OPTIMIZATION OF AIR PERMEABILITY OF INTERLOCK KNITTED FABRICS USING DIFFERENT EXPERIMENTAL DESIGN

Serin (MAVRUZ) MEZARCIOZ, R.Tugrul OGULATA
The University of Cukurova, Department of Textile Engineering, Adana, Turkey
smavruz@cu.edu.tr

Abstract
In this paper, air permeability of interlock knitted fabrics was optimized and investigated by comparing with the results of full factorial design tries all the combination of parameters having effect of performance value, and Taguchi design which is a recently famous approach. Taguchi design was used to determine the optimum design values and contribution of each factor. In the evaluations, analysis of variance and signal to noise (S/N) ratio were used. These results were confirmed with the full factorial design. The best combinations determined by using full factorial and Taguchi experimental design are the same. Closeness of the results of the predictions based on the calculated S/N ratios and experimental values show that Taguchi experimental design technique can be used successfully both optimization and prediction.
Key words: Experimental design, Taguchi design, Full factorial design, Knitted fabric

Introduction
Knitted fabrics are known for their excellent comfort properties. They possess high extensibility under low load allowing comfortable fit on any part it is pulled onto. Due to the manner in which yarns and fabrics are constructed, a large proportion of the total volume occupied by a fabric is, usually, airspace. The distribution of this airspace influences a number of important fabric properties such as warmth and protection against wind and rain in clothing, and efficiency of filtration in industrial cloths [1]. Also, the air permeability and the porosity of a knitted structure will influence its physical properties such as the bulk density, the moisture absorbency, the mass transfer and the thermal conductivity [2]. Air permeability is defined as the volume of air in liters, which is passed in one minute through 100 cm^2 (10 cmx10 cm) of the fabric at a pressure difference of 10 mm head of water [3].
The Taguchi method, pioneered by Dr. Genichi Taguchi and also called the "robust design method", greatly improves engineering productivity [4]. Taguchi focused on minimizing the effect of causes of variation. The product or process performs consistently on target and is relatively insensitive to uncontrollable factors. In comparison with a traditional full factorial design of experiments, Taguchi's methods in general provide a significant reduction in the size of experiments, thereby speeding up the experimental process [5]. In Taguchi design approach, there are three design stages, which are system, parameter and tolerance designs [4,6,7]. The parameter design approach has been adopted for studying the effect of parameters on the air permeability of interlock knitted fabrics.
Two major tools used in Taguchi method are the orthogonal array (OA) and the signal to noise ratio (SNR or S/N ratio). OA is a matrix of numbers arranged in rows and columns. Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments. The experimental results are then transformed in to a Signal to Noise (S/N) ratio. Taguchi recommends the use of S/N ratio to measure the quality characteristics deviating from the desired value. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics [8].
The method of calculating the S/N ratio depends on whether the quality characteristic is smaller-the-better, larger-the-better, or nominal-the-best [6,8-11]. In our study, we adopt the "bigger is better" approach. The S/N ratio for this type of response was used and given below:

$$\text{S/N} = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \quad (1)$$

Where; n is the number of experiments in the orthogonal array and y_i is the ith measured value. Detailed information about Taguchi method can be found in many books [6,9,10].

Taguchi design has been applied many different areas, even in service systems [7]. However, studies about application of Taguchi design in textile industry are very new. Some researchers used this design for different textile process [4,7,12-15]. Also, any research has been found on the air permeability of interlock knitted fabrics using Taguchi experimental design.

In this study, the effect of some yarn and fabric properties on the air permeability of interlock fabrics was analyzed using Taguchi design. Firstly, we calculate the S/N ratios of experimental observations. Then we find the optimum conditions influencing air permeability of interlock fabrics for each of the parameters. These results were confirmed with the full factorial design.

Determination of control factors

During the relaxation treatment, knitted fabrics tend to go back to the original forms by getting away the stress. Since relaxation treatment has changed shape of the loop, it would be affect the fabric performance properties. The type of yarn production (ring, compact and open-end) impressed the physical features of yarns and fabrics produced from these yarns would be demonstrated different performance properties. If amount of yarn that is essential for one stitch are increased, the fabrics are looser and its pores increases. Hence, air permeability value of fabric is affected.

So, relaxation type, yarn type and loop length affecting on air permeability values were selected as control factors. Here, yarn type was assumed as yarn parameter, relaxation type and loop length were assumed as fabric parameter affecting on air permeability.

After determining the control factors, the levels of each factor have to be determined. The most commonly used yarn and knitting types were considered to determine the levels of the factors. Here, dry relaxation, wash relaxation and full relaxation were selected as relaxation type. Ring, compact and open end yarns were selected as the yarn type. 0,31, 0,34 and 0,37 cm were selected as loop length. As a result, each of control factors was evaluated with 3 levels.

Materials and Method

After determining the control factors and their levels ring, compact and open end yarns were manufactured with 100% cotton and Ne 30/1 yarn number (used yarns were produced at nearly closed machine settings each other). By using these yarns, interlock fabrics were knitted with 3 different fabric tightness on Mayer circular knitting machine (24 gauge, 30” diameter, 2240x2 total needle count, with a positive yarn feeding system).

Table 1 gives the levels of various parameters and their designation.

Table 1. Parameters and their levels

		Levels		
Parameter	Designation	1	2	3
Relaxation type	A	Dry	Washed	Full
Yarn type	B	Ring	Compact	Open end
Loop length	C	0,31	0,34	0,37

The following relaxation treatments were applied to fabrics after knitting.

Dry relaxation: Fabrics were conditioned for at least 24 hours in the standard atmosphere (20ºC, 65 %RH). *Washed relaxation:* After dry relaxation, fabrics were washed in a domestic washer at 30ºC min 45 using 0.05% wetting agent. After wetting, fabrics were briefly hydro

extracted. Then they were conditioned in the same way as the dry relaxation method. *Full relaxation:* Wash relaxation procedure was repeated for five times.
Air permeability of the samples were measured via standard TS 391 EN ISO 9237 method, using the Textest FX 3300 air permeability tester. The measurements performed at a constant pressure drop of 100 Pa (20 cm^2 test area). Ten samples were tested each group and expressed as mm/s. All tests were performed under standard atmospheric conditions (20ºC, 65 %RH).
An $L_9(3^3)$ orthogonal array table was used (Table 2).

Table 2. Orthogonal matrix for sample production

	Parameters		
Order	**A**	**B**	**C**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Analysis, results and discussions

Taguchi design

The Taguchi optimization method consists of the following steps: Each S/N ratio can be obtained from observations according to the formula of higher the better. For each significant factor, the level corresponding to the highest S/N ratio is chosen as its optimum level. A search for the factors that have a significant effect on the S/N ratio is then performed through an analysis of variance (ANOVA) of the S/N ratios [4,6].
In data analysis, S/N ratios are used to allow control of the response as well as to reduce the variability about the response. The use of ANOVA is to calculate the statistical confidence associated with the conclusion drawn [16].
Table 3 shows the average value of the air permeability of fabrics for each experimental point and the S/N ratios calculated by formula 1. Each experimental trial was conducted with ten replications.

Table 3. Experimental layout using an L_9 orthogonal array table and S/N ratio of experimental results

	Factors and levels				
Exp. no	**A**	**B**	**C**	**Average air permeability values (mm/s)**	**S/N ratio (dB)**
1	D	R	0,31	911,70	59,19
2		C	0,34	1338,00	62,52
3		OE	0,37	1329,00	62,47
4	W	R	0,34	431,70	52,69
5		C	0,37	564,80	54,89
6		OE	0,31	313,72	49,85
7	F	R	0,37	478,50	53,30
8		C	0,31	221,75	47,81
9		OE	0,34	393,90	51,72

D: Dry relaxation, W: Washed relaxation, F: Full relaxation, R: Ring, C: Compact, OE: Open end

For all levels, it was obtained average SNR as shown in Table 4. Main effects plotted for SNR is shown in Figure 2. It implied that the largest impact in process consist of $A_1B_2C_3$ respectively. Maximum air permeability levels configuration for SNR are $A_1B_2C_3$ which means that A (dry relaxation), B (compact yarn), C (0,37 cm loop length).

Table 4. Response table for S/N ratio

Factors	Average S/N (dB)			
	Level 1	Level 2	Level 3	Delta
A- Relaxation type	61,39*	52,48	50,94	10,45
B- Yarn type	55,06	55,07*	54,68	0,39
C- Loop length	52,28	55,64	56,89*	4,61

*: Optimum parameter level

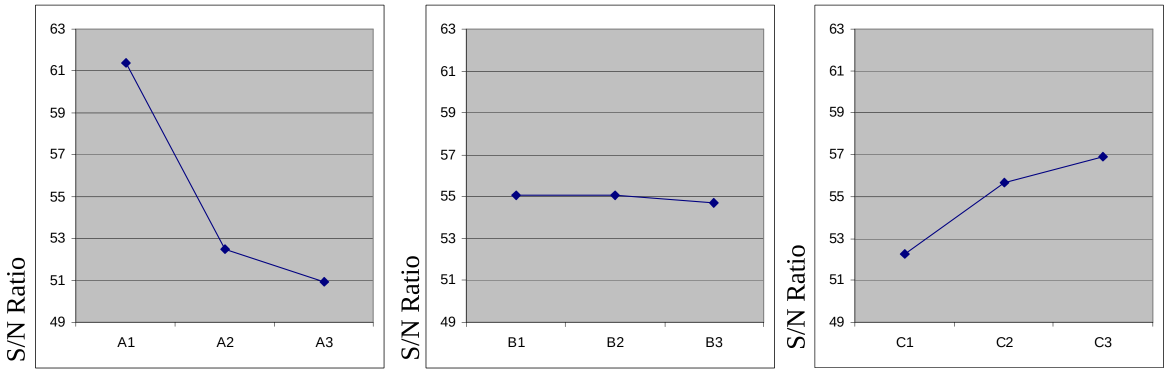

Figure 2. The effect of process parameters on S/N data-Factor A (relaxation type), factor B (yarn type), factor C (loop length)

ANOVA Analysis

The end of results of S/N analysis was used for realization of ANOVA. It is the quantitative measure of the influence of individual factors/parameters. It is important for determining the relative importance of the various factors/parameters. ANOVA was performed for S/N ratios with Design Expert 6.0.1 statistical program ($\alpha = 0.05$). An ANOVA table for S/N ratio was given in Table 5.

Table 5. ANOVA table for the S/N

Factors	Sum of squares	Degree of freedom	Mean square	F value	Prop>F	Percentage contribution (%)
Model	225.39	6	37.56	44.15	0.0223 significant	-
A	191.06	2	95.53	112.27	0.0088	84.14
B	0.30	2	0.15	0.18	0.8504	0.13
C	34.03	2	17.01	19.99	0.0476	14.98
Residual	1.70	2	0.85			0.75
Total	227.09	8				
R-squared: 0,99						

The sum of squares, mean square, F value, residual and also percentage contribution of each factor were shown in above ANOVA table. The degrees of freedom (df) for each factor is calculated as:

$$df = \text{number of level} - 1$$

With respect to Table 5, prob values lower than 0.05 shows that the established model is meaningful. Since the value of R^2 is 0.99, expressiveness of the model is high. This indicated that relaxation type (A) and loop length (C) the most significant effect on fabric air permeability values. The contribution of different factors in decreasing order as: Relaxation type (84.14 %), loop length (14.98 %), yarn type (0.13 %) and undefined parameters (0,75 %). As seen from Table 5, the yarn type has almost no effect on air permeability on knitted fabrics.

In order to find which interactions between factors are significant, the main interaction plot of air permeability was drawn using Design-Expert. Taguchi design suggests studying the interactions between two single factors only [15]. The interactions between each two factors (all possible combinations) were given in Figure 3. An interaction is said to exist if the effect of change in level of one factor is opposite to the effect of change in level in another factor. In

Figure 3, if the line connecting levels 1, levels 2 and levels 3 of both factors are parallel or almost parallel; this indicates that there is no meaningful interaction taking place between these factors. No interaction means the effect of the first factor remains the same regardless of the level of the second factor and vice versa. From this standpoint, there are no meaningful interactions between factors A and B (A*B), A and C (A*C), B and C (B*C).

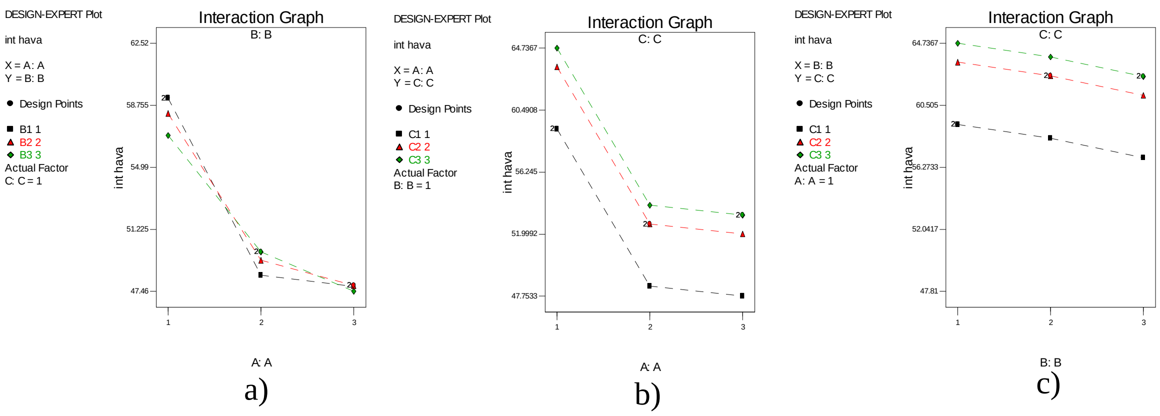

Figure 3. Main interaction plot for S/N (a- AxB, b-AxC, c- BxC)

Confirmation experiment

Conducting a confirmation experiment is a crucial final step of a Taguchi design. The confirmation experiment was carried out at the optimum setting of the significant parameters. Its purpose is to verify that the optimum conditions suggested by the matrix experiment do indeed give the projected improvement. The confirmation experiment is performed by conducting a test with optimal settings of the factors and levels previously evaluated. The predicted value of multiple S/N ratio at optimum level (η_0) is calculated by formula 2.

$$\eta_0 = \eta_m + \sum_{i=1}^{j} (\eta_i - \eta_m) \qquad (2)$$

Where, j is the number of factors and η_m is the mean value of multiple S/N ratios in all experimental runs, η_i are the multiple S/N ratios corresponding to optimum factor levels [9,17].

S/N ratio calculated for optimum level as follow:

$$\eta_o = \eta_m + (\eta A_1 - \eta_m) + (\eta B_2 - \eta_m) + (\eta C_3 - \eta_m) \qquad (3)$$

η_o is optimum S/N ratio, η_m is the overall mean of S/N values, ηA_1 is the average value of S/N at first level of relaxation type, ηB_2 is the average value of S/N at the second level of yarn type and ηC_3 is the average value of S/N at third level of loop length. According to the formula (3), η_o was found as 63,47 dB.

If the S/N is known and we want to learn about the expected result that will make the S/N. The procedure is to back-transform S/N to find expected performance value [10,18]. When 63.47 dB value could be set formula 1, obtained value is 1490,7 mm/s. Values of air permeability of other combinations will be expected with same formula.

Also, knitted fabric was produced according to the optimum design and initial design. Air permeability of these fabrics was measured from ten different places of fabric. Average of the results was determined as 1556 mm/s for optimum design (Table 6). This result is very close to the result estimated by Taguchi design (1490,7 mm/s).

Initial design is accepted as $A_1B_1C_1$ then S/N ratio is obtained according to the initial and optimum design how much profit is provided to find with Taguchi design (Table 6).

Table 6. Results of optimum and initial design

	Initial	Optimum levels	
		Prediction	Experimental
Design	$A_1B_1C_1$	$A_1B_2C_3$	$A_1B_2C_3$
Performance values (mm/s)	911,7	1490,7	1556,0
S/N (dB)	59,19	63,47	63,84

Table 6 show that the improvement in S/N ratio at the optimum level was found to be 4,65 dB. The value of air permeability (mm/s) at this optimum level is 1556,0 against the initial parameter setting of 911,7. As a result, the increase in the value of air permeability can be obviously seen.

Full Factorial Design

With respect to the Table 1, the number of combination that must be created for full factorial design is $3^3=27$. 10 of these 27 different combinations were produced previously for the Taguchi design experiments. The rest of the combinations (17), were also produced and the values of air permeability were determined experimentally. The experiment results of all combinations produced with respect to full factorial design were listed in Table 7. The numbers inside the parentheses indicate the experiment numbers used in Taguchi design in Table 3.

When the results in Table 7 are investigated, it is seen that the sample 22 having the combination $A_1B_2C_3$ provides the maximum value of air permeability (1556,00 mm/s). It is seen that combination is same as the combination determined by Taguchi experimental design technique. Also ANOVA analysis with $\alpha=0,05$ was performed to the values gained from the full factorial design and the results were listed in Table 8. When the ANOVA results of 27 experiments performed with respect to the full factorial design and 9 experiments performed with combinations according to the orthogonal matrix (L_9) were compared, it was determined that percentage contribution of the factors affecting air permeability were very close the each other.

Table 7. Experimental layout using an full factorial experimental design

Exp. no	A	B	C	Average air permeability (mm/s) (experimental)	Predicted with Taguchi design (calculated)	% Relative error
1 (1)	1	1	1	911,70	877,06	3,80
2	2	1	1	289,10	314,66	8,84
3	3	1	1	244,38	263,52	7,83
4	1	2	1	1050,00	877,06	16,47
5	2	2	1	310,50	314,66	1,34
6 (8)	3	2	1	221,75	263,52	18,84
7	1	3	1	944,85	839,18	11,18
8 (6)	2	3	1	313,72	300,15	4,33
9	3	3	1	275,00	251,58	8,52
10	1	1	2	1313,00	1289,92	1,76
11 (4)	2	1	2	431,70	462,25	7,08
12	3	1	2	370,75	387,20	4,44
13 (2)	1	2	2	1338,00	1292,07	3,43
14	2	2	2	413,67	462,75	11,86
15	3	2	2	344,10	387,78	12,69
16	1	3	2	1310,00	1234,66	5,75
17	2	3	2	448,10	442,81	1,18
18 (9)	3	3	2	393,90	370,62	5,91
19	1	1	3	1554,00	1489,06	4,18
20	2	1	3	577,80	533,76	7,62
21 (7)	3	1	3	478,50	447,21	6,54
22 (optimum design)	**1**	**2**	**3**	**1556,00**	**1490,70**	4,20
23 (5)	2	2	3	564,80	534,52	5,36
24	3	2	3	478,00	447,66	6,35
25 (3)	1	3	3	1329,00	1425,66	7,27
26	2	3	3	568,10	510,98	10,05
27	3	3	3	504,20	427,96	15,12

Table 8. ANOVA table for the mean response

Factors	Sum of squares	Degree of freedom	Mean square	F value	Prop>F	Percentage contribution (%)
Model	4.897E+006	6	8.161E+005	124.86	<0.0001significant	-
A	4.379E+006	2	2.189E+006	334.96	<0.0001	87.10
B	2495.71	2	1247.86	0.19	0.8277	0.050
C	5.153E+005	2	2.577E+005	39.42	<0.0001	10.25
Residual	1.307E+005	20	6536.30			2.6
Total	5.027E+006	26				
R-squared: 0,97						

With respect to Table 8, prob values lower than 0.05 shows that the established model is meaningful. Since the value of R^2 is 0.97, expressiveness of the model is high.
Experimental values in Table 7 were the values found out by the full factorial experimental design, and the predicted values were calculated by using formula 2 with respect to the Taguchi experimental design.
Also, the values of percentage relative error are evaluated, since software to be used, shortening the numbers by computer, personal mistakes are considered. Figure 4 shows the measured and calculated values of air permeability graphically.

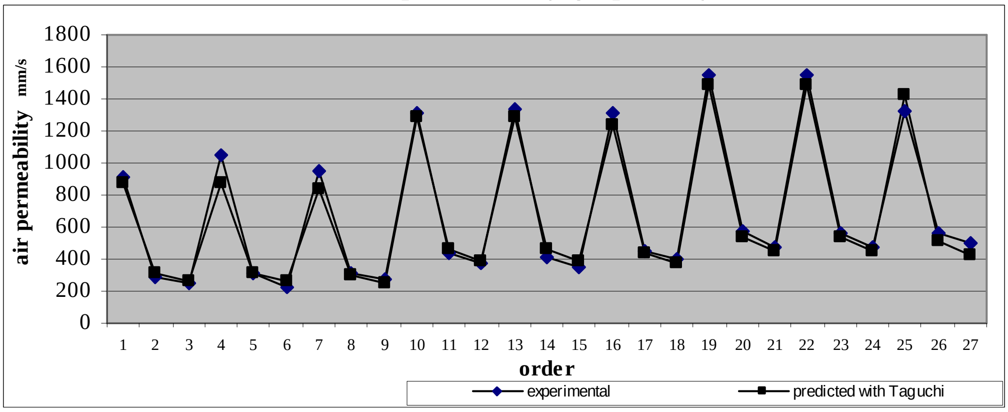

Figure 4. Comparison of experimental results and the predicted values

As seen from Table 7 and Figure 4, experimental results and predicted values are much closed.

Conclusion

In this research, we intended to a process for optimizing interlock fabric conditions using Taguchi design to maximize the air permeability of knitted fabrics. These results were confirmed with the Full Factorial Design. Firstly, important affecting parameters for the air permeability value of interlock fabrics were determined as relaxation type, yarn type and loop length and an L_9 orthogonal array was used in planning the Taguchi experiments.
Based on the S/N ratio and ANOVA analyses, relaxation type and loop length the most significant effect on fabric air permeability values. Also, the optimum levels of these parameters obtained in this paper, which was $A_1B_2C_3$; this corresponds to relaxation type of dry relaxation, yarn type of compact yarn, loop length of 0,37 cm. In addition to this, S/N ratio has been considerably improved as compared to initial parameter settings of the experiment.
At the end of relaxation processes, the structure of the knitted fabrics is getting tighter and the porous are getting smaller. So the value of air permeability decreases. As a result of the analysis, it is seen that yarn type has no effect on air permeability statistically. However since the compact yarns structure is smoother, the air permeability of fabrics knitted with these yarns is determined some higher. Increasing the loop length, looser the structure and so the values of air permeability increases.

The best combinations determined by using full factorial and Taguchi experimental design are the same. However in order to get the same results while 27 experiments must be performed for full factorial design, only 9 experiments are needed for Taguchi design.
Closeness of the results of the predictions based on the calculated S/N ratios and experimental values show that Taguchi experimental design technique can be used successfully both optimization and prediction.
The main advantage of the Taguchi parameter design, as opposed to the classic factorial design methods, lies in the introduction of noise factors in the experimentation which provoke an uncontrolled variation leading to a noise insensitive response, therefore to higher reproducibility. Taguchi approach provides systematic, simple and efficient methodology for the optimization of the near optimum design parameters with only a few well-defined experimental sets and determine the main factors to affect the process. Taguchi design is an important tool for robust design. It offers a simple and systematic approach to optimize design for performance, quality and cost.

References

1. Karaguzel, B., *Characterization and Role of Porosity in Knitted Fabrics*, MSc Thesis, North Carolina State University, Department of Textile Engineering, Chemistry and Science, 2004, pp.132.
2. Dias, T., Delkumburewatte, G.B, *Fibers and Polymers*, Vol.9, No.1, 2008, pp.76-79.
3. TS 391 EN ISO 9237, Textiles-Determination of the Permeability of Fabrics to Air. *Turkish Standards Institution*, 1999, Ankara.
4. Park, C.K., Ha, J.Y. 2005, *Textile Research Journal*, Vol. 75, No.3, 2005, pp.245-252.
5. Singh, S., Shan, H.S., Kumar, P., *Quality and Reliability Engineering International*, Vol.18, 2002, pp.273-283.
6. Taguchi G., Chowdhury, S., Wu, Y., *Taguchi's Quality Engineering Handbook*. John Wiley&Sons, Inc. ISBN 0-471-41334-8, 2005, p.1662.
7. Zeydan, M., *International Journal of Clothing Science and Technology*, Vol.20, No.2, 2008, pp.104-118.
8. Naveen, S.A., Aravindan, S., Noorul Haq, A., *Advances in Production Engineering & Management Journal*, Vol.4, No.1-2, 2009, pp.47-58.
9. Ross, P.J., *Taguchi Techniques for Quality Engineering*, Mcgraw-Hill International Editions, ISBN 0-07-114663-6. 1996, pp.329.
10. Roy, R.K., *Design of Experiments Using the Taguchi Approach*, A Wiley-Interscience Publication, ISBN 0-471-36101-1, 2001, pp.538.
11. Palanikumar, K. *Journal of Reinforced Plastics and Composites*, Vol.25, No.16, 2006, pp.1739-1751.
12. Liasi, E., Du, R., Simon, D., Bujas-Dimitrejevic, J., Liburdi, F., *International Journal of Clothing Science and Technology*, Vol.11, No.5, 1999, pp.300–314.
13. Cheng, K.P.S., Li, C.H.L., *Textile Research Journal*, Vol.72, No.12, 2002, pp.1079-1087.
14. Webb, C.J., Waters, G.T., Thomas, A.J., Liu, G.P., Thomas, C., *Journal of the Textile Institute*, Vol.98, No.4, 2007, pp.327-336.
15. Onal, L., Zeydan, M., Korkmaz, M., Meeran, S., *Textile Research Journal*, Vol.79, No.5, 2009, pp.468-478.
16. Chen, Y.H., Tam, S.C., Chen, W.L., Zheng, H.Y. (1996), International Journal of Materials&Product Technology, Vol.11, No3/4, 1996, pp.333-344.
17. Dubey, A. K., Yadava, V. (2007), *International Journal of Precision Engineering and Manufacturing*, Vol.8 No.4, 2007, pp.10-15.
18. Savaskan, M., *Comparative Analysis of Design of Experiment Techniques on the Performance Evaluation and Optimization of Hard Ceramic Coated Drill Bits*", Phd Thesis, Istanbul Technical University, Inst. of Natural and Appl. Sci., (in Turkish), 2003, pp.277.