Title: Optimization of Axial Misalignment due to Glass Drilling by Statistical Methods

Authors: Faruk HARMANCI, Sabri ÖZTÜRK

Optimization of Axial Misalignment due to Glass Drilling by Statistical Methods

Faruk HARMANCI[1] , Sabri ÖZTÜRK[*2]

Abstract

Flat glass has a significant utilization in the domestic appliances sector. Drilling of glass is frequently used in the white goods sector. In this research, the glass drilling method is explained in detail, the determined axial misalignment values using the tool rotation speed and the feed rate were investigated. The drilling operation with its parameters must be optimized precisely, in order to have good control over the productivity, quality, and cost aspect of the application. Using the Ø18.3 mm drill tool, drilling process was performed with different rotation speeds (rpm) and feed rates (mm/sec). The impressions of drilling parameter on output variable were investigated using Analysis of Variance (ANOVA). Probabilistic uncertainty analysis based on Monte Carlo simulation was carried out. According to the results, the suggested model and optimization method could be used for estimating axial misalignment and this investigation is reliable and proper for figuring out the problems met in machining operations. Furthermore, Monte Carlo simulations were obtained quite effective for identification of the uncertainties in axial misalignment that could not be possible to be caught by deterministic ways. The optimum axial misalignment value was found to be 0.11823 mm.

Keywords: Flat Glass, Drilling, Axial Misalignment, Analysis of Variance (ANOVA), Monte Carlo Simulation

[1] Bolu Abant İzzet Baysal University, harmancifaruk@gmail.com, ORCID ID: 0000-0002-2892-7436
[*] Corresponding Author
[2] Bolu Abant İzzet Baysal University, sabriozturk@ibu.edu.tr, ORCID ID: 0000-0002-1377-9338

1. INTRODUCTION

The glass material is known as one of the amorphous materials that are cooled down from the molten state without showing crystallization. The glass is resistant to chemical interactions, easy to recycle, no chemical leakage as in plastic materials and can also withstand extreme cold and temperature [2].

Glass is a kind of inorganic brittle structure. It has many excellent properties such as hardness, transparency, good temperature stability, homogeneity and corrosion resistance. Such features are widely used in the glass optics industry, the semiconductor industry, the military industry, and many similar places. Glass material plays an important role in the biomedical industry [3].

Glass, first softens and then becomes fluent. If sufficient heat is applied, the glass material flows like water. Glass material is defined as a mine. However, there is a significant change when compared to other mines. This change is not the melting point, the softening point. Glass is a mixture formed with together of silicon dioxide (SiO2) and mineral oxides. It is an interesting condition in the structure of the atom, which feature gains real meaning to glass.

Because of these interesting features of glass material, neither exactly is a liquid nor is it like a true solid with a crystal structure. It has an important place between these two situations. The arrangement of atoms in the glass material is random as in a liquid material. As a result, glass is not affected by gravity due to these reasons and it has the feature of protecting the shape [4].

According to myths, the people's comments about the glass are related to the fact that a Phoenician sailor flows from the sands under a pot where he cooks on the beach for dinner. This showed us the source of the glass. However, according to archaeological evidence, the construction of the first glass was made in Eastern Mesopotamia and Egypt [5-6].

In next to the production of glass materials, the processing of glass has an important place.

It is a material with a crystal-free (amorphous) structure and exhibiting glass transition when heated from a liquid state, covering each solid [1].

According to the information we have investigated, the basic processes applied to the glass material are as follows; glass material production, cutting process, edge processing, grinding process, hole drilling, printing process, annealing and tempering processes.

First of all for glass drilling process, the glass should be drill to certain dimensions. Previous research, shear strength, tooling features and by working on processing temperatures has investigated that costs can be reduced. Most features must be taken into account when glass cutting process was applied [7].

The adequate selection of cutting tool affects the success of drilling process. Obviously the effective of the machining operation depends on the features of drilling tools, obtained the quality of workpiece layer surface in interaction with the operation conditions and workpiece materials. Glass drilling is carried out with two drills of the same diameter. Hole drilling process is done with drills in the upper and lower section. When we look at the machining, the surfaces processed using the manufacturing processes are affected by the cutting parameters. Incorrectly selected machining parameters result in rapid wear and break of the cutting tools. Therefore, it causes economic losses due to the deterioration of work piece and surface quality [8].

In recent years, the use of soda-lime glass, which is an organic material in many engineering fields, is superior in comparison to other materials with hardness, low density, low heat and electrical conductivity [9-12].

Cutting parameters are very important in drilling operations. During the drilling operations, many undesirable situations were occurred such as excessive surface roughness, axial misalignment, burr formation, tool wear and circularity.

Many analysis methods have been used for the optimization of the parameters used for glass

machining and for the design of the experiment. Also, the experimental design of Taguchi method is used for planning of experiments [13-17].

For drilling of glass, drill performance needs to be critically evaluated in their economic and commercial impact. In this case, tests are conducted in order to analyze the axial misalignment due to glass drilling under different cutting speed and feed rates.

First, ANOVA is used for data analysis to determine the degree of importance of the drilling factors. Then, the axial misalignment as a response variable of the drilling operation is measured and correlated with different drilling parameters. Mathematical models based on multi non-linear regression analysis have been described and the stochastic prediction of axial misalignment of drilling with probabilistic uncertainty analysis has been determined by the Monte Carlo simulation.

Therefore, it is ensured that efficiency and sensitivity are increased by a good determination of the optimum cutting parameters [18]. A vertical type Coordinate Measuring Machine (CMM) was used to determine the axial misalignment during drilling.

2. MATERIAL and METHODS

Drilling process is employed with glass drilling tolls. The drills are composed of two parts, the metal body and the diamond-binder mixture in the cutter. As a comparison between different types of diamonds, hardness and abrasion resistance is one of the most important features of diamond. In the literature, diamond hardness measurement was reported [19].

The diamonds used in the cutting tools are coated with nickel or titanium in order to better cut them and to keep the diamond grains of the binders well. The coating extends the life of a material and provides strength. Soft binders are used in drills. The binder and abrasive parts of the drilling tools are approximately 8 to 10 mm in length.

As an experiment sample, bronze reflective glass was used in Figure 1. Different input variables were chosen throughout the experiments. Moreover, each drilling test was repeated three times to abstain experimental errors.
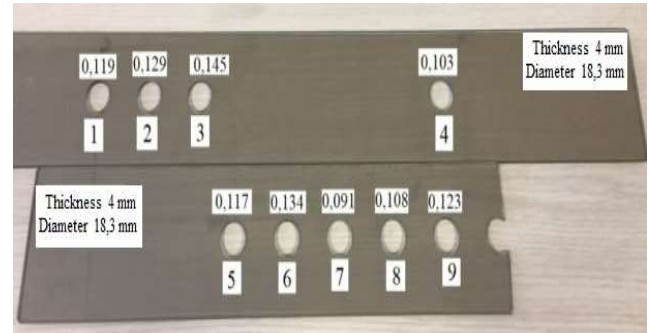

Figure 1. Test samples

As shown in Figure 2, axial misalignment resulting from the hole drilling was measured by CMM (Coordinate Measuring Machine). Vertical type CMM device is used. The measurement is realized at the end of the machine probe tip. The device moves in X, Y and Z axes. To tell you where to use the CMM devices; it is used to check whether the parts to be measured are within the geometric tolerances.
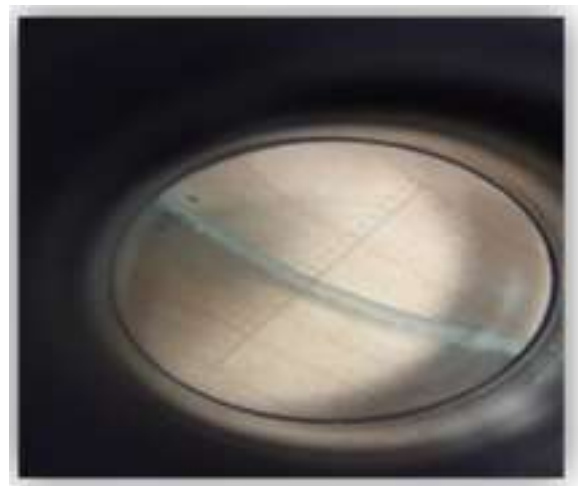

Figure 2. Measuring axial misalignment

Coordinate Measuring Machines (CMM) are reliable tools in validation rooms or laboratories. It is based on more data processing capabilities including the ability to measure complex parts, change the geometry with its powerful service point, coordinate subtraction and the ability to adjust point coordinates [20].

The controlled ambient temperature is 20±2 °C. It is a basic parameter that the machine performs a methodologically accurate measurement at such a stable ambient temperature. For this reason, temperature compensated CMM's have been developed in recent years [21].

How the data obtained by variance analysis (ANOVA) interact in themselves and to investigate the effects of emerging interactions on dependent variables. It is used to determine the variability between the groups to be compared with this analysis method [22].

Another method of analysis is the regression analysis method, which enables us to analyze the functional relations between dependent and independent variables by mathematical modeling with systematically and comprehensively [23].

An uncertainty analysis has to be applied to define the unexpressed part of the suggested MNLR model. One of the main novel part of the current investigation was achieved as probabilistic uncertainty analysis based on the Monte Carlo simulation.

Monte Carlo method is a numerical method that can solve math problems by using random samples. This method is very useful in real solutions. It is a method based on probability theory [24].

Monte Carlo technique is known as a technique, which aims to achieve the result by selecting randomly from a plurality of probability distributions in an experiment or a simulation study [25, 26].

3. EXPERIMENTAL RESULTS

Statistical analysis and optimization were employed by obtaining the experimental data in the current study. Table 1 shows the revolutions, feed rate and axial misalignment values used in the experiments. The sample glass thickness is 4 mm.

Firstly, it is examined how the independent variables have an interaction with variance analysis. Variance analysis method is preferred when the number of independent variables is high. To predict the axial misalignment of the drilling application, an MNLR model achieved with the high coefficient number of adjusted and predicted regression.

Table 1. Experimental design and results

Drill Diameter = Ø 18.3 mm		
Rotation Speed (rpm)	Feed Rate (mm/sec)	Axial Misalignment (mm)
3200	2.5	0.119
3200	2.75	0.129
3200	3	0.145
3450	2.5	0.103
3450	2.75	0.117
3450	3	0.134
3700	2.5	0.091
3700	2.75	0.108
3700	3	0.123

Another important outcome is also unexpressed part of the variability in response variable could not be described by suggested best-fit MNLR model. Thereby, an uncertainty analysis has to be applied to explain the unexplained part of the suggested MNLR model. One of the main new breakthroughs of this research is the probability uncertainty analysis based on the Monte Carlo simulation has been successfully achieved.

Table 2. Variance analysis for Ø18.3 mm drill tool

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	0.12	1	6.003E-004	0.11	0.12	
A-Rotation Speed	-0.012					1.00
B-Feed Rate	0.015					1.00

AB	1.500E-003	1.00
A²	1.672E-003	1.17
B²	1.672E-003	1.17

Table 2 shows variability of the tool rotation speed and the feed rate. Although, these statistical coefficients characterized the strong part of the suggested MNLR model was found significant, they were not adequate to describe the obtained MNLR model completely. Therefore, some extra statistical coefficients should be calculated for the further identification of the obtained MNLR model.

Variation inflation number (VIF) can be identified as fundamental points that indicated the multicollinearity, in order to meet the criteria that underlie the assumption in the design of the MNLR model. VIF factor should be between from 0 to 10.

As it can be showed in Table 2, VIF value was calculated lower than 10.

All parametrical data in the distribution of variance are calculated by dividing the results by the arithmetic mean and the result is divided by the number of data. When we take the square of the standard deviation, it gives us the variance.

Axial misalignment mathematical model $= 0.86507 - 2.97968E - 004\, x\, A - 0.17064\, xB + 2.40000E - 005\, x\, A\, x\, B + 2.67586E - 008\, x\, A^2 + 0.026759\, x\, B^2$ (1)

Using the data obtained from the experiments was used in the mathematical model. This model is the equation of the curve obtained from the graph in Figure 6.

Table 3. Quadratic model ANOVA analysis of response surface for Ø18.3 mm drill tools

Source	Sum of Square	df	Mean Square	F Value	P-value Prob > F	
Model	2.194E-003	5	4.389E-004	209.95	< 0.0001	significant
A-Tool Rotation Speed	8.402E-004	1	8.402E-004	401.93	< 0.0001	
B-Progress Amount	1.320E-003	1	1.320E-003	631.56	< 0.0001	
AB	9.000E-006	1	9.000E-006	4.31	0.0767	
A²	7.725E-006	1	7.725E-006	3.70	0.0960	
B²	7.725E-006	1	7.725E-006	3.70	0.0960	
Residual	1.463E-005	7	2.090E-006			
Lack of Fit	7.832E-006	3	2.611E-006	1.54	0.3354	Not significant
Pure Error	6.800E,006	4	1.700E-006			
Cor. Total	2.209E-003	12				

Since F value is 209.95, it expresses the importance of the model (Table 3). We create our model according to the experimental data obtained. The terms A and B, where probabilistic values (p) are less than 0.05, are important for the model. It is desirable that the lack of fit is high. In the analysis, the low mismatch value of 1.54 indicates that the model cannot be used for a study conducted in this way.

Table 4. Analysis values for Ø18.3 mm drill tools

Standart Deviation	1.446E-003	R-Square	0.9934
Mean	0.12	Adj R-Squared	0.9886
C.V.%	1.23	Pred R-Squared	0.9612
PRESS	8.575E-00E	Adeq Precision	54.299
-2 Log Likelihood	-141.17	BIC	-125.78
		AICc	-115.17

The mean value of the axial misalignment was found 0.12 mm. The percentage value of R squared variation may be valid by 0.9934 (Table 4). The R squared value assumes that each argument in the model describes the dependent variables.

The estimated R squared value was found 0.9612. It is seen that there is a difference of 4% compared to the actual values. That is, it shows the difference between the data obtained from the experiments and the data obtained from our model.
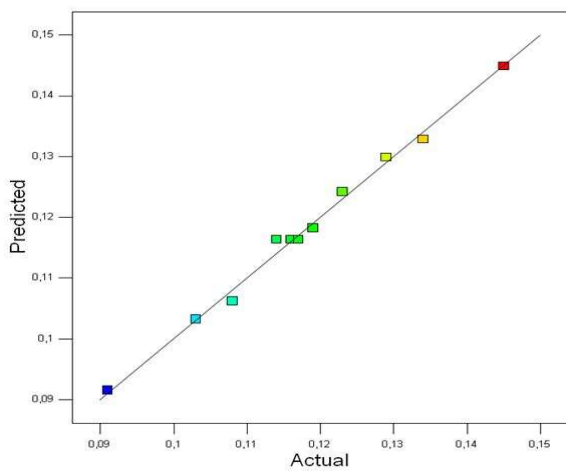

Figure 3. Plot of predicted versus actual results

The data obtained from the experiments and the data obtained from the mathematical model were found to be close to each other as can be seen in Figure 3.
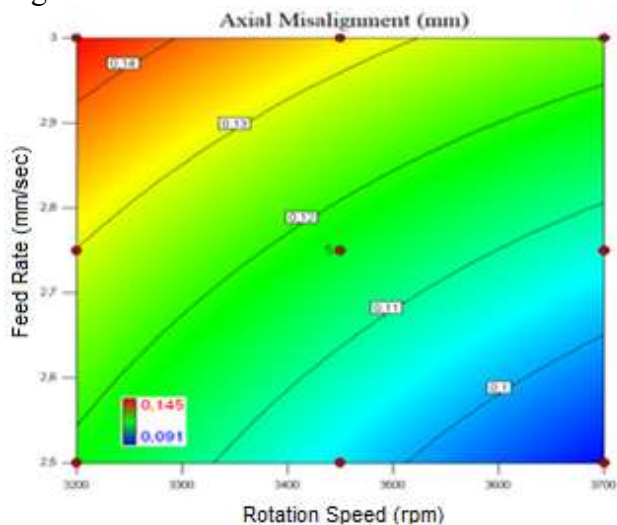

Figure 4. Dual interaction effects of input variables on axial misalignment

Difference in the tool rotation speed and the feed rate, in terms of axial misalignment can be observed in Figure 4. According to the graph, the lowest axial misalignment value was found 0.091 mm and the highest axial misalignment value was found 0.145 mm.
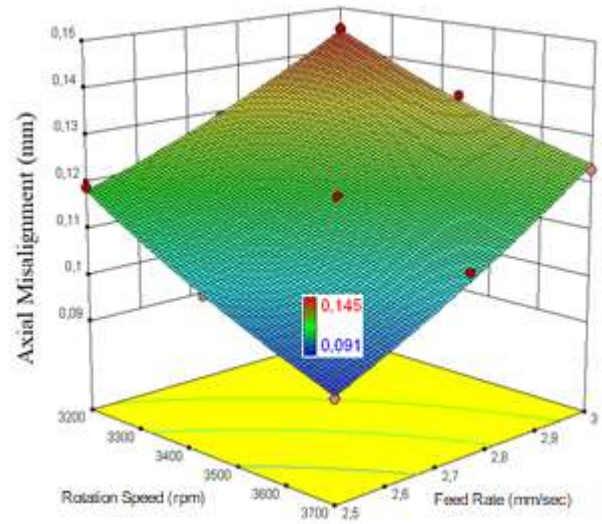

Figure 5. Three-dimensional response graph for the rotation speed and feed rate as compared to the axial misalignment value

As the amount of progression in Figure 5 increases, the value of the axial misalignment also increases. The tool rotation speed also has an effect on axial misalignment. In the three dimensional graph, the lowest axial misalignment value was found 0.091 mm and the highest axial offset value was found 0.145 mm.
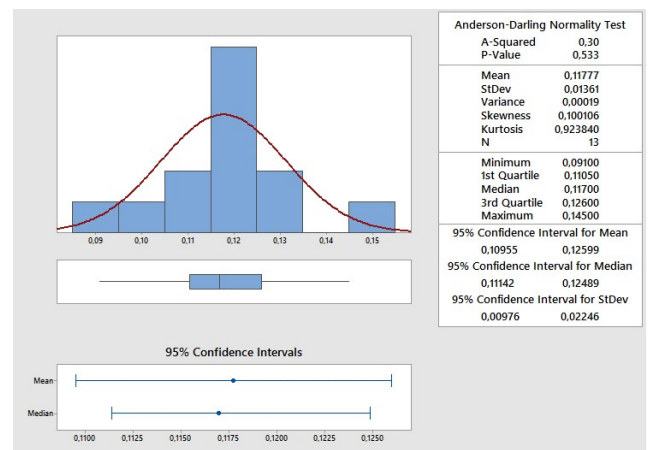

Figure 6. Conclusion with descriptive statistics of experimental drilling results for all the input variables

The histogram distribution of the response variable obtained from experiments can be seen in Figure 6. This model produced with very low values found in P values suggests that it is logical and meaningful.

Less experimentation is required with ease of experimental design. It is saving time as a positive situation. According to the results of our 13 tests and at the same time, the average axial misalignment value in the 95% confidence interval was found 0.11777 mm.
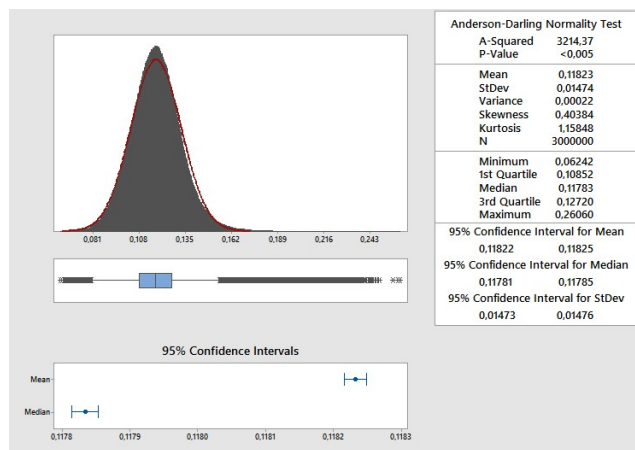

Figure 7. The result of Monte Carlo simulation

For the unpredictable ratio, Monte Carlo method produced 100 thousand random data for explanatory variables and 30 repetitions were made. Our explanatory variables are the tool rotation speed and the feed rate. As can be observed in Figure 7, the range of mean values of the Monte Carlo simulation was determined. According to the Figure 7, the mean value was quite closely with the mean value obtained from experimental results. This is the distribution of the produced data. Then, this data are produced in the generated mathematical model and axial misalignment values are generated.

It was observed that the graph obtained by experimental data and the standard deviation and average of the data produced by Monte Carlo method were close to each other. According to the results of three billion experiments, the mean value of the axial misalignment was found to be 0.11823 mm when we consider the 95% confidence interval [27].

4. CONCLUSION

In this work, the drilling characteristics and effect of the drilling parameters on the axial misalignment are studied for optimizing the drilling operations. Drilling parameters are statistically significant in controlling average axial misalignment value in flat glass machining. ANOVA analysis method was used to understand the accuracy of the model. Conclusions demonstrated that input variables are influential on the drilling operation. It is seen in our practice that there is no uncertainty as it is seen that the standard deviation of these data, which is derived by the experimental data. By incorporating Monte Carlo uncertainty analysis, not only the suggested model depends on MNLR has been made more realistic, but also to predict the surface roughness more accurately.

With the mathematical model produced, it is possible to select the cutting parameters with the optimization method for the axial misalignment value.

The axial misalignment results of the drilling parameters used in the glass drilling were optimized with statistical methods. The result of optimization the most ideal values were determined by statistical method.

From experimental results, the drilling application that optimized is considered proper for manufacturing processes. It can be applied if it provides the desired axial misalignment for industrial applications.

REFERENCES

[1] E.D. Zanotto and J.C. Mauro, "The Glassy State of Matter: Its Definition and Ultimate Fate," Journal of Non-Crystalline Solids, vol. 471, pp. 490-495, 2017.

[2] M. Sayuti, A.D. Sarhan Ahmed, and M. Hamdi, "Optimizing the Machining Parameters in Glass Grinding Operation on the CNC Milling Machine for Best Surface Roughness," Advanced Materials Research, vol. 154-155, pp. 721-726, 2011.

[3] J. Cheng, C. Wang, X. Wen, and Y. Gong, "Modeling and Experimental Study on Micro-fracture Behavior and Restraining Technology in Micro-grinding of glass," International Journal of Machine Tools and Manufacture, vol. 85, pp. 36-48, 2014.

[4] Ö. Küçükerman, "Glass Art and Examples from Traditional Turkish Glassware," Turkey Isbank Culture Publications, vol. 271, Art Series: 39, 1985.

[5] E. Axinte, "Glasses as Engineering Materials: A review," Materials and Design, vol. 32, pp. 1717-1732, 2011.

[6] B. Karasu, O. Bereket, E. Biryan, and D. Sanoğlu, "The Latest Developments in Glass Science and Technology," El-Cezerî Journal of Science and Engineering, vol. 4, no 2, pp. 209-233, 2017.

[7] S. Öztürk, "Microstructural Analysis of Metal-bond Diamond Tools in Grinding of Flat Glass, Material," Wissen Schaft Und Werkstoff Technik/Materials Science And Engineering Technology, vol. 45, no. 3, pp. 187-191, 2014.

[8] K. Habalı, H. Gökkaya, and H. Sert, "Experimental Investigation of the Effects of Cutting Tool Coating Materials on Surface Roughness in Machining of AISI 1040 Steel," Journal of Polytechnic, vol. 9, no. 1, 35-38, 2006.

[9] S. Ozturk, "Grinding of flat glass with Fe- and Cu-based diamond tools." Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, vol. 232, no. 9 pp. 1561-1568 2018.

[10] M. F. Kahraman, and S. Öztürk, "Experimental study of newly structural design grinding wheel considering response surface optimization and Monte Carlo simulation." Measurement, vol. 147, arcticle num. 106825, 2019.

[11] S. Öztürk, and M. F. Kahraman, "Modeling and optimization of machining parameters during grinding of flat glass using response surface methodology and probabilistic uncertainty analysis based on Monte Carlo simulation," Measurement, vol. 145, pp. 274-291, 2019.

[12] M. F. Kahraman, H. Bilge, and S. Öztürk, "Uncertainty analysis of milling parameters using Monte Carlo simulation, the Taguchi optimization method and data-driven modeling," Materials Testing, vol. 61, no. 5, pp. 477-483, 2019.

[13] S. Ozturk, "Application of the Taguchi method for surface roughness predictions in the turning process," Materials Testing, vol. 58, no. 9, pp. 782-787, 2016.

[14] S. Ozturk, "Application of ANOVA and Taguchi Methods for Evaluation of the Surface Roughness of Stellite-6 Coating Material," Materials Testing, vol. 56, no. 11-12, pp. 1015-1020, 2014.

[15] E. Kuram, and B. Ozcelik, "Multi-objective optimization using Taguchi based grey relational analysis for micro-milling of Al 7075 material with ball nose end mill," Measurement, vol. 46, no. 6, pp. 1849-1864, 2013.

[16] S. Ozturk, "Machinability of stellite-6 coatings with ceramic inserts and tungsten carbide tools," Arabian Journal of Science and Engineering, vol. 39, no. 10, pp. 7375-7383, 2014.

[17] M. F. Kahraman, H. Bilge, and S. Öztürk, "Uncertainty analysis of milling parameters using Monte Carlo simulation, the Taguchi optimization method and data-driven modeling," Materials Testing, vol. 61, no. 5, pp. 477-483, 2019.

[18] Ş. Bayraktar, Y. Siyambaş, and Y. Turgut, "Drilling Process: A Review," Sakarya University Journal of the Institute of Science and Technology, vol. 21, no. 2, pp. 120-130, 2017.

[19] V. Blank, M. Popov, G. Pivovarov, N. Lvova, and S. Terentev, "Mechanical Properties of Different Types of Diamond," Diamond and Related Materials, vol. 8, pp. 1531-1535, 1999.

[20] R. Calvo, R. D'Amato, E. Gómez, and R. Domingo, "A Comparative Experimental Study of an Alternative CMM Error Model Under Least-squares and Minimum Zone Fittings for İndustrial Measuring," Procedia Engineering, vol. 132, pp. 780-787, 2015.

[21] D. Kubátová, M. Melichar, and J. Kutlwašer, "Evaluation of Repeatability and Reproducibility of CMM Equipment," Procedia Manufacturing, vol. 13, pp. 558-564, 2017.

[22] M. Kayri, "The Multiple Comparison (Post-Hoc) Techniques to Determine the Difference Between Groups in Researches," Fırat University Journal of Social Science, vol. 19, no. 1, pp. 51-64 2009.

[23] Y. Dursun, and E. Kocagöz, "Structural Equation Modeling and Regression: A Comparative Analysis," Erciyes University Faculty of Economics and Administrative Sciences Journal, vol. 35, pp. 1-17, 2010.

[24] T.F. Çavuş, and E. Yanıkoğlu, "Reliability Analysis of Complex Systems with Monte Carlo Method," Sakarya University Journal of the Institute of Science and Technology, vol. 7, no. 3, pp. 99-102, 2003.

[25] A. Hançerlioğulları, "Monte Carlo Simulation Method and Mcnp Code System," Kastamonu Education Journal, vol. 14, no. 2, pp. 545-556, 2006.

[26] M. F., Kahraman, and S Öztürk, "Uncertainty analysis of cutting parameters during grinding based on RSM optimization and Monte Carlo simulation," Materials Testing, vol. 61 no. 12, pp. 1215-1219, 2019.

[27] F. Harmancı, "Optimization of Cutting Parameters During Drilling of Glass with Using Statistical Methods," Msc Thesis, Abant Izzet Baysal University Graduate School of Natural and Applied Sciences, Bolu, 2018.