(REFEREED RESEARCH)

THE OPTIMIZATION OF WOVEN FABRIC TENSILE STRENGTH WITH TAGUCHI METHOD BASED ON GREY RELATIONAL ANALYSIS

KUMAŞ KOPMA MUKAVEMETİNİN GRİ İLİŞKİLER ANALİZİNE DAYALI TAGUCHİ METODU İLE OPTİMİZASYONU

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ABSTRACT

In this study, the optimization of woven fabric tensile strength with Taguchi Method based on Grey Relational Analysis was investigated. Weaving structures twill 3/1, 2/2 ve 2/1 (Z) that are the most commonly used in the textile sector, were used. The sample fabrics were produced at the same conditions. They were dyed a jet dyeing machine in three different dye rates (1%, 3% and 5%). After dyeing process, fabrics were raised in two passages. Tensile strength and Breaking Elongation% of the fabrics were tested. The optimum input of weaving structure type, dye intensity and raising level have been determined for the best tensile strength and breaking elongation% by using Taguchi Method based on Grey Relational Analysis. Weaving structure Twill 2/1, dye intensity 1%, without raising combination was the best combination for input parameters.

Keywords: Breaking Elongation, Fabric, Grey Relational Analysis, Optimization, Taguchi Method, Tensile Strength.

ÖZET

Bu çalışmada kumaş kopma mukavemetinin Gri İlişkiler Analizine dayalı Taguchi Metodu ile optimizasyonu araştırıldı. Tekstil sektöründe en çok kullanılan örgü yapılarından olan dimi 3/1, 2/2 ve 2/1 (Z) örgü yapılarından dokunan kumaşlar üzerinde araştırma yapılmıştır. Bu amaçla aynı çalışma koşullarında numune kumaşlar üretildi. Bunlar %1, %3 ve %5 olmak üzere üç ayrı boya oranında numune jet boya makinesinde boyanmıştır. Terbiye prosesinden sonra, kumaşlar iki pasaj şardonlanmıştır. Kumaşlara kopma mukavemeti ve % kopma uzama testi uygulanmıştır. Kopma mukavemeti ve % kopma uzamasını en iyileyecek örgü türü, boya şiddeti ve şardon işlemine ait optimum girdi parametreleri Gri İlişkiler Analizine Dayalı Taguchi Metodu uygulanarak belirlenmeye çalışılmıştır. 2/1 (Z) örgü yapısı %1 boya oranı ve şardonsuz kombinasyon girdi parametreleri için en iyi kombinasyondur.

Anahtar Kelimeler: Kopma Uzaması, Kumaş, Gri İlişkiler Analizi, Optimizasyon, Taguchi Metodu, Kopma Mukavemeti.

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1. INTRODUCTION

Textile materials (fiber, yarn, fabric, etc.) are exposed to various forces during uses. These forces may be perpendicular to the plane and parallel. Fabrics, one of the textile materials, are exposed forces in two directions, the warp direction and weft direction (1). The fabric strength for these forces determines the performance characteristics of the fabrics. For this purpose, performance tests (stiffness, abrasion resistance, pilling, tear strength, bursting strength, etc.) are applied on the fabric. The most important of them are the tensile strength and breaking elongation % tests. Tests are applied on the fabric for warp and weft direction.

There are many studies on the strength tests to determine the fabric performance characteristics in Textile. Some of these are: Kumpikaite (2008), examined the effects of fabric weaving structure on tensile strength and breaking elongation. Özdemir and Yavuzkasap (2012), investigated the effects of fabric weaving structure and density of the weft on tensile strength, breaking elongation and tear strength of double layer upholstery fabric. Ünal and Taşkın (2007), in their studies, using polyester yarns, plain and twill fabrics in different density of the warp and weft were produced. The weft and warp tensile strength performance of the fabrics were examined before and after washing (2-4).

There are many processes that may weaken the fabrics mechanically during the production. Raising is one of these processes and affects the weft direction. Some of the studies are: Carfagi et al. (2005) observed a system aimed to develop raising process in their study. Sabır and Maralcan, (2010), were investigated the drum speed in the raising process and the number of raising passages of the effects on various fabric properties (5, 6).

There are many experimental studies on textiles on determining the performance characteristics of fabrics optimization. In these studies, in the present circumstances to determine the best optimization techniques are used. The solution of multiple performance features optimization problem is possible with the use of multi-objective optimization techniques. Taguchi Method Based on Grey Relational Analysis is one of them. Multi-criteria decision-making methods convert multiple performance responses into a single response by using Taguchi method. In this way, the problem would be transformed single response optimization problem. Taguchi Method Based on Grey Relational Analysis is a new approach, considering at least two and more than two quality characteristics collectively. Taguchi applications based on Grey Relational Analysis are used in various industry fields (7-15).

In this study, the effects of woven fabrics' weaving structure, dye intensity and raising process (Input Parameters) on fabric quality characteristics tensile strength and breaking elongation (output parameters) were investigated using Taguchi Method based on Grey Relational Analysis. By applying this method; the best combination of performance characteristics of the input parameters was determined for the tensile strength (warp and weft direction) and breaking elongation % (warp and weft directions).

2. MATERIAL AND METHOD

2.1. Material

In the study, weaving structure of twill that is appropriate for raising process is decided to use. The most commonly used twill weaving structures of 3/1, 2/2 and 2/1 (Z) are selected. The yarn count used in the fabrics, the warp and weft direction, is Ne 28/2 and its blend is 63/32/5 % Polyester/Viscose/Spandex. Fabrics are dyed 1%, 3% and 5% by three different dyes at rate 1%, 3% and 5% in a jet dyeing machine. After finishing process, fabrics were raised two passages. Sample fabrics are manufactured in the same working conditions in a selected mill. The working conditions are seen in Table 1.

2.2. Method

In this study, Taguchi Method based on Grey Relational Analysis is applied. In Table 2, input parameters and output parameters will be optimized are summarized.

Input parameters and theirs levels are shown in Table 3. According to the Table, in case of using a full factorial experimental design experiment numbers will be 27 (3^3). There are a lot of ortogonal series in Taguchi's desing of experiment such as L4, L8, L9, L16. The levels of the design parameters determine which one of these series will be chosen in the experimental design. The study's desing of experiment is 3^3 and then L9 ortogonal desing was selected in the study. With Taguchi Methods used in the study, the trial numbers was reduced from 27 to 9. Table 3, shows L9 Taguchi orthogonal layout with the factors and levels and Table 4 shows the test plan.

Table 1. Working Conditions of Sample Fabrics Production

FABRIC FEATURES	Density of Warp per cm : 34							
	Density of Weft per cm: 22							
	Weight (gr/m): 490							
	Weight (gr/sqm): 306							
WEAVING WORKING CONDITIONS	Brand of Weaving Machine: Picanol Gamma Max (Year: 2006)							
	Speed of Weaving Machine (rpm): 500							
	Reed Number : 120/2							
FINISHING WORKING CONDITIONS	Brand of Dyeing Machine: Dilmenler Jet Dyeing							
	Fixe Conditions	**Burning**	**Washing**	**Fixe**	**Drying Conditions**	**Drying 1**	**Drying 2**	**Emulsion**
	Speed (m/min)	140	20	20	Speed (m/min)	25	25	20
	Temperature (^oC)	30	80	190	Temperature (^oC)	160	160	17

Table 2. Input Parameters and Outputs

Test Parameters: (Input Variables)	**Outputs:** (Response Variables)
- Weaving Structure	- Tensile Strength (N)
- Dye Intensity	- Breaking Elongation %
-Number of Raising Passage	

Table 3. Selected experimental design L9 (16)

Factor No (Code)	Factors	Level Number	Values of the Levels
1(A)	Weaving Structure	3	Twill 2/1, 2/2, 3/1
2(B)	Dye Intensity	3	%1, %3, %5
3(C)	Number of Raising Passage	3	Without Raising, One Passage Raising, Two Passages Raising

Table 4. Test Plan for Selected L9 Experimental Design

Experiment Number	A (Weaving Structure)	B (Dye Intensity)	C (Number of Raising Passage)
1	1 (Twill 2/1)	1 (1%)	1 (Without Raising)
2	1 (Twill 2/1)	2 (3%)	2 (One Passage Raising)
3	1 (Twill 2/1)	3 (5%)	3 (Two Passages Raising)
4	2 (Twill 2/2)	1 (1%)	2 (One Passage Raising)
5	2 (Twill 2/2)	2 (3%)	3 (Two Passages Raising)
6	2 (Twill 2/2)	3 (5%)	1 (Without Raising)
7	3 (Twill 3/1)	1 (1%)	3 (Two Passages Raising)
8	3 (Twill 3/1)	2 (3%)	1 (Without Raising)
9	3 (Twill 3/1)	3 (5%)	2 (One Passage Raising)

Tensile strength and breaking elongation % performance tests on sample fabrics have been made according to TS EN ISO 13934-1 test standard with the Titan® test device.

2.2.1. Grey Relational Analysis Method

Grey Relational Analysis, allows the optimization of more than one performance characteristics. In this method, the steps are; 1. Experimental Design and its application 2. Signal -Noise (S / N) Ratio Calculation 3. Decision Matrix Creating 4. Data Normalization 5. Weighting of Normalized Data 6. Calculation of Alternatives Ranking Points 7. Optimum Factor Level Determination, 8. ANOVA test 9. Finding Optimum Solution. Processing steps and equations used are summarized in Table 5. The Larger –The Better S/N ratio is used in Taguchi Method in step and the formula used is given in Equation 12. MINITAB® 15 software package was used in implementation of Taguchi method. (Table 4 of the symbols used in the equation expression is given in the list of symbols.)

Table 5. Formulas used in Grey Relational Analysis (17,18)

STEPS	DEFINITIONS		FORMULAS
Step 1.	The reference sequence of length n is as follows		$x_0 = \left(x_0(1), x_0(2), x_0(3), ..., x_0(n)\right)$ (1)
Step 2.	Data Normalization	The Larger-The Better	$x_i(k) = \dfrac{x_i^o(k) - \min x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)}$ (2)
		The Smaller- The Better	$x_i(k) = \dfrac{\max x_i^o(k) - x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)}$ (3)
		The Nominal- The Better	$x_i(k) = 1 - \dfrac{\left\lvert x_i^o(k) - x^o \right\rvert}{\max x_i^o(k) - x^o}$ (4)
Step 3.	The m number series going to be compared with x^o series		$x_i = \left(x_i(1), x_i(2), x_i(3), ..., x_i(n)\right)$ $i = 1,2,3....m$ (5)
Step 4.	Grey Relational Coefficient is calculated.		$\varepsilon\left(x_0(k), x_i(k)\right) = \dfrac{\Delta_{\min} + \xi\Delta_{\max}}{\Delta_{oi}(k) + \xi\Delta_{\max}}$ (6) $\Delta_{oi}(k) = \left\lvert x_0(k) - x_j(k) \right\rvert$ (7) $\Delta_{\min} = \min_j \min_k \left\lvert x_0(k) - x_j(k) \right\rvert$ (8) $\Delta_{\max} = \max_j \max_k \left\lvert x_0(k) - x_j(k) \right\rvert$ (9)
Step 5.	Weights Determination		*W*
Step 6.	Grey Relational Degree is calculated by Equation	If impact on the performance of the output is equal,	$\gamma(x_0, x_i) = \dfrac{1}{n}\sum_{k=1}^{n} \varepsilon(x_0(k), x_i(k))$ (10)
		If impact on the performance of the output is not equal,	$\gamma(x_0, x_i) = \dfrac{1}{n}\sum_{k=1}^{n} W_k \varepsilon(x_0(k), x_i(k))$ (11)
Step 7.	Determination of the new levels of the test factors.		
Step 8.	Performing ANOVA test		
Step 9.	Implementation of Taguchi Method. Making prediction and confirmation test with the optimal value.	The Larger- The Better	$S/N = -\ 10\log \dfrac{\sum_{i=1}^{n} \dfrac{1}{y_i^2}}{n}$ (12) $\eta = \eta_m + \sum_{i=1}^{j} (\eta_i - \eta_m)$ (13)

3. RESULTS AND DISCUSSION

In this study, according to L9 Taguchi Experimental Design, experiments are done and results are given in Table 6. Factors affecting the process in the first row (A, B, C) and response variables; Tensile Strength (weft direction), Tensile Strength (warp direction), Breaking Elongation% (weft direction), Breaking Elongation% (warp direction) are given. The first column in the table indicates the number of experiments. The experimental results are given in the last four columns.

Table 6. Results of Experiments According to L9 Taguchi Experimental Design (16)

	Experiment Parameters (Input Variables)			Outputs (Response Variables)			
Experiment Number	**A (Weaving Structure)**	**B (Dye Intensity)**	**C (Number of Raising Passage)**	**Tensile Strength (weft direction) (N)**	**Tensile Strength (warp direction) (N)**	**Breaking Elongation% (weft direction)**	**Breaking Elongation% (warp direction)**
1	1 (Twill 2/1)	1 (1%)	1 (Without Raising)	1261,66	1878,05	46,73	49,15
2	1 (Twill 2/1)	2 (3%)	2 (One Passage Raising)	927,69	1697,43	42,48	45,58
3	1 (Twill 2/1)	3 (5%)	3 (Two Passages Raising)	915,91	1745,34	39,18	40,93
4	2 (Twill 2/2)	1 (1%)	2 (One Passage Raising)	942,79	1913,86	40,01	51,68
5	2 (Twill 2/2)	2 (3%)	3 (Two Passages Raising)	525,82	1754,43	36,35	47,58
6	2 (Twill 2/2)	3 (5%)	1 (Without Raising)	1062,74	1581,09	39,47	41,62
7	3 (Twill 3/1)	1 (1%)	3 (Two Passages Raising)	579,39	1982,78	35,12	56,31
8	3 (Twill 3/1)	2 (3%)	1 (Without Raising)	1080,4	1774,11	39,84	46,66
9	3 (Twill 3/1)	3 (5%)	2 (One Passage Raising)	784,61	1845,58	39,19	51,83

4. Application of Grey Relational Analysis Method

Step 1: Determination of the Reference series. The reference series for four performance outcomes are given in Table 7 (Equation 1).

Step 2: Data Normalization. The normalization matrix generated using Equation 2 are seen in Table 6

Step 3: Distance matrix is calculated with Equation 5 (Table 7).

Step 4: Grey relational coefficient matrix of Distance matrix calculated is obtained using. Equation (6-9) (Table 8).

Step 5: Performance outcomes were calculated as equally weighted.

Step 6: Grey Relational Degree is calculated by Equation 10. Grey relational degree and ranking are shown in Table 8. As seen from the table, the experiment with the highest grey relational degree is (1) of the experiment.

Grey relational degree graph is given in Figure 1. As seen in the figure, Grey relation degree of Experiment No. 1 is the highest.

Step 7: After calculating Grey relational degree, new levels of experimental factors are determined. Calculated new Factor levels are shown in Table 9. As seen from the table, the difference between the levels of factor B ((Dye Intensity) is the biggest and this factor is understood as the most influential parameter.

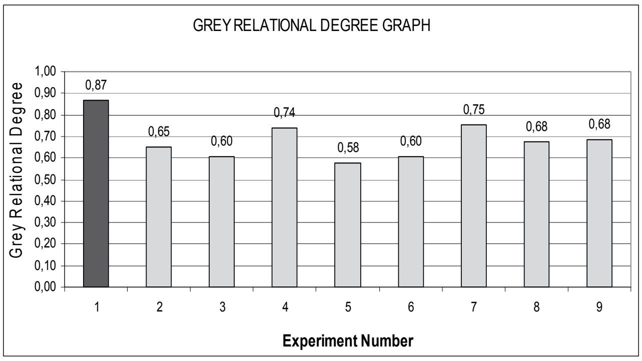

Figure 1. Grey Relational Degree Graph for Outputs

The graph of the parameters levels is given in Figure 2. Here optimal parameter levels are seen as A1B1C1 (experiment No. 1). This means that weaving structure Twill 2/1, dye intensity 1%, without Raising.

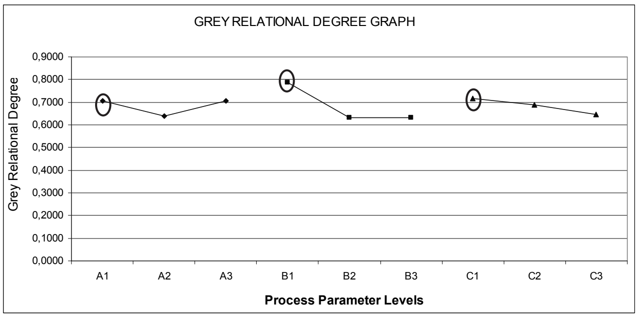

Figure 2. Parameter Levels Graph

Table 7. Application Step1-3 of Grey Relational Analysis Method

	Reference Series For Outputs				Normalization Matrix for Outputs				Distance Matrix for Outputs			
	Tensile Strength (weft direction) (N)	Tensile Strength (warp direction) (N)	Breaking Elongation% (weft direction)	Breaking Elongation% (warp direction)	Tensile Strength (weft direction) (N)	Tensile Strength (warp direction) (N)	Breaking Elongation% (weft direction)	Breaking Elongation% (warp direction)	Tensile Strength (weft direction) (N)	Tensile Strength (warp direction) (N)	Breaking Elongation% (weft direction)	Breaking Elongation% (warp direction)
Reference Series	1261,66	1982,78	46,73	56,31	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
1	**1261,66**	1878,05	**46,73**	49,15	1,00	0,74	1,00	0,53	0,00	0,26	0,00	0,47
2	927,69	1697,43	42,48	45,58	0,55	0,29	0,63	0,30	0,45	0,71	0,37	0,70
3	915,91	1745,34	39,18	40,93	0,53	0,41	0,35	0,00	0,47	0,59	0,65	1,00
4	942,79	1913,86	40,01	51,68	0,57	0,83	0,42	0,70	0,43	0,17	0,58	0,30
5	525,82	1754,43	36,35	47,58	0,00	0,43	0,11	0,43	1,00	0,57	0,89	0,57
6	1062,74	1581,09	39,47	41,62	0,73	0,00	0,37	0,04	0,27	1,00	0,63	0,96
7	579,39	**1982,78**	35,12	**56,31**	0,07	1,00	0,00	1,00	0,93	0,00	1,00	0,00
8	1080,4	1774,11	39,84	46,66	0,75	0,48	0,41	0,37	0,25	0,52	0,59	0,63
9	784,61	1845,58	39,19	51,83	0,35	0,66	0,35	0,71	0,65	0,34	0,65	0,29

Table 8. Application Step 4-6 of Grey Relational Analysis Method

	Tensile Strength (weft direction) (N)	**Tensile Strength (warp direction) (N)**	**Breaking Elongation% (weft direction)**	**Breaking Elongation% (warp direction)**	**Grey Relational Degree**	**Ranking**
1	1,00	0,79	1,00	0,68	0,87	1
2	0,69	0,58	0,73	0,59	0,65	6
3	0,68	0,63	0,61	0,50	0,60	7
4	0,70	0,85	0,63	0,77	0,74	3
5	0,50	0,64	0,53	0,64	0,58	9
6	0,79	0,50	0,62	0,51	0,60	8
7	0,52	1,00	0,50	1,00	0,75	2
8	0,80	0,66	0,63	0,61	0,68	8
9	0,61	0,75	0,61	0,77	0,68	4
Mean Grey Relational Degree					**0,68**	

Table 9. Calculated New Factor Levels

Factors	Levels			Max-Min
	1	2	3	
A	**0,7070**	0,6392	0,7045	0,0678
B	**0,7873**	0,6333	0,6301	0,1572
C	**0,7160**	0,6900	0,6448	0,0712

Step 8: This step is performed ANOVA test. ANOVA test results are given in Table 10. Accordingly, factor B (Dye Intensity) has the highest F value. Second is factor A (Weaving Structure), third is factor C (Number of Raising Passage). Factor B (Dye Intensity), which has the highest F value is the most effective factor. (Paint violence) factor is the most influential factor. This situation is also supported by Contribution (%) value.

Confirmation Test

Confirmation test results are shown in Table 12. Predicted grey relational degree under optimum conditions is calculated using Equation 13. According to the table, the difference between grey relational degree of woven fabric produced under optimum conditions and grey relational degree in the initial process conditions is 0.22, This value is the improvement of the grey relational degree. As shown in Table14, Tensile Strength (weft direction) is improved from 927,69 to 1261,66 N, Tensile Strength (warp direction) is improved from 1697,43 to 1878,05, Breaking Elongation % (weft direction) is improved from 42,48 to 46,73%, Breaking Elongation % (warp direction) is improved from 45,58 to 49,15.

Table 10. ANOVA test of Grey Relational Degree

Analysis of Variance for Means						
Source	DF	Seq SS	Adj SS	Adj MS	F	Contribution (%)
A	2	0,008863	0,008863	0,004432	2,95	13,0154
B	2	0,048435	0,048435	0,024218	**16,14**	**71,1275**
C	2	0,007796	0,007796	0,003898	2,60	11,4486
Residual Error	2	0,003002	0,003002	0,001501	4,4085	
Total	8	0,068096				

Step 9: The final step is to calculate S / N ratio applying the Taguchi Method. (Table 11) (Equation 12).

Table 11. Determination S/N Ratio

Experiment Number	A (Weaving Structure)	B (Dye Intensity)	C (Number of Raising Passage)	S/N (dB)
1	1	1	1	-1,48430
2	1	2	2	-3,60324
3	1	3	3	-4,28012
4	2	1	2	-2,53173
5	2	2	3	-5,05721
6	2	3	1	-4,22669
7	3	1	3	-2,28425
8	3	2	1	-3,30233
9	3	3	2	-3,57267

Table 12. Performance Results obtained by using Initial and Optimum Parameters

	Initial Process Parameters	Optimum Process Parameters	
		Prediction	Experiment
Level	A1B2C2	A1B1C1	A1B1C1
Tensile Strength (weft direction) (N)	927,69		1261,66
Tensile Strength (warp direction) (N)	1697,43		1878,05
Breaking Elongation% (weft direction)	42,48		46,73
Breaking Elongation% (warp direction)	45,58		49,15
Grey Relational Degree	0,65	0,8503	0,87
The Improvement of Grey Relational Degree		0,22	

5. CONCLUSION

In this study, the effect of PES/Viscose/Spandex blended woven fabrics, weaving structure, dye intensity and number of raising passage on the selected fabric quality parameters Tensile Strength (weft direction) Tensile Strength (warp direction), Breaking Elongation% (weft direction), Breaking Elongation% (warp direction) were analyzed with using Taguchi Method based on grey relational analysis. For this purpose, L9 Taguchi experimental design was used. With using Grey relational analysis, four performance outputs were converted to one response and optimum input parameters were determined. Analysis suggested that weaving structure Twill 2/1, dye intensity 1%, without raising combination was the best combination. This combination was included in the test plan as Experiment No. 1. Also performed confirmation test, showed improvements in performance outputs. As multi-criteria optimization technique of Taguchi Method based on grey relational analysis can be used in textile research.

6. Symbol List

$x_i(k)$: After Normalization i. series k. value

$x_i^o\ (k)$: i series k. original value

$\min x_i^o(k)$: Minimum value in i series

$\max x_i^o(k)$ Maximum value in i series

x^o : Desired ideal value

x_i : m series with comparing x^o series

$\varepsilon(x_0(k), x_i(k))$: Grey relational coefficient at point k.

k: k. rank in n length of series

k=1,2,...,n

j=1,2,…m

ξ : a coefficient between (0,1)

$\Delta_{\min}$: Minimum value in the series

$\Delta_{\max}$: Maximum value in the series

$\Delta_{oi}(k)$: k. value in the series

$\gamma(x_0, x_i)$: Grey relational degree in i. rank

W_k : Total weight must be 1

y_i: Experimental results,

n: Experiment number

η : Grey relational degree predicted by optimum design

η_m : Mean grey relational degree

η_i : The value of calculated new factor levels in optimum combination

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