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Araştırma Makalesi – Research Article

Grey Relationship Analysis of Cutting Forces and Surface Roughness in Turning using Cryo-treated and Untreated Cutting Tools

Kriyojenik İşlem Uygulanmış ve Uygulanmamış Kesici Takımlar Kullanılarak Tornalamada Kesme Kuvvetleri ve Yüzey Pürüzlülüğünün Gri İlişkiler Analizi

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ABSTRACT

The aim of this experimental study is to establish the optimum heat treatment procedure and machining parameters to obtain values of cutting force and surface roughness in machining AISI 1050 workpiece by utilizing grey relations analysis based on Taguchi method. In this regard, machining operations were carried out at three different cutting speeds and three different feed rates at a constant depth of cut. Taguchi mixed-level design L18 (2^2 3^2) was chosen for machining experiments. The optimum heat treatment and machining parameters for determination of cutting force and surface roughness values were identified according to the fact that higher the Signal/Noise ratio is better based on grey relations analysis of Taguchi method. The results showed that the optimum parameters for surface roughness and cutting forces were obtained as 0.1 mm/rev at feed rate and 180 m/min at cutting speed with cryo-treated cutting tool. According to ANOVA table and Signal/Noise ratios, it was specified that the most effective parameters on cutting forces and surface roughness were feed rate, cutting speed and heat treatment conditions, respectively.

Keywords: ***Surface Roughness, Cutting Forces, ANOVA, Grey Relations Analysis, Taguchi***

ÖZ

Gerçekleştirilen bu deneysel çalışmanın amacı, Taguchi Gri ilişkiler yöntemi kullanarak AISI 1050 çeliğinin tornalanmasında kesme kuvveti ve yüzey pürüzlülüğü değerlerini elde etmek için optimum ısıl işlem şartlarını ve işleme parametrelerini belirlemektir. Bu doğrultuda tornalama işlemleri, sabit kesme derinliğinde üç farklı kesme hızı ve üç farklı ilerleme değerlerinde gerçekleştirilmiştir. Tornalama deneyleri için Taguchi L18 (2^2 3^2) karma seviyeli tasarım dizilimi seçilmiştir. Yüzey pürüzlülüğü ve kesme kuvveti değerleri için en ideal ısıl işlem ve işleme parametreleri Taguchi Gri ilişkiler yöntemine göre sinyal/gürültü oranı en büyük en iyidir yaklaşımı ile tespit edilmiştir. Sonuçlar yüzey pürüzlülüğü ve kesme kuvvetleri için optimum parametrelerin kriyojenik ısıl işlem uygulanmış kesici takım ile, ilerleme değerinin 0,1 mm/dev ve kesme hızının 180 m/dak olduğu durumda

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elde edildiğini göstermiştir. ANOVA tablosu ve sinyal/gürültü oranlarına göre, kesme kuvvetleri ve yüzey pürüzlülüğü üzerinde en etkili parametreler sırasıyla ilerleme, kesme hızı ve ısıl işlem şartı olduğu tespit edilmiştir.

***Anahtar Kelimeler**: Yüzey pürüzlülüğü, Kesme Kuvvetleri, ANOVA, Gri ilişkiler Analizi, Taguchi*

I. INTRODUCTION

In recent years, cryogenic heat treatment, which has an important place especially in the field of manufacturing, has been used more widely every passing day. In particular, the cryogenically heat treatment, applied to cutting tools, gives the cutting tools many features such as wear resistance, strength and toughness. Thanks to these features, workpieces can be machined more easily with these cutting tools. Cryogenic heat treatment makes significant contributions to the quality of surface properties, reduction in cutting forces (Fc) and tool wear. Fc and surface roughness (Ra) obtained during turning process of workpiece are important in terms of both cost and machining time. In machining process, values of the Fc and the Ra that occur depending on the machining conditions are desired to be low as much as possible. Therefore, in recent years, many statistical tools have been used to interpret experimental results obtained in the field of machining. One of these statistical tools is Grey Relations Analysis (GRA) based on Taguchi design, by which appropriate machining parameters can be established to acquire the desired low values of the Fc and the Ra, especially in metal cutting.

Mia et al. optimized the interaction parameters of the tool-chip by using GRA. According to the results of the GRA, authors obtained that cutting speed and then feed rate were the most effective parameters on the experimental results [1]. Debnath et al. investigated the effects of cutting parameters and cutting fluid conditions, which are control factors, on Ra and tool wear, which are the responses, in the machining, by using the Taguchi design. Authors revealed that the most suitable machining conditions for the desired Ra and tool wear are medium depth of cutting, high cutting speed, low feed and low cutting fluid flow during high-speed cutting [2]. Lin revealed the impact of cutting parameters on tool life, Fc and Ra via using GRA and Taguchi method. Using the GRA, the author identified feed rate, depth of cut, and cutting speed are the most effective parameters based on results of the experiments [3]. Rao et al. investigated the Ra values being derived from turning of AA7075 workpiece depending on the cutting parameters by utilizing Taguchi L9 orthogonal array and ANOVA (Analysis of Variance). According to Taguchi results, authors found that the most important cutting parameters effective on the Ra were cutting speed and feed rate; and they achieved low Ra when optimal combination of machining parameters was selected as 0.2 mm/rev feed, 0.5 mm depth of cut and 1000 m/min cutting speed [4]. Çetin et al. applied ANOVA, regression and S/N ratio to identify the impact of machining conditions on Ra and Fc during machining of AISI 304L workpiece. They revealed that the experimental values, obtained for Ra and Fc and the values of the regression mathematical models were very close to each other. Authors also found that feed rate and depth cutting were effective on reducing Fc and improving Ra [5]. Salvi et al. analyzed the Ra values obtained in hard turning process by using the Taguchi orthogonal design. The authors observed that feed rate was more effective than cutting speed to achieve low Ra [6].Zerti et al. researched an experimental and statistical study using GRA to determine the effect of turning parameters on the Ra and productivity results obtained as a result of machining AISI D3 steel with ceramic inserts. In conclusion, authors established that cutting speed and depth of cut were the most influential machining parameters on the results of experiment (surface quality and productivity) [7]. Uzun used GRA to define the relationships between Ra, tool wear and Fc values. He applied austempering process to workpiece subjected to three different holding times and two different temperatures. According to the GRA, he achieved the conditions that gave the highest cutting performance at 375°C with a holding time of 120 minutes [8]. Bhattacharya et al. predicted the impact of machining parameters on power consumption and Ra during high-speed turning of AISI 1045 steel by using Taguchi method and ANOVA. The authors found that the cutting speed has a more significant effect than the other cutting parameters on power consumption and Ra values [9]. Tzeng et al. optimized the cutting parameters utilized in turning by using Taguchi and GRA. Consequently, authors found that the depth of cutting was the most effective parameter on Ra. Additionally; they determined the effect of the parameters on the experimental results using ANOVA [10]. Nalbant et al. conducted a study revealing the effect of optimum cutting parameters on Ra using ANOVA and Taguchi method. The authors revealed that the control factors such as cutting tool nose radius, feed rate and depth of cut have the most meaningful effect on the response parameter Ra, respectively. The percentage contributions of insert radius, feed rate and depth of cut are 48.54, 46.95 and 3.39, respectively. [11]. Günay et al. utilized Taguchi L18 to define the optimum Ra in turning workpieces has two different hardness. They found that the feed rate has an effect on the Ra values obtained from the 50 HRc workpiece surface, while the cutting speed has an effect on the Ra values obtained from the 62 HRc workpiece surface [12]. Sarıkaya and Güllü investigated the cutting parameters by utilizing GRA based on Taguchi in machining Haynes 25 specimen. According to multiple optimization results, the optimum control parameters were specified as fluid flow rate 180 m/min, cutting speed 30 m/min and cutting fluid vegetable oil [13]. Ramesh et al. used the GRA to identify the impact of turning parameters on cutting insert temperature in turning. In the light of their analysis results, authors defined that the low tool insert temperature engenders low tool insert wear

[14]. Alaba et al. examined the effect of MQL and vegetable oil on turning AISI 1039 steel using Taguchi-grey relational analysis. In their study, authors found that they improved the surface roughness by 44% and the cutting temperature by 12%. According to the grey relations analysis results, they found that the most effective parameter in terms of cutting parameters was the feed rate [15].

As a result of reviewing the literature, various statistical and experimental studies based on experimental design methods and analyses have been conducted to reveal the impacts of machining and cutting parameters on experimental results emerging from the machining of workpieces [1-15]. However, unlike the literature, no study has been found that examines the effects of heat treatment conditions and machining parameters on the Fc and Ra values resulting from turning with cryo-treated and untreated cutting tools using Taguchi GRA. The cryogenic process applied to cutting tools helps the workpieces be processed more easily by giving them properties such as wear resistance and toughness. When we look at the literature, AISI 1050 steel is widely used in many areas. For this reason, machining such a material with a cryogenically treated cutting tool will be faster and more efficient in terms of both time and cost. With this statistical and experimental study, it is aimed to reveal the parameters affecting the Fc and Ra values when machining workpiece materials in CNC lathe operations.

II. MATERIAL AND METHOD

A. Workpiece Material

AISI 1050 steel is a medium carbon steel that includes about 0.5% carbon and is often utilized in a wide range of applications due to its good machinability and combination of mechanical characteristics. Microstructure of this material, it consists of a fine lamellar perlitic structure that has 20 µm average column length in the primer ferritic matrix. Because of the lamellar cementite phases AISI 1050 contain, the formability and machinability of medium and high carbon steels are quite difficult, and they raise the cost. So, their fatigue, impact toughness, ductility and machining behavior can importantly be improved with spheroidizing heat treatment which is conducted with long-time annealing about at eutectoid transformation temperatures. In the experiments, AISI 1050 steel, which is widely used in general use and is often utilized in the production of machine components, was utilized as the workpiece material. The dimensions of the workpiece were prepared as 60 mm in diameter and 300 mm in length. The workpiece was longitudinally turned at a depth of cutting of 1.5 mm to eliminate surface defects arising from the manufacturing phase. At the end of this process, the workpieces were made ready for experiments.

B. Cutting Tools and Tool Holder

Turning experiments were performed by a CNC lathe by using a CVD coated WC-Co insert with the ISO-1832 code WNMG and a chip breaker form MP, which is recommended for the processing of medium carbon steels. This insert is a cutting tool suitable for medium cutting for stainless and carbon steels. PWLNR 2525M08 tool holder and WNMG inserts were used in machining experiments. The cutting insert was chosen as CVD coated carbide (TiCN + Al_2O_3 + TiN). The properties of cutting tool geometry are represented as follow: clearance angle: 0^0, corner radius: 0.8 mm, rake angle: 7^0, approach angle: 95^0, side cutting edge angle: 5^0. The picture of this cutting insert is given in Figure 1.

Figure 1. WNMG insert utilized in the experiments

C. Identifying Cutting Parameters and Machining Experiments

For machining experiments, the AISI 1050 workpieces supplied with a diameter of 60 mm were reduced to 57 mm in diameter to clean the outer surface. Then, after their faces were machined and tailstock holes were formed, the workpiece became ready for processing. The machining parameters utilized in the cutting experiments were determined by taking into account the recommendations of the cutting tool manufacturer and ISO 3685 requirements. Accordingly, machining parameters in turning experiments were determined as given in Table 1.

Table 1. Machining parameters used in cutting experiments

Feed rate (mm/rev)	0.1, 0.2, 0.3
Cutting Speed, V (m/min)	180, 200, 220
Depth of cutting, a (mm)	2

D. Measurement of Ra and Fc

According to the specified machining conditions, Ra value of the surfaces after machining tests was measured with the portable "Hommel T500 Tester" device. Ra values were estimated by taking the arithmetic mean of the values taken from three separate measurements performed 4.8 mm long from the workpiece surface. The cutting force (Fc) acting on the tool during machining experiments were measured using a KISTLER 5070 dynamometer.

E. Cryogenic Heat Treatment

In the light of the literature research, it has been understood that the cryogenic heat treatment applied to cutting inserts is generally subjected to a period of 24 hours [16, 17]. Therefore, deep cryogenic heat treatment was applied to the CVD-coated cutting insert used for turning experiments at -146 °C. The schematic stages of this cryogenic process are given in Figure 2. It is seen that the cutting tools were placed in the heat treatment furnace and the furnace temperature was gradually reduced to -146 °C under computer control. Then, the cutting tools were kept in the oven at -146 °C for twenty-four hours. Finally, the cutting tools in the oven were gradually brought back to room temperature. The final phase change of the cutting tools was completed by tempering heat treatment twice by increasing the room temperature furnace to 200 °C.

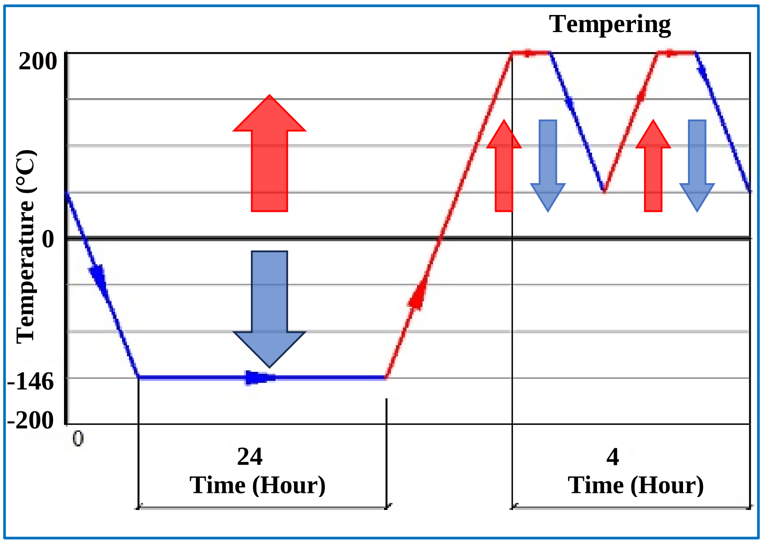

Figure 2. Cryogenic process diagram

F. Grey Relations Analysis

In this experimental study, GRA based on Taguchi was utilized to optimize the effects of heat treatment type and machining parameters on Ra and Fc values. In grey relationships, the first step to normalize the values is to convert the values to values in the range of zero and one. In this method, the most important thing in normalizing the factors affecting the results is the chosen approach. At this stage, if small impact factor values are a desired feature, the values close to "0" are chosen, while the values close to "1" are selected for large values in normalization [18,19].

The Ra and Fc values obtained in the turning process with cryo-treated and untreated cutting tools were normalized between zero-one (0-1). Three different approaches can be used to normalize the values attained as a result of the experiments:
If "Lowest is best", the test results are normalized as follows:

$$y_i(k) = \frac{max x_i^0(k) - x_i^0(k)}{max x_i^0(k) - min x_i^0(k)} \tag{1}$$

Where, $y_i(k)$, $minx_i^0(k)$, $maxx_i^0(k)$ and $x_i^0(k)$ correspond to the GRA, minimum values, maximum values and normalization values, respectively. In the GRA, while defining GRA degree, the relation degree of 18 series (y0 (k) ve yi (k), i=1, 2, 3, ….28; k=1,2) is defined. The GRA coefficient ξi (k) is determined by using following equations:

$$\xi_i(k) = \frac{\Delta_{min} - \partial\Delta_{max}}{\Delta_{oi}(k) - \partial\Delta_{max}} \quad (2)$$

$$\Delta_{oi}(k) = \|y_o(k) - y_i(k)\| \quad (3)$$

$$\Delta_{max} = max_{\forall j \in i}\, max_{\forall k} \|y_o(k) - y_i(k)\| \quad (4)$$

$$\Delta_{min} = min_{\forall j \in i}\, min_{\forall k} \|y_o(k) - y_i(k)\| \quad (5)$$

In the equations 2-5, ∂ = discrimination coefficient (0-1), $\partial = 0.5$ is generally taken in the literature, $\Delta_{oi}(k)$ the absolute deviation value between $y_o(k)$ and $y_i(k)$ and [17, 18]. $\Delta_{\max}$, is the maximum value of Δ_{oi}values, and Δ_{min} is the minimum value. GRA degree (ϒi) is attained by averaging the GRA formation coefficients and this degree can be found by using following equation:

$$\Upsilon_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad (6)$$

In Equation 6, the symbol n represents the GRA coefficient attained from normalized response values. A high degree of GRA occurrence shows a strong connection between $y_i(k)$ and $y_o(k)$. When two series with the same values are compared, the GRA degree becomes 1.

G. Taguchi Signal/Noise (S/N) Ratio

Taguchi method S/N ratio has been utilized by many researchers in the analysis of data that obtained from experimental [1, 7, 14, 20]. In Taguchi design, the desired value for the output characteristic is called Signal (S), and the undesirable value for the output characteristic is called Noise (N). In this study, the S/N ratio equation was used according to the “larger is better” approach in the Taguchi L18 (2^2 3^2) mixed array. Because the higher the analysis degree of grey relationships (closer to 1) indicates that the relationship is better. Therefore, experimental results were evaluated according to the “larger is better” approach. In the analysis of experimental values, 3 types of S/N ratio formulas were used in Taguchi design: “nominal is better” (Equation 7), “smaller is better” (Equation 8) and “larger is better” (Equation 9). These formulas are given below:

$$S/N = 10\log\left(\frac{\bar{y}^2}{s^2}\right) \quad (7)$$

$$S/N = -10log\frac{1}{n}\left(\sum_{i=1}^{n} y_i^2\right) \quad (8)$$

$$S/N = -10log\frac{1}{n}\left(\sum_{i=1}^{n} \frac{1}{y_i^2}\right) \quad (9)$$

In Equation 9, $\bar{y}$; where yi represents the calculated values for Fc and Ra, while n and s represent the number of experiments performed and the standard deviation of the response values, respectively.

H. ANOVA

In ANOVA, which is a statistical method, there are two types of variables: control factors and response results. The aim of ANOVA is to find out which control factors are affective on the response values. The significant of control factors in an ANOVA table is defined by the P value of each control factor. If P value is less than 0.05, it is considered "statistically meaningful" in scientific parlance. Additionally, it reveals how affective each control factors indicated in the ANOVA table is on the response value of PCR value. An ANOVA table contains percentage contribution ratios (PCR), statistics (F), degrees of freedom (DF), sum of squares (SD), mean of squares (MS), and P values demonstrating the level of significance of each control factor on the response [21-23].

III. STATISTICAL ANALYSIS AND DISCUSSION

A. Grey Relation Analysis

Taguchi mixed array, representing the turning results attained based on values of the Ra and Fc obtained from the machined workpieces at a constant depth of cutting, with 3 different cutting speeds and feeds, was designed as L18 (2^2 3^2). The Taguchi mixed array corresponding to the experimental sequence performed according to L18 experimental setup and the responses are given in Table 2. When the control factor and response values in Table 2 are analyzed, it is seen that responses such as Ra and Fc values change according to the change in control factors such as heat treatment type and cutting parameter. The heat treatment type numbers in Table 2 indicate "cryo-treated cutting insert" with number 1 and "untreated cutting tool" with number 2. In determining GRA based on Taguchi for responses such as Ra and Fc, the average grey relational degree was calculated for that parameter after the same level values were collected and averaged. For the second levels, this process is repeated to create a response table for the Grey relational degrees. The calculated grey relations degree and ranking of measurement results of the Fc and the Ra, their normalized values and the absolute deviation values obtained are shown in Table 3.

Table 2. Taguchi L18 (2^2 3^2) mixed array, Ra and Fc values

Experiment No	Heat Treatment Type	Cutting Speed	Feed	Fc, Fc	Ra, Ra
1	1	180	0.1	599	0.517
2	1	180	0.2	948	0.967
3	1	180	0.3	1306	1.058
4	1	200	0.1	588	0.563
5	1	200	0.2	933	1.077
6	1	200	0.3	1280	1.123
7	1	220	0.1	577	0.653
8	1	220	0.2	926	1.16
9	1	220	0.3	1255	1.2
10	2	180	0.1	588	0.548
11	2	180	0.2	935	1.057
12	2	180	0.3	1289	1.15
13	2	200	0.1	576	0.62
14	2	200	0.2	925	1.11
15	2	200	0.3	1277	1.257
16	2	220	0.1	566	0.737
17	2	220	0.2	910	1.28
18	2	220	0.3	1247	1.333

For each experiment performed, GRA coefficients and GRA degrees were calculated with these coefficients. While estimating the coefficients, the discriminant coefficient was taken as ∂=0.5 [17, 18]. The GRA coefficient given in Table 3, with a value of 1, shows the highest relationship between Ra and Fc values. When Table 3 is examined, it is understood that experiment no one (1) is the highest value among the GRA degrees. It can be understood from Table 3 that this type of heat treatment has cryo-treated, feed rate 0.1 mm/rev and cutting speed 180 m/min values.

Table 3. Rankings for L18 mixed array, calculated Grey relational coefficient, normalized values and Grey relational degree

Experiment No	Normalized Values		Grey Relational Coefficient		Grey Relational Degree	Ranking
	Fc	Ra	Fc	Ra		
1	**0.9554**	**1.0000**	**0.9181**	**1.0000**	**0.959**	**1**
2	0.4838	0.4485	0.4920	0.4755	0.484	7
3	0.0000	0.3370	0.3333	0.4299	0.382	13
4	0.9703	0.9436	0.9439	0.8987	0.921	3
5	0.5041	0.3137	0.5020	0.4215	0.462	9
6	0.0351	0.2574	0.3413	0.4024	0.372	14
7	0.9851	0.8333	0.9711	0.7500	0.861	5

8	0.5135	0.2120	0.5068	0.3882	0.448	11
9	0.0689	0.1630	0.3494	0.3740	0.362	16
10	0.9703	0.9620	0.9439	0.9294	0.937	2
11	0.5014	0.3382	0.5007	0.4304	0.466	8
12	0.0230	0.2243	0.3385	0.3919	0.365	15
13	0.9865	0.8738	0.9737	0.7984	0.886	4
14	0.5149	0.2733	0.5075	0.4076	0.458	10
15	0.0392	0.0931	0.3423	0.3554	0.349	17
16	1.0000	0.7304	1.0000	0.6497	0.825	6
17	0.5351	0.0650	0.5182	0.3484	0.433	12
18	**0.0797**	**0.0000**	**0.3520**	**0.3333**	**0.343**	**18**

B. Results of S/N Ratio

In this experimental study, the effects of machining parameters such as cutting speeds and feed rate on responses such as Ra and Fc which obtained the cryo-treated and untreated cutting insert were optimized with the GRA based on Taguchi. The experiments were performed according to Taguchi L18 (2^2 3^2) mixed array and the control factors were taken as heat treatment type (cryo-treated and untreated) and cutting speeds (180, 200 and 220 m/min) and feed (0.1, 0.2 and 0.3 mm/rev). The heat treatment type was determined as two levels, the cutting speed and feed rate were determined as three levels, and the response values were determined as Ra and Fc values. Response values were optimized S/N ratio values GRA based on Taguchi. With the rankings attained as a result of grey relations, the effects of heat treatment type, cutting speed and feed rate on Ra and Fc values were investigated, depending on S/N ratio. The control factors such as heat treatment type, cutting speed and feed rate and their levels utilized in the turning experiments are indicated in Table 4.

Table 4. Control factors and their levels

Control Factors	Factors Levels		
	Level 1	**Level 2**	**Level 3**
Heat Treatment Type	1 (Cryo-treated)	2 (Untreated)	
Cutting Speed, m/min	180	200	220
Feed rate, mm/rev	0.1	0.2	0.3

The graph obtained according to responses values calculated by S/N ratios and GRA based on Taguchi and showing the effects of their interrelationships on values of the Ra and Fc according to heat treatment type and machining parameters are given in Figure 3.

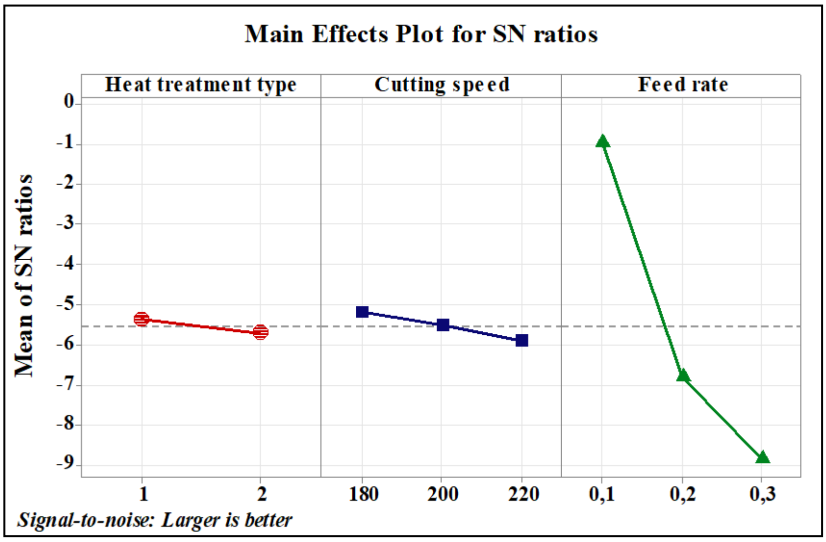

Figure 3. Signal noise (S/N) ratio main effect graph for responses

Looking at the average of S/N ratios graph in Figure 3, the optimum machining parameters for values of Ra and Fc were obtained as heat treatment type cryo-treated cutting insert, cutting speed 180 m/min and feed rate

0.1 mm/rev. S/N ratio values calculated according to GRA based on Taguchi L18 mixed array are presented in Table 5. When Table 5 is analyzed, according to S/N ratios, it has been defined that the heat treatment type, cutting speed and feed values are at the first level among all control factors, making responses such as Ra and Fc values optimum.

Table 5. S/N ratios calculated according to grey relations degree

Level	Heat Treatment Type	Ra	Fc
1	**-5.3528**	**-5.1660**	**-0.9453**
2	-5.6874	-5.5009	-6.7831
3		-5.8933	-8.8320
Delta	0.3345	0.7274	7.8867
Ranking	3	2	1

In other words, the delta value represents the effect of the control factors on the responses. In other words, the delta value shows heat treatment type, cutting speed and feed rate on responses such as Ra and Fc. Here, both the "Delta" value and the ranking in Table 5 show that feed rate is the most effective control factor on responses. When ranking values in Table 5 are looked into, it can be seen that feed rate, cutting speed and heat treatment type are effective on responses, respectively. From the results given for the control factor values in Figure 3 and Table 5, it is understood that the optimum responses (Ra and Fc) occur with a cryo-treated cutting tool, cutting speed of 180 m/min and feed rate of 0.1 mm/rev. As a result, according to S/N ratios calculated by GRA based on Taguchi design, the feed rate is determined to be the most significant and effective factor on Ra and Fc values.

C. Results of ANOVA

Statistically tool that indicates the effect of control factors such as heat treatment, cutting speed and feed rate on response values such as Ra and Fc is ANOVA results. In the assessment of ANOVA results, according to the GRA, the response values are the Ra and Fc results, while the control factors are heat treatment type, cutting speed and feed. ANOVA results based on GRA and S/N ratio values are given in Table 6.

Table 6. ANOVA values for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Importance
Heat treatment type	1	0.001972	0.001972	0.001972	5.20	0.042	**Significant**
Cutting speed	2	0.008628	0.008628	0.004314	11.38	0.002	**Significant**
Feed rate	2	0.980206	0.980206	0.490103	1292.30	0.000	**Significant**
Residual error	12	0.004551	0.004551	0.000379			
Total	17	1260.2					

In statistically analyses, whether the value of control parameter is statistically meaningful or not can be stated with "P" value. If "P" control factor value is less than 0.05, it is meaningful; if it is greater, it is not meaningful [21-23]. When "P" control factors in Table 6 are analyzed to display the effect of control factors on the response values, it is concluded that the heat treatment type, cutting speed and feed (0.042-0.002 and 0.000 <0.05) were statistically significant. Additionally, the effect of control factors such as heat treatment, cutting speed and feed rate on the response values such as Fc and Ra can be evaluated by looking at "F" value in Table 6. Here, a large "F" value means that the importance value on the response values of the control factors is high. In this direction, it has been comprehended that the most effective parameter on responses (Fc and Ra) are feed rate.

IV. CONCLUSION

In this study, response; the Fc and Ra values which attained in turning AISI 1050 steel with cryo-treated and untreated cutting tools at a constant depth of cutting, with three different feed rates and cutting speeds, were optimized with GRA based on Taguchi. The results obtained from the analysis of GRA based on Taguchi are given below:

- According to S/N ratio values calculated by GRA based on Taguchi, it was defined that feed rate, one of the cutting parameters, is the most effective factor on response values (Ra and Fc).
- Depending on Taguchi-based grey relations ranking and S/N ratios, it was seen that feed rate, cutting speed and heat treatment type were the factors affecting the Fc and Ra values, respectively.

- According to the grey relations ranking and S/N ratios, the heat treatment type cryo-treated, which optimizes response values (Ra and Fc), was obtained at a cutting speed of 180 m/min and a feed rate of 0.1 mm/rev.
- According to the grey relations ranking, the best conditions in the ranking of Ra and Fc values were realized in experiment number one, while the worst conditions were realized in experiment number eighteen. In other words, the best machining conditions are achieved with cryo-treated cutting tool, the cutting speed is 180 m/min and the feed rate is 0.1 mm/rev, while the worst machining conditions are achieved with untreated cutting tool, the cutting speed is 180 m/min and the feed rate is 0.3 mm/rev.
- The results of statistical obtained from experimental data and GRA based on Taguchi design have shown that it is an analysis and experimental design that can be successfully applied in machining operations such as turning.

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