Araştırma Makalesi / Research Article

OPTIMIZATION OF COATING PROCESS PARAMETERS FOR COLOR DIFFERENCE AFTER ABRASION OF DENIM FABRICS BY USING TAGUCHI METHOD

Hüseyin Gazi TÜRKSOY[1]
http://orcid.org/0000-0003-4594-880X
Sümeyye ÜSTÜNTAĞ[1*]
https://orcid.org/0000-0002-2625-4063
Münevver Ertek AVCI[2]
https://orcid.org/0000-0002-7360-7407
[1]Erciyes University, Department of Textile Engineering, Kayseri, Turkey
[2]Malatya Turgut Özal University, Yeşilyurt Vocational School, Malatya, Turkey

Gönderilme Tarihi / Received: 16.07.2019
Kabul Tarihi / Accepted: 15.12.2019

ABSTRACT: The study presents an investigation on the optimizing of various coating process parameters for color difference after abrasion of denim fabrics by using Taguchi method. The parameters selected for optimization are squeeze pressure, viscosity of coating fluid, fabric passing speed, drying temperature and weft density. An L27 (3^5) orthogonal array was chosen as experimental plan. In the evaluations with Taguchi Method, analyses of the signal to noise ratio (S/N) and variance (ANOVA) were used. It was found that the most effective input parameter for color difference is drying temperature. Also, the satisfying combination for minimum color difference was determined as 17 picks/cm weft density, 120°C drying temperature, 30 dPa.s viscosity, 5 bar squeeze pressure, 10 m/min fabric passing speed.

Keywords: Denim Fabric, Coating, Taguchi Method, Color Difference, Martindale Abrasion Tester, Spectrophotometer.

DENİM KUMAŞLARININ AŞINMA SONRASI RENK FARKLILIĞI İÇİN KAPLAMA İŞLEM PARAMETRELERİNİN TAGUCHI YÖNTEMİ İLE OPTİMİZASYONU

ÖZET: Bu çalışma, denim kumaşların aşınmasından sonra görülen renk farklılığı için çeşitli kaplama işlem parametrelerinin optimize edilmesi üzerine bir araştırma sunmaktadır. Optimizasyon için seçilen parametreler, sıkma basıncı, kaplama maddesinin viskozitesi, kumaşın geçiş hızı, kurutma sıcaklığı ve atkı sıklığıdır. Deney planı olarak L27 (3^5) ortogonal dizini seçilmiştir. Taguchi Metodu ile yapılan değerlendirmelerde sinyal-gürültü oranı (S/N) ve varyans (ANOVA) analizi kullanılmıştır. Renk farkı için en etkili girdi parametresinin kurutma sıcaklığı olduğu bulunmuştur. Ayrıca, minimum renk farkı için tatmin edici kombinasyon, 17 tel/cm atkı yoğunluğu, 120°C kurutma sıcaklığı, 30 dPa.s viskozite, 5 bar sıkma basıncı, 10 m/dak kumaş geçiş hızı olarak belirlenmiştir.

Anahtar Kelimeler: Denim Kumaş, Kaplama, Taguchi Metodu, Renk Farklılığı, Martindale Aşınma Cihazı, Spektrofotometre.

Sorumlu Yazar/Corresponding Author: *sumeyyeustuntag@erciyes.edu.tr*
DOI: *10.7216/1300759920192611602, www.tekstilvemuhendis.org.tr*

***This study was presented at "2nd International Congress of Innovative Textiles (ICONTEX2019)", April 17-18, Çorlu, Turkey*

1. INTRODUCTION

Denim is a strong, durable fabric constructed in a twill weave with indigo dyed warp and white weft yarns. Denim is traditionally woven with 100% cotton yarn; however, today it's blended with PET to control shrinkage and wrinkles, and elastane to add stretch. Different looks and varying hues can be achieved on the same raw denim fabric by applying different dry and wet processes. Denim finishing is an important textile operation for added value to denim fabrics and making them attractive to younger customers, particularly by equipping them with a faded or worn fashion look. Numerous finishing process exist in the denim industry to accomplish such a need, including like washing, bleaching, printing, coating etc. [1].

Coating form a thin layer on the denim surface and thus change the surface attributes of the treated fabric. The coating process can be applied either on a small area or on the whole denim surface. Such a finish is simple to apply but provides a fast surface treatment for specific effects such as brightness, smoothness and leather appearance. Generally, coating process of a denim garment is performed by using any of the methods of knife, foam and rotary screen coating [2]. Abrasion can lead to degradation in the performance of the coating, especially in cases where the substrate material is only on the surface of the fabric. Denim fabrics, which are largely coated for aesthetic purposes, are subject to wear in many ways during use. When abrasion occurred, coating on the fabric surface will be rubbed out and color differences occur on the fabric surface. While the color difference due to the usage of classical denim fabrics is an expected situation, the color differences due to wear in coated denim fabrics are not desired by consumers.

It is thought that the effect of the coating process can vary with the control parameters of the coating technique. The effect of coating process parameters on color difference of denim fabrics is important issue. The present study is focused on optimizing the various coating process parameters for color difference after abrasion of denim fabrics by using Taguchi method, a leading optimization technique reducing the experimental period and cost.

1.1. Description of the Taguchi method

The classical experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out as the number of the process parameters increases. To solve this problem, Taguchi method provides a simple, efficient and systematic approach to optimize designs for performance, quality, and cost. In recent years, the rapid growth of interest in the Taguchi method has led to numerous applications of the method in a world-wide range of industries, including textile [3-16]. Taguchi involves the stages of system design, parameters design, and tolerance design. System design involves the application of scientific and engineering knowledge required in manufacturing a product; parameter design is employed to find optimal process values for improving the quality characteristics; and tolerance design consists of determining and analyzing tolerances in the optimal settings recommended by parameter design [17, 18]. The parameter design is a key step in the Taguchi method to achieving high quality without increasing cost and so, the parameter design is adopted in this paper, to reduce the color difference that occurs after abrasion of the coated denim fabrics.

The Taguchi technique is a methodology for finding the optimum setting of the control factors to make the product or process insensitive to the noise factors. The Taguchi technique is based upon the technique of matrix experiments. The experimental matrices are special orthogonal arrays, which allow the simultaneous effect of several process parameters to be studied efficiently. The purpose of conducting an orthogonal experiment is to determine the optimum level for each factor and to establish the relative significance of the individual factors in terms of their main effects on the response [19].

Taguchi recommends the use of the S/N (signal to noise) ratio to measure the quality characteristics deviating from the desired values. Usually, there are three categories of quality characteristic in the analysis of the S/N ratio, i.e. the-lower-the-better, the-higher-the-better, and the nominal-the-better. 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. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design [10].

2. MATERIALS AND METHOD

Minitab Version 16.0 software package was used to the parameter design of Taguchi method. The parameter design of the Taguchi method includes the following steps: (1) define the problem and the objective; (2) identification of control factor and levels; (3) selection of the appropriate orthogonal array and assignment of design parameters to the orthogonal array; (4) conducting of the experiments based on the arrangement of the orthogonal array; (5) analysis of the experimental results using the S/N and ANOVA analyses; (6) selection of the optimal levels of design parameters; (7) verification of the optimal design parameters through the confirmation experiment; and (8) calculation of improving rate using optimum factor levels. In the study, the experimental design and analysis of the test results were carried out according to these steps.

The most important stage in the Taguchi method is the identification of control factor. In this study, the factors selected for optimization are squeeze pressure, viscosity of coating fluid, fabric passing speed, drying temperature and weft density. Each parameter was investigated at three levels to study the non-linearity effect of the process parameters (Table 1). L27 the orthogonal array table (Table 2) was chosen to determine experimental plan, because it is the most suitable for the conditions being investigated; five parameters with three levels.

Table 1. Control factors and levels for the experimental design.

Code	Factors	Levels		
		1	2	3
A	Weft density (picks/cm)	14	17	20
B	Drying temperature (°C)	120	140	160
C	Viscosity (dPa.s)	30	50	70
D	Squeeze pressure (Bar)	3	5	7
E	Fabric passing speed (m/min)	10	20	30

After determining the control factors and their levels, three denim fabric samples were manufactured with 3/1 Z twill structure by Çalık Denim Inc. Ne 8.2/1 ring yarn were used as the warp yarn with a density of 17 ends/cm for all fabric samples. The weft density of the denim fabrics was used as control parameter and Ne 10.4/1 ring core-spun yarns (%95 cotton and %5 Elastane-70 dtex) were used as weft yarn with three different densities (14, 17 and 20 picks/cm). Depending on the Taguchi experiment design, the coating of the denim fabrics was applied by the Rotary Screen Coating Method, which is the deposition of a coating material on a substrate through a mesh screen by squeezing. A standard coating pat used in the mill was used for the coating of the denim fabrics. The color differences of the coated denim fabrics were evaluated after abraded with the Martindale Abrasion and Pilling Tester at 15000 cycles according to TS EN ISO 12947-3 standard. The Minolta CM 3600D model spectrophotometer (Figure 1) and the following formula (Formula1) were used to determine the color difference (ΔE) of the fabrics.

$$\Delta E = \sqrt{[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]} \quad (1)$$

Figure 1. Martindale Abrasion Tester and Spectrophotometer.

3. RESULTS AND DISCUSSION

In the Taguchi optimization method, analysis of response depends upon whether smaller or larger value of the response is desired. In this study, the color difference was classified under the response type "smaller is better", because the high value of color difference is not a desirable feature in terms of coated denim fabrics. The formula used for the calculation of the S/N ratio are given in Formula 2.

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

where yi denotes the data obtained from experiments; n represents the number of experiments. Regardless of category of the performance characteristics, a greater S/N value corresponds to a better performance. Therefore, the optimal level of the coating parameters is the level with the greatest S/N value. The experimental layout using an L27 orthogonal array, average color difference values and the calculated S/N ratios for all tests are given in Table 2.

Table 2. L27 the orthogonal array, average ΔE values and S/N ratios.

Order	Parameters					Color Difference (ΔE)	S/N Ratio (dB)
	A	B	C	D	E		
1	1	1	1	1	1	13.12	-22.37
2	1	1	1	1	2	13.47	-22.59
3	1	1	1	1	3	14.43	-23.20
4	1	2	2	2	1	14.68	-23.33
5	1	2	2	2	2	14.97	-23.51
6	1	2	2	2	3	15.93	-24.04
7	1	3	3	3	1	15.01	-23.54
8	1	3	3	3	2	15.82	-23.99
9	1	3	3	3	3	13.77	-22.80
10	2	1	2	3	1	13.26	-22.46
11	2	1	2	3	2	14.58	-23.27
12	2	1	2	3	3	13.47	-22.65
13	2	2	3	1	1	14.50	-23.23
14	2	2	3	1	2	15.26	-23.68
15	2	2	3	1	3	14.51	-23.23
16	2	3	1	2	1	13.34	-22.50
17	2	3	1	2	2	12.25	-21.79
18	2	3	1	2	3	13.63	-22.71
19	3	1	3	2	1	13.33	-22.51
20	3	1	3	2	2	13.17	-22.45
21	3	1	3	2	3	14.13	-23.01
22	3	2	1	3	1	15.19	-23.65
23	3	2	1	3	2	14.91	-23.50
24	3	2	1	3	3	13.96	-22.90
25	3	3	2	1	1	13.84	-22.86
26	3	3	2	1	2	13.27	-22.47
27	3	3	2	1	3	13.82	-22.83

In the Taguchi method, the average effect of each factor on the multiple quality characteristics at different levels is determined. This is equal to the sum of all S/N ratios corresponding to a factor at a particular level divided by the number of repetitions of the factor level [17]. The factor levels corresponding to the maximum average effect are selected as the optimum level. For color difference values of coated denim fabrics, the average factor effect is shown in Table 3, and the main effects plotted for S/N are shown in Figure 2. The delta value was calculated by subtracting the largest value from the lowest from among the values in each column. A higher delta value means that the difference at the selected level for a given factor is highly pronounced.

Based on the S/N ratio, the optimum levels of the coating parameters for color difference are 17 picks/cm weft density, 120°C drying temperature, 30 dPa.s viscosity, 5 bar squeeze pressure, 10 m/min fabric passing speed (Figure 2). Also, it was found that the most effective input parameter is drying temperature (B) and second effective input parameter is weft density (A). In Figure 2, it is seen that drying process at 140 °C significantly increases color difference after abrasion. Moreover, it is observed that the color difference of the coated denim fabrics increases with the increase of the viscosity which is the third effective parameter. This may be related to the higher penetration of the low viscosity coating material into the fabric structure.

Table 3. Response table for the S/N ratio of ΔE output

Factors	Average S/N, dB				
	Level 1	Level 2	Level 3	Delta	Rank
A	-23.26	-22.84*	-22.91	0.43	2
B	-22.72*	-23.45	-22.83	0.73	1
C	-22.80*	-23.05	-23.16	0.36	3
D	-22.94	-22.87*	-23.20	0.32	4
E	-22.94*	-23.03	-23.04	0.10	5

*: Optimum parameter level.

The level of importance of the coating parameters for color difference is determined by using ANOVA (Table 4). According to the result of ANOVA, only the drying temperature has a statistical effect on color difference after abrasion. Also, statistical results showed that the contribution rates of A, B, C, D and E factors are 12.05, 36.03, 7.66, 6.68 and 0.70% for the color difference of coated denim fabrics, respectively. In addition, the error contribution ratio is around 36.87%, which indicates the interaction of factors is effective.

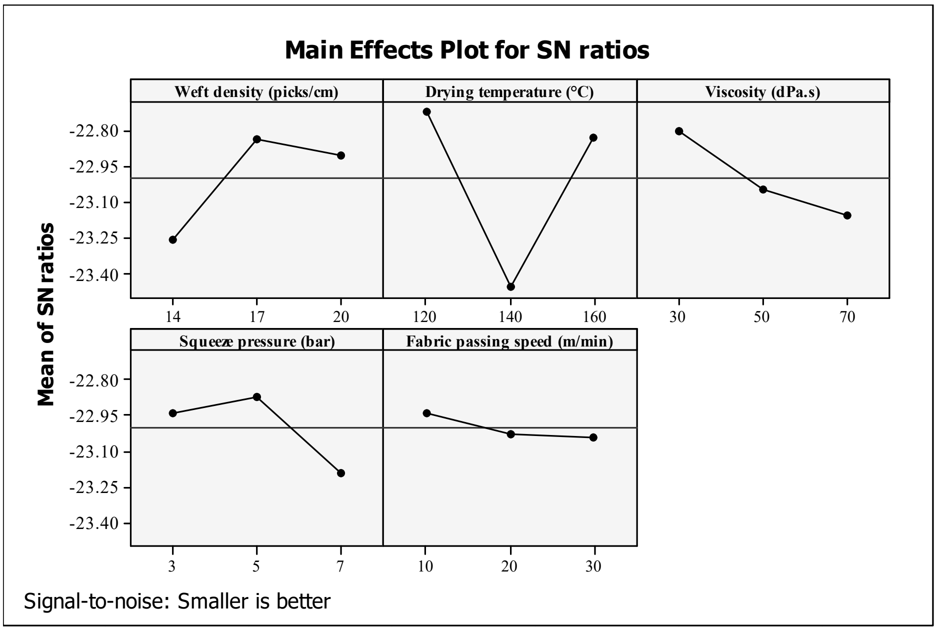

Figure 2. Main effects plot for S/N of ΔE output.

Table 4. ANOVA table for S/N ratio of ΔE output

Factor	*df*	*Sum of squares (SS)*	*Mean square (MS)*	*F-value*	*P*	*Percentage contribution (%)*
A	2	0.938	0.469	2.61	0.104	12.05
B	2	2.805	1.402	7.82	0.004	36.03
C	2	0.596	0.298	1.66	0.221	7.66
D	2	0.520	0.260	1.45	0.264	6.68
E	2	0.055	0.027	0.15	0.860	0.70
Residual	16	2.870	0.179	-	-	36.87
Total	26	7.784	-	-	-	100

3.2. Confirmation tests

The confirmation experiment is the final step of the design of an experiment. The confirmation experiment is performed by conducting a test with optimal settings of the factors and levels previously evaluated [17]. The predicted value of the multiple S/N ratio at the optimum level is calculated as:

$$\eta_0 = \eta_m + \sum_{i=1}^{j} (\eta_i - \eta_m) \quad (3)$$

where, η_m is total mean of S/N ratio, j is the number of factors, and η_i are the multiple S/N ratios corresponding to optimum factor levels. The predicted S/N ratio of optimum design is found to be -22.16 dB for color difference. If the S/N is known and we want to learn about the result expected that will make the S/N, the procedure is to back-transform S/N to find the performance value expected [5]. When the predicted S/N was placed into Formula 2, the predicted color difference values of the optimum design was obtained as 14.77 (ΔE).

In this study, after determining the optimum conditions and predicting the response under these conditions, a new experiment (A2B1C1D2E1) was conducted with the optimum levels of the coating parameters. The average of the experimental results was determined as 13.39 and S/N ratio was calculated as -22.54 dB using Formula 2. These results are very close to that predicted by Taguchi design. The comparison of the predicted ΔE with the experimental ΔE using the optimal coating parameters is given in Table 5.

Table 5. Results of the confirmation experiment for ΔE.

	Starting Coating Parameters	*Optimal coating parameters*	
		Prediction	Experiment
Optimal Level	A1B1C1D1E1	A2B1C1D2E1	A2B1C1D2E1
ΔE	7.36	14.77	13.39
S/N ratio	-22.37	-22.16	-22.54

The confidence interval (CI) of predicted S/N value for the optimum factor level combination at 95% confidence band is calculated to determine whether the results of the confirmation experiments are reasonable or not. The CI is calculated by:

$$CI = \sqrt{F_{\alpha;1,DF_{MSe}} * MSe * \left(\frac{1+m}{N} + \frac{1}{n_r}\right)} \quad (4)$$

In Eq. 4, F_α is the value of F table, α is the error level, DF_{Mse} is the degree of freedom of mean square error, m is the degrees of freedom of j factors, N is the number of the total experiments and n_r is the number of repetitions in the confirmation experiments. For the present study, CI was found ±0.531 and this means that the verification experiments for S/N ratio results are located in the confidence interval (Eq. 5).

Predicted optimum S/N-CI<Experimental optimum S/N< Predicted optimum S/N+CI (5)

-22.16-0.531<-22.54<-22.16+0.531

-22.69<-22.54<-21.63

Finally, first trial (A1B1C1D1E1) is selected as the initial design (S/N=-22.37 dB), and the difference (d) is obtained between the S/N ratio of the selected design (S/N_i) and the predicted S/N ratio of the optimal design (S/N_0) as shown Eq.6. The recovery rate was determined by the calculated "d" value. According to this calculation, the color difference after abrasion of coated denim fabrics under optimum conditions was found to be decreased 1.05 times.

$$d = \frac{S}{N_i} - \frac{S}{N_o} \quad (6)$$

$$d = -10\log L_i - (-10(\log L_o))$$

$$\frac{L_o}{L_i} = 10^{\frac{d}{10}}$$

4. CONCLUSIONS

In this study, the optimum coating conditions was determined for the color difference after abrasion of denim fabrics by Taguchi method. With the S/N and ANOVA analyses, the optimal combination of the process parameters and the level of importance of the coating parameters was determined. Based on the S/N ratio, the optimum levels of the coating parameters for ΔE are 17 picks/cm weft density, 120 °C drying temperature, 30 dPa.s viscosity, 5 bar squeeze pressure, 10 m/min fabric passing speed. According to ANOVA test, it was determined that the drying temperature has a statistically significant effect on the color difference of denim fabrics. Statistical results showed that the contribution rates of A, B, C, D and E parameters are 12.05, 36.03, 7.66, 6.68 and 0.70% for the color difference of coated denim fabrics, respectively. The color difference of coated denim fabrics under optimum conditions is found to be improved 1.05 times. Moreover, the confirmation tests indicated that it is possible to decrease the color difference relatively by using the proposed optimal coating conditions.

REFERENCES

1. http://fashion2apparel.blogspot.com/2018/11/denim-fabric-finishing-techniques.html, 21 Mart 2019.
2. Paul, R., (2015) Denim Manufacture, Finishing and Applications, Woodhead Publishing Series in Textiles: Number 164, Elsevier, pp. 1-599.
3. Lai, H., Chang, Y., Chang, H., (2004), A robust design approach for enhancing the feeling quality of a product: a car profile case study, International Journal of Industrial Ergonomics, vol.35, no.1, pp. 445-460.
4. Jung, J. J., Kim, S.,Park, C. K., (2016), Optimization of Digital Textile Printing Process using Taguchi Method, Journal of Engineered Fibers and Fabrics, vol.11, no.2, pp.51-59.
5. Mavruz, S., Ogulata, R. T., (2010), Taguchi Approach for the Optimisation of the Bursting Strength of Knitted Fabrics, FIBRES & TEXTILES in Eastern Europe, vol.18, no.2 (79), pp.78-83.

6. Maqsood, M., Hussain, T., Ahmad, N., and Hawab Y., (2017), Multi-response optimization of mechanical and comfort properties of bi-stretch woven fabrics using grey relational analysis in Taguchi method, The Journal of The Textile Institute, 108:5, pp. 794-802.

7. Nassif, GA, (2017), Using Taguchi Methodology to Optimize Woven Fabrics Air Permeability, Journal of Textile Science & Engineering, Volume 7, Issue 6, pp. 2-4.

8. Ahmad, N., Kamal, S., Raza, Z. A., Hussain, T., Anwar, F., (2016), Multi-response optimization in the development of oleo-hydrophobiccotton fabric using Taguchi based grey relational analysis, Applied Surface Science, 367, pp. 370-381.

9. Shabaridharan K., Das, A., (2014), Analysis of thermal properties of multilayered fabrics by full factorial and Taguchi method, The Journal of The Textile Institute, vol. 105, no. 1, pp. 29-41.

10. Yang, W. H., Tarng, Y. S., Design optimization of cutting parameters for turning operations based on the Taguchi method, Journal of Materials Processing Technology, 84, 122-129.

11. Shaker, K., Umair, M., Maqsood, M., Nawab, Y., Ahmad, S., Rasheed, A., Ashraf, M., and Basit, A., (2015), A Statistical Approach for Obtaining the Controlled Woven Fabric Width, AUTEX Research Journal, vol. 15, no 4, pp. 275-279.

12. Raza, Z. A., Anwar, F., (2017), Fabrication of chitosan nanoparticles and multi-response optimization in their application on cotton fabric by using a Taguchi approach, Nano-Structures & Nano-Objects, 10, pp.80–90.

13. Ramirez-Montoya, L., Hernandez-Montoya, V., Montes-Moran, M., (2014), Optimizing the preparation of carbonaceous adsorbents for the selective removal of textile dyes by using Taguchi methodology, Journal of Analytical and Applied Pyrolysis, 109, pp.9-20.

14. Oguz, E., Keskinler, B., Çelik, C., Çelik, Z., (2006), Determination of the optimum conditions in the removal of Bomaplex Red CR-L dye from the textile wastewater using O3, H2O2, HCO3 and PAC, Journal of Hazardous Materials, 131, pp.66-72.

15. Fazeli, F., Tavanai, H., Hamadani, A. Z., (2012), Application of Taguchi and Full Factorial Experimental Design to Model the Color Yield of Cotton Fabric Dyed with Six Selected Direct Dyes, Journal of Engineered Fibers and Fabrics, Volume 7, Issue 3, pp.34-42.

16. Perumalraj, R., and Dasaradan, B. S., (2011), Optimization of electromagnetic shielding tester process parameters for conductive textile composite materials through Taguchi design and ANOVA, Perumalraj et al./ Elixir Elec. Engg., 40, pp. 5477-5482.

17. Tosun, N., Cogun, C. and Tosun, G., (2015), A study on kerf and material removal rate in wire electrical discharge machining based on Taguchi method, Journal of Materials Processing Technology, 152, pp.316-322.

18. Güneş, S.; Manay. E.; Şenyiğit, E.; Özceyhan, V., (2011), A Taguchi approach for optimization of design parameters in a tube with coiled wire inserts, Applied Thermal Engineering, 31, pp. 2568-2577.

19. Gaitonde, V.N., Karnik, S.R., Paulo Davim, J., (2008), Taguchi multiple-performance characteristics optimization in drilling of medium density fibreboard (MDF) to minimize delamination using utility concept, Journal of materials processing technology, 196, pp. 73-78.