Review Article

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To cite to this article: Oğuz, N. S. & Akarslan, F. (2022). APPLICATIONS OF TAGUCHI EXPERIMENTAL DESIGN METHOD IN THE FIELD OF TEXTILE. International Journal of Engineering and Innovative Research , 4(2), p:134-142 . DOI: 10.47933/ijeir.1039263

DOI: 10.47933/ijeir.1039263

To link to this artice: https://dergipark.org.tr/tr/pub/ijeir/archive

International Journal of Engineering and Innovative Research

http://dergipark.gov.tr/ijeir

APPLICATIONS OF TAGUCHI EXPERIMENTAL DESIGN METHOD IN THE FIELD OF TEXTILE

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https://doi.org/10.47933/ijeir.1039263

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(**Received:** 21.12.2021; **Accepted:** 29.04.2022

ABSTRACT: The aim of this study is to investigate the Taguchi experimental design method and the studies conducted in the field of textiles. Taguchi experimental design method is widely used in engineering field. Experiments are carried out in order to obtain the optimum values of the product designed or produced in the field of engineering. It is difficult to make the experiments because of the large number of parameters in the studies made. Therefore, with the Taguchi experimental design method, less experimentation can be done in shorter time and an accurate test strategy is being developed. Thus, saving is provided from time and cost, high quality and low cost production is achieved. In this study, information was given about Taguchi experimental design method and Taguchi applications in the field of textile.

Keywords: Taguchi, Experimental Design, Textile.

1. INTRODUCTION

In order for the product designed and produced in engineering studies to have the best performance, the features and factors affecting the performance should be determined, and experiments should be carried out to obtain the optimum values [1].

Experimental design methods were developed by Fischer for use in agricultural research in the 1920s [2,3]. In addition, the analysis of the data obtained as a result of experimental studies, the "Analysis of Variance (ANOVA)" method, which is widely used today, was used and developed [4].

Thanks to the experimental design methods, the quality of the products is increased, the cost is reduced, the product is used more efficiently, and the production process is controlled in the most efficient way [5].

Due to the inadequacy of classical methods in experimental design, full factorial, fractional factorial and Taguchi methods are used in statistical experiment design [6].

In the full factorial experimental design method, at least two or more parameters and the combination obtained by multiplying the levels of these parameters with each other are used. Blocking is used to prevent unknown and uncontrollable errors from affecting the experiment.

In this method, experimental analysis is performed using ANOVA (analysis of variance) and regression analysis. The effect of a parameter on the experiment can be calculated with this method [6].

Since all level combinations of the parameters are tried one by one with the full factorial experimental design method, there is an increase in cost and a loss of time. Therefore, with the fractional factorial experiment design method, in which the number of experiments is reduced fractionally, cost and time savings are achieved. When a two-level experiment with seven parameters is performed with the full factorial experiment design method, 27=128 experiments are performed, while in the fractional factorial experiment design method, it is up to the researcher to decide on the construction of the experiment as fractional and 64 experiments can be done with ½ fraction or 32 experiments with ¼ fraction [6].

Taguchi method is an experimental design method established to provide the optimum combination between different levels of different parameters. It is one of the most used experimental design [6].

Genichi Taguchi, using his own name, developed a method to reduce the number of experiments with the analyzes he made before the experiment [7]. In the 1960s, the Taguchi method was used in the manufacturing industry, and it was widely used in the field of engineering, contributing to new developments [8].

While all experiments are performed in the full factorial test method, the most suitable test combinations are determined by using orthogonal arrays in the Taguchi test method. The number of factors, the number of levels and their interactions determine orthogonal arrays [9]. Table 1 shows the comparison of the number of full factorial experiments with the number of Taguchi experiments. As can be seen in the table, the number of experiments is greatly reduced with the Taguchi method, thereby providing convenience. While the full factorial experimental design is based on all factors and combinations, the fractional factorial design uses some of the combinations. More time is spent on traditional designs. The cost of these methods is high and the results can be erroneous. The Taguchi method, on the other hand, overcame these problems and made fractional factorial design simpler [10].

Table 1. Comparison of the number of full factorial experiments with the number of Taguchi experiments [9]

Number of factors	Number of levels	Number of Full Factorial Experiments	Taguchi Number of Experiments
2	2	4 (2^2)	4
3	2	8 (2^3)	4
4	2	16 (2^4)	8
7	2	128 (2^7)	8
15	2	32768 (2^{15})	16
4	3	81 (3^4)	9

With the Taguchi experimental design method, it uses controllable factors before, during and after production in the best way and minimizes the variable against uncontrollable factors [4].

In this study, it is aimed to investigate the Taguchi experimental design method and studies in the field of textiles. When the literature is examined, factorial design, response surface method and Taguchi method are commonly used; It has been seen that the Taguchi method is preferred more because of less experiments, fast results and cost savings. It has been seen that this method makes significant contributions to the production process and product performance [11].

2. TAGUCHI EXPERIMENTAL DESIGN STAGES

The Taguchi experimental design method consists of three basic concepts: system design, parameter design, and tolerance design.

System Design: In order to realize the best product design with the least cost by evaluating all the materials at hand, the current technological developments are researched and a feasibility study is carried out on the usability in the system [6].

Parameter Design: It is the most important step in process improvement and renewal. The improvement of the parameter is achieved by optimizing the product to be produced or developed. Uncontrollable parameters that negatively affect the quality of the product during production are determined and the effect of these parameters is minimized [6].

Tolerance Design: In cases where the desired target is not achieved, these deviations are reduced by making additional studies and finding the losses that deviate from the target value [6].

The following steps are followed in the implementation of the Taguchi experimental design method [12,13]:

Selection of factors affecting the experiment by using methods such as brainstorming and cause-effect diagram, determining the interaction between factors: There are controllable and uncontrollable factors in the Taguchi method. Designs and experiments are carried out according to the number of controllable factors.

Determination of experimental factor levels: Factor levels can be two, three or more.

Choosing orthogonal arrays: Many factors can be tested with the least number of orthogonal arrays, and it provides the opportunity to change factor levels.

Assignment of experimental factors to columns: Factors are assigned to columns according to orthogonal order by using linear graphics and triangular tables.

Performing the experiments: The data is analyzed according to the selected performance statistics. Therefore, performance statistics should be determined correctly.

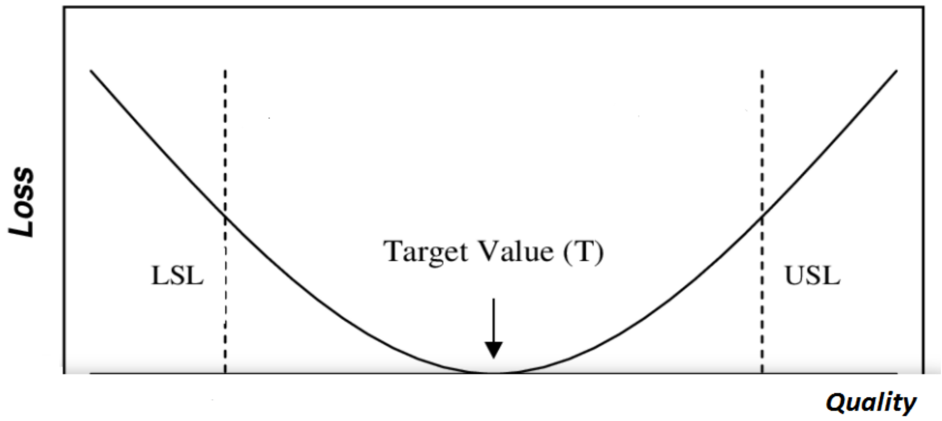
Analysis of the results: Analysis is made using methods such as analysis of variance, graphical representation of factor effects, spreadsheet method.

Confirmation of the experiments: When the factor obtained as a result of the experiment, the level combination reached the best performance characteristic, the experiment reached its goal.

By following these steps, the best experimental parameters are determined [13].

3. LOSS FUNCTION IN TAGUCHI EXPERIMENTAL DESIGN

In cases where there is a deviation from the target value, cost evaluation is made with the Taguchi loss function. In conventional quality control, if the value of the part is outside the specification limit, the part is reworked or scrapped. If the value of the part is within the specification limit, it is accepted. With the traditional method, there is either no loss or complete loss. Taguchi developed the Taguchi loss function, thinking that this method does not reflect the truth. In the Taguchi loss function shown in Figure 1., the horizontal axis represents the amount of deviation from the target, and the vertical axis represents the monetary loss that occurs after the product leaves the factory. In the formula shown below (1), it is seen that with the increase in the deviation from the target value, the loss increases in the ratio of the square of the deviation [4].



LTL: Lower Tolerance Limit
UTL: Upper Tolerance Limit

Figure 1. Taguchi loss function [4]

$$Loss=k.(Y-T)^2 \qquad (1)$$

T: "Target value"
Y: "Measured value of quality variable"
k: "The coefficient that converts the deviation into currency" [4]

It is aimed to minimize the loss that may occur with the Taguchi loss function.

4. TEXTILE APPLICATIONS

Kuo and Fang (2006) determined the optimum dyeing conditions by using the Taguchi method in order to obtain the desired color during dyeing of the nylon-lycra mixed raw fabric, and it was observed that the optimum dyeing conditions obtained from the Taguchi method were compatible with the experiments [14].

20-40% of reactive dyes are mixed with waste water. Waste water needs to be treated because reactive dyes impair the aesthetic properties of waste water and reduce the amount of dissolved oxygen in nature. For this purpose, the most suitable test parameters were determined with the Taguchi method to ensure color removal from textile wastewater by using modified zeolite [15].

Taguchi and fully active experimental design methods were used to examine the effect of twist direction on the mechanical properties of cord fabric such as tensile strength, elongation at break, and force values at a certain elongation. The data obtained are compatible with each other in both experimental design methods, and it has been stated that it is more suitable than other experimental design methods because the least number of experiments can be done thanks to the Taguchi method [16].

Simulation method and Taguchi experimental design method were used to shorten the process of obtaining raw fabric used in contract manufacturing apparel enterprises. When the simulation model established with the obtained data is compared, the lead times of the fabrics are compatible with each other. It has been observed that the cost and lead time are reduced with the simulation system. The total stock amount variable was also minimized with the Taguchi method [17].

The properties affecting the bursting strength of knitted fabrics were optimized using the Taguchi experimental design method. The data obtained as a result of the experimental study were found to be compatible with the Taguchi method [18].

By using the Taguchi method, Mezarcıöz and Oğulata (2010) optimized the breaking strength values of single jersey fabrics. Contrary to the full factorial experimental design, which causes time and cost loss, the number of experiments is reduced with the Taguchi method [19].

Taguchi method was used to provide color removal of reactive dyes used in textile industry under appropriate conditions using Reactive Red 198 as reactive dye and pistachio shell as absorbent material. It has been seen that the appropriate experimental conditions are determined by the Taguchi method, the number of experiments is reduced by the Taguchi method, time and cost loss is prevented, and the pistachio shell is a good absorbent material [20].

Yazıcı (2010), in the dyeing process of staple acrylic fiber used in carpet production with cationic dyestuff, used the Taguchi method to obtain optimum values in the dyeing process, and a more efficient dyeing process was achieved, and cost savings were achieved [21].

Alhalabi and Sabır (2011) used the Taguchi method to examine the effect of the lubricant used to prevent static electricity in synthetic fiber spinning on the quality parameters of ring yarn obtained from polyester fiber. Optimum static electricity and lubricant amount were determined by Taguchi method [22].

Mutlay (2011) states that one of the accidents that pose the greatest threat to the environment and human health today is chemical and oil spills. Scattered liquid contaminants can be effectively cleaned using porous textile structures. The xylene and diesel fuel retention properties of absorbent textile fillers produced from expanded graphite-based fibrous structures were investigated. The highest absorption value of liquid pollutants in the literature was achieved with the Taguchi experimental design method [23].

Demirbaş and Yıldız (2012) used the Taguchi method for the optimization of adsorption experiments in the use of silica for the removal of textile dyestuff from wastewater. With the Taguchi method, fewer experiments were performed than with the traditional method, and time and cost savings were achieved [24].

Kocatüfek (2013) obtained thermoplastic composite by adding glass fiber at different rates to polyamide-based materials. The effect of this method, which is used in these composites obtained by using the hot plate method, on the plate temperature, welding time, heating time and joining stroke, was achieved by reducing the number of experiments with the Taguchi experimental design method. On the other hand, when the experimental and numerical data were compared, it was seen that the Taguchi method was successfully applied to polyamide 6 materials. On the other hand, it has been observed that the welding strength of the 30% glass fiber added polyamide 66 material is not compatible in experimental and numerical data due to thermal deterioration caused by time and temperature. Instead of Taguchi L9 orthogonal matrix used in the study, it is suggested to design Taguchi orthogonal matrix at new levels [25].

Özgür (2013) investigated the effects of texture structure, dye intensity and raising process on some quality properties of woven fabrics such as breaking strength, tear strength, pilling. The data obtained from the results were analyzed statistically and the compatibility of the results obtained from the full factorial experimental design with the Taguchi experimental design was examined. Except for the pilling process, all experiments were found to be compatible with the Taguchi experimental design [26].

The Taguchi method was used to optimize the experimental conditions in the electrocoagulation method used in the treatment of textile wastewater. The variables affecting the electrocoagulation method were optimized with the Taguchi method [27].

It was desired to remove acidic, basic and reactive dyes by using vegetable wastes and carbon. Optimum conditions in the experiment were determined using the Taguchi method [28].

Sabir and Özgür (2014) applied bending length test to fabrics produced in different knitting texture, dyeing ratio and raising process. When the results were analyzed, it was seen that the data obtained by the Taguchi method were largely compatible with the experimental results [29].

With the Taguchi method, the optimization of the sizing process in different yarn counts, delivery speeds and viscosity values of 100% cotton yarn was investigated. Thanks to the Taguchi method, fewer experiments were performed, resulting in cost savings [30].

Nano fiber production was carried out by electrospinning method using polymethyl methacrylate polymer. It was observed that the electrospinning process parameters were optimized by the Taguchi method [31].

Woven fabrics with twill weave structure were dyed in three different dye ratios and raised in two passages. In addition, tensile strength and elongation at break tests were applied to the fabrics [32].

The most suitable knit structure, dye ratio and raising type were determined for the optimization of breaking strength and elongation at break with the Taguchi method.

Özgen and Altaş (2016) determined that yarn count, slub thickness, slub length, slub distance control factors were determined in Taguchi L9 orthoganal design after weaving slub yarns with different properties as 1/3 twill fabric. The effect of the slub yarn structure produced with different properties on the air permeability of the woven fabric was investigated. The results of the analysis showed that the slub thickness is the most effective factor in the air permeability of the woven fabric [33].

Avcu (2017) used the Taguchi method to improve the wear performance of automotive seat upholstery produced using double-layered woven fabric. The mechanical properties such as thickness measurement, weight, tear strength, elongation, abrasion resistance of woven fabrics produced using polyester yarn were examined and the most suitable tissue structure in terms of mechanical properties was determined by Taguchi method [34].

Özmen (2017) determined the order of importance of the factors that may cause a change in yarn quality in a yarn production facility with the Taguchi method. Thus, time and cost savings were achieved by making fewer experiments [35].

The removal of Astrazon Black MBL (AB) dye, which is prepared synthetically with garden soil used as an adsorbent, was investigated by modeling with the taguchi method. After treatment, oxidation-reduction potential (ORP) and FTIR analyzes were carried out by working with the removal of both color and organic matter content in the synthetic dye solution, adsorption and Fenton processes under different operating conditions. It has been concluded that high rates of color can be removed with the soil used and organic materials can be held on the surface [36].

Üstündağ et. al., 2022, it is presented that the optimum levels of coating process parameters for the tear strength and hardness properties of cotton/elastane blended denim fabrics are determined by Taguchi method and Gray relational analysis [37].

5. CONCLUSIONS

Contrary to traditional methods, significant improvements are achieved in experimental performance with the Taguchi experimental design method. In the studies, it was seen that the test results were compatible with the Taguchi experimental design and the experimental process parameters were optimized by the Taguchi method. By making fewer experiments in a shorter time, cost savings are achieved not only for researchers in the field of textiles, but also for studies in other fields. The use of Taguchi experimental design method in studies in universities and industry provides great convenience in studies.

Conflict of Interest

No conflict of interest was declared by the authors.

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