotton	0.29	39	30.14	131	1.46	2.45
37	Staple Cotton	0.34	33	21.53	155	1.89	2.88
38	Staple Cotton	0.35	35	19	164	2.1	3.05
39	Staple Cotton	0.34	38	21.56	167	1.9	2.88
40	Staple Cotton	0.32	36	25.12	134	1.7	2.64

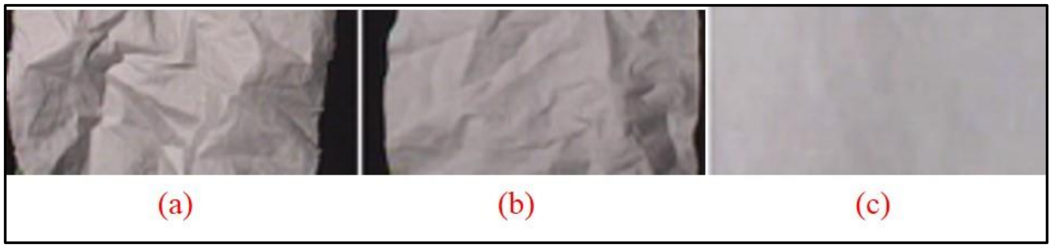


Fig. 3. Comparing wrinkle grade of cotton fabric sample after (a) scouring, (b) blowing steam of unfinished cotton fabric, and (c) blowing steam of finished cotton fabric

The theoretical base of this network has been described in Section 2-2-3. In Figs 4 to 7 there are four parameters as inputs of developed neural network. The first and second parameters are thickness and weight of the fabric samples. the weft density of fabric as the number of weft yarns per centimeter is the third parameter and finally, the linear density of weft yarn (Ne), is the next one. Ne is used as the English Cotton Count in the cotton yarn spinning industry. The fifth and sixth columns of Table 2 are the wrinkle grades of the samples after scouring and the finishing process, respectively. The finishing agents produced with melamine-formaldehyde have better properties in comparison to the urea-formaldehyde products. These properties include stability against hydrolyzing and the fastness of washing. But, the bending resistance of the fabric treated by this finishing agent and the content of formaldehyde is problematic [9]. According to the mentioned drawbacks, this study used the polycarboxylic acid agent for the crosslinking of the cellulose molecular chains as the anti-creasing agent in the finishing process of the cotton fabric samples. The wrinkling of the fabric is affected by the crosslinking of the chains.

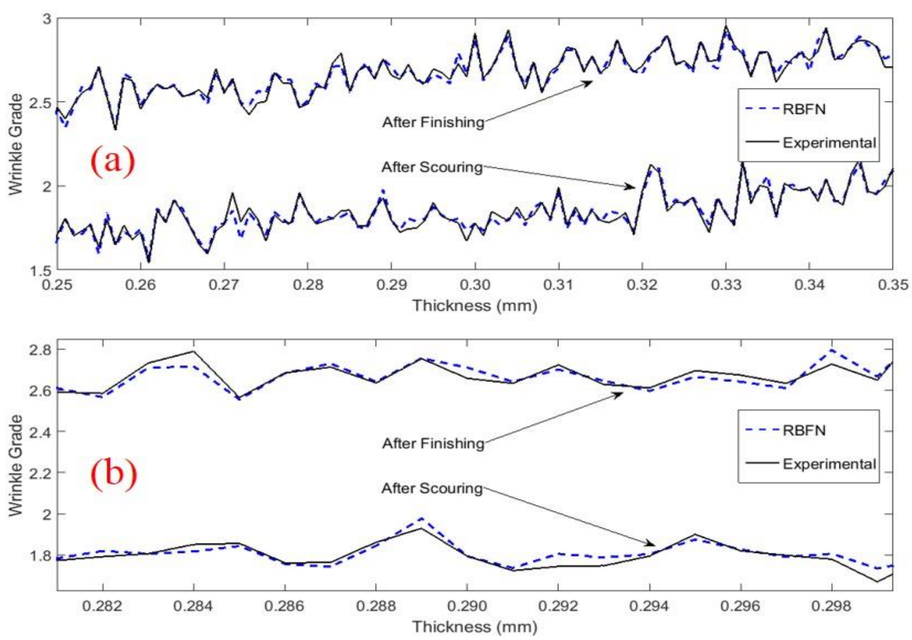


Fig.4. Wrinkle grade evaluation by thickness of fabric after finishing and scouring treatment (a). common (b). Zoom of (a)

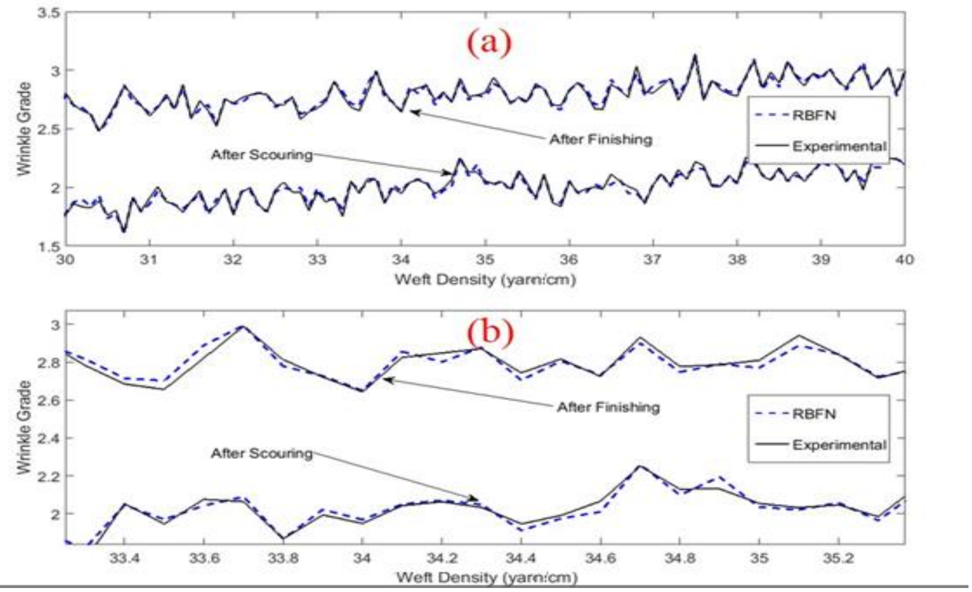


Fig. 5. Wrinkle grade evaluation by weft density of fabric after finishing and scouring treatment (a) Common, (b) Zoom of (a)

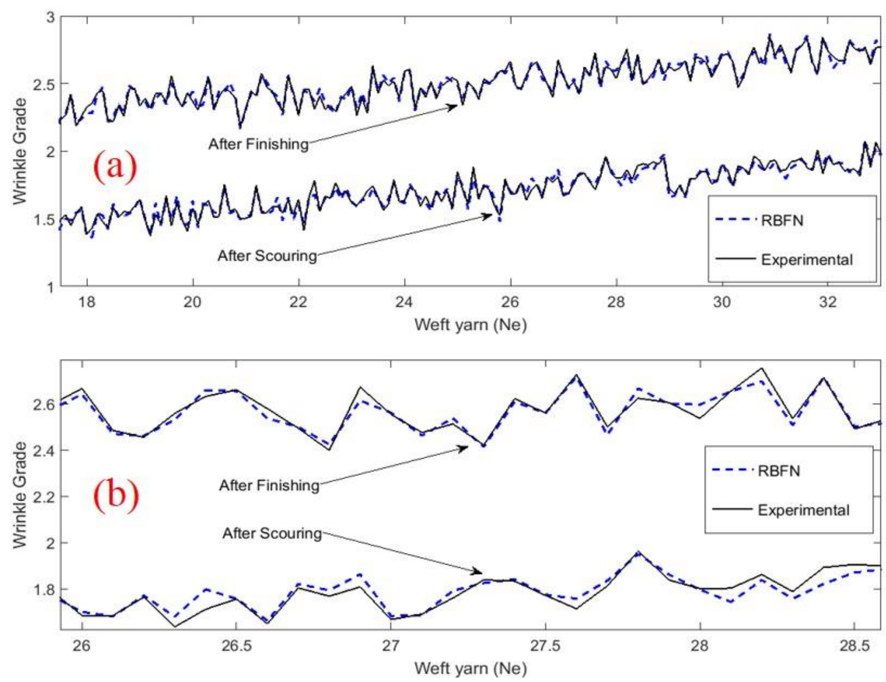


Fig. 6. Wrinkle grade evaluation by weft linear density (Ne) of fabric after finishing and scouring treatment (a) Common, (b) Zoom of (a)

Figs. 4, 6, and 7 show there is a good agreement between the developed model of the neural network and the experiments. Therefore, this model could be used for predicting the wrinkle grade of the fabric according to the input parameters mentioned in Figs. 4, 6, and 7. The effect of scouring and the anti-wrinkling finishing process on the wrinkle grade of the samples are evaluated by analyzing the results reflected in Fig. 8. According to this figure, the anti-wrinkling finish of the fabrics is more effective on the wrinkle resistance of the samples.Fig. 8 that supported by the values reflected in Table 3, shows that the wrinkle grade of the samples is evaluated according to the weft yarn density in the fabric thickness of T=0.29, 0.31, 0.32, and 0.33mm. This figure shows that by increasing the weft yarn density in the thickness of 0.29, 0.32, and 0.33mm, the wrinkle grade of the samples decreases. According to this figure, the wrinkle grade values at the fabric thickness of 0.29, 0.32, and 0.33mm have maximum and minimum values, respectively. Therefore, the wrinkle grade of the samples increases by increasing the fabric thickness. By evaluating the weft yarn linear density and weight of the fabric values at marked zones (values of weft density and thickness are constant), Table 3 shows that by increasing the linear density of the weft yarn or weight of the fabric, the wrinkle grade of the samples increases.

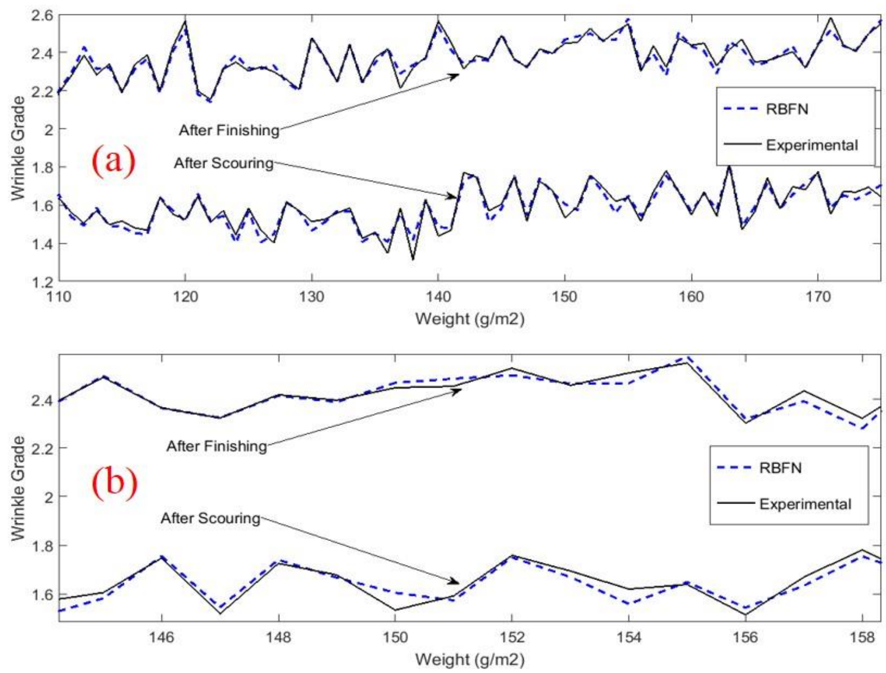


Fig. 7. Wrinkle grade evaluation by weight of fabric after finishing and scouring treatment (a) Common (b) Zoom of (a)

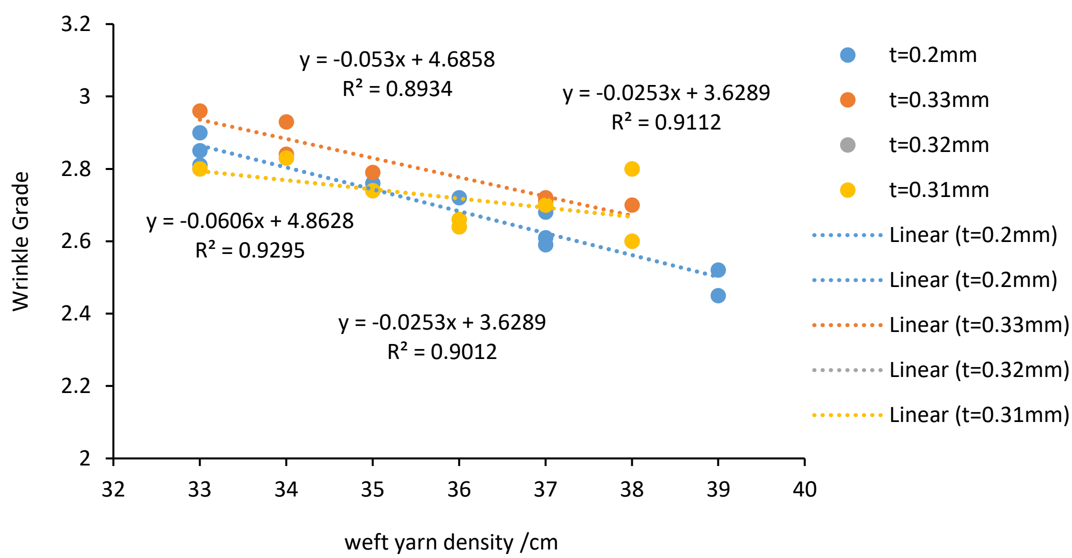


Fig. 8. Wrinkle grade of cotton fabric samples with different thickness of fabric

Finally, by increasing the thickness, weight, and weft linear density of the samples, the wrinkle grades decreased. Accordingly, the output results of the developed neural network reflected in Fig. 8 show that the wrinkle grade of the cotton samples increased by increasing of the weft density of the fabric. By increasing of linear density of the weft yarn, weight, and thickness of the fabric, the bending resistance of the fabric increased. Therefore, the wrinkle resistance of the fabric increased by increasing the bending resistance.

Table 3. Wrinkle grade of cotton fabric samples with 0.29,0.31,0.32, and 0.33 mm of thickness

Material	Thickness (mm)	Weft Density (yarn/cm)	Linear density of Weft yarn (Ne)	Weight (g/m²)	Wrinkle Grade (after scouring)	Wrinkle Grade (After Finishing)
Staple Cotton	0.29	33	30.31	120	1.55	2.85
Staple Cotton	0.29	33	21.37	151	1.54	2.9
Staple Cotton	0.29	33	30.24	120	1.57	2.81
Staple Cotton	0.29	35	30.23	122	1.57	2.76
Staple Cotton	0.29	36	30.32	124	1.52	2.72
Staple Cotton	0.29	37	25.10	150	1.5	2.68
Staple Cotton	0.29	37	30.31	127	1.49	2.61
Staple Cotton	0.29	37	30.15	126	1.50	2.59
Staple Cotton	0.29	39	30.14	131	1.46	2.45
Staple Cotton	0.29	39	25.03	153	1.48	2.52
Staple Cotton	0.31	32	18.87	155	2.00	3.00
Staple Cotton	0.31	34	18.83	160	1.90	2.89
Staple Cotton	0.31	36	24.88	154	1.82	2.94
Staple Cotton	0.31	37	18.68	164	1.82	2.91
Staple Cotton	0.31	38	30.05	138	1.8	2.79
Staple Cotton	0.32	33	25.66	138	1.72	2.80
Staple Cotton	0.32	34	18.92	160	1.75	2.83
Staple Cotton	0.32	35	25.60	143	1.78	2.74
Staple Cotton	0.32	36	21.55	164	1.69	2.66
Staple Cotton	0.32	36	25.12	134	1.7	2.64
Staple Cotton	0.32	37	19.00	165	1.85	2.7
Staple Cotton	0.32	38	30.23	126	1.62	2.6
Staple Cotton	0.32	38	25.18	150	1.79	2.8
Staple Cotton	0.33	33	25.22	136	1.90	2.96
Staple Cotton	0.33	34	25.05	133	1.82	2.84
Staple Cotton	0.33	34	25.16	142	1.91	2.93
Staple Cotton	0.33	35	25.12	146	1.73	2.79
Staple Cotton	0.33	37	18.86	169	1.89	2.71
Staple Cotton	0.33	37	25.14	147	1.67	2.72
Staple Cotton	0.33	38	21.60	171	1.65	2.7

4. Conclusions

The chemical structure of cotton fabric has been evaluated in the presence of wrinkles. It is observed that the wrinkling of fabric is made by the movement of the cellulose chains of cotton in the washing process. These movements occur in an amorphous area of the structure by hydrogen bonds. Therefore, a polycarboxylic acid as a green anti-wrinkle finishing agent is used for the crosslinking of the cellulose chains in the finishing bath. This agent also has the lowest environmental impact. The wrinkle grade of the fabric samples was evaluated by the weight and thickness of the fabric as well as the density and linear weight of weft yarn. Subsequently, a new radial basis function neural network was introduced for modeling. In this RBFN network, the parameters of thickness, weight, density of weft, and linear density of weft yarn were introduced as input, and the wrinkle grade of fabric was considered as the output. As it has been shown, the network output accurately matched the output of the laboratory's wrinkles, and this network model could be used in future research. The results of this study showed a decrease in the wrinkling of the cotton fabric samples by using the green finisher in the anti-wrinkling finishing process; also, by increasing the weight and thickness of the fabric and linear density of the weft yarn (Ne), the wrinkling decreased. According to the results, the fabric wrinkle of the samples increased by increasing the weft density. The modeling results of the RBFN network were in good agreement with the experimental values, and this model could predict the wrinkle grade of cotton fabrics. Also, the mentioned anti-wrinkle material was more effective on the wrinkle resistance of the samples. This study also showed that the use of the green material in the finishing process reduced the environmental impact on the textile industry.

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