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Research Article

Optimisation of Machining Parameters ın Turning 17-4 Ph Stainless Steel Using the Grey-Based Taguchi Method

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ABSTRACT

In this study, an experimental optimization on cutting forces and surface roughness in turning of 17-4 PH stainless steel using wiper and conventional insert cutting tools with dry cutting condition were presented. The influences of feed rate, depth of cut, and corner radius on surface roughness and cutting force were examined. In order to optimize the turning process, Grey Relational Analysis optimization method was used. The influence of each parameter on obtained results was determined by using analysis of variance (ANOVA). The relationship between dependent parameters and independent parameters were modeled by Regression analysis. The optimal machinability of 17-4 PH stainless steel with coated carbide insert was successfully determined in this study.

Keywords: Grey Relational Analysis, ANOVA, Taguchi method, Cutting Geometry

17-4 Ph Paslanmaz Çeliğin Tornalama İşleminde Taguchi Metodu İle Grey-Based Optimizasyonu

ÖZ

Bu çalışmada; 17-4 PH paslanmaz çeliğin silici ve geleneksel kesici uçlar ile kuru şartlarda tornalanmasının kesme kuvvetleri ve yüzey pürüzlülüğüne etkileri gri tabanlıtaguchi optimizasyonu sunulmuştur. İlerleme oranının, kesme derinliğinin ve köşe radisünün kesme kuvveti ve yüzey pürüzlülüğü üzerine etkileri incelendi. Gri ilişki analiz optimizasyon metodu kullanıldı. Her bir parametrenin elde edilen sonuçlara etkisinin tayini içinde varyans analizi (ANOVA) kullanılmıştır. Bağımlı değişkenlerle bağımsız değişkenler arasındaki ilişki regresyon analizi ile modellendi. Bu çalışmada 17-4 PH paslanmaz çeliğin kaplamalı karbid uç ile optimal işlenebilirliği tayin edildi.

Anahtar kelimeler: Gri ilişki analizi, Taguchi, ANOVA, Kesici geometrisi

1.Introduction

Machining has maintained its importance for years and the researches in this field have been closely followed by the manufacturers. Every act of manufacturing has a cost and there are several factors which determine cost. The cost of cutting tools and the cost of the workpiece can be considered as the two important factors in question. Thus, to lower the manufacturing cost and buy the product on cheaper, those factors should be taken into consideration.

For the cutting tools to be long lived and to prevent the waste of the raw material by

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producing the workpiece at the required level of quality, the need for the optimization of the cutting performance and conditions has arisen. To achieve that, the factors which affect the life of the cutting tools and the determination of the quality of the workpiece have been searched by the scientists. (Shaw, 2005).The researches have revealed the fact that there are a number of parameters and conditions in turning, which affect the above-mentioned points (Cakir, 2000). Tool manufacturers are continuously improving their materials, offering new coatings for cutting edges and modifying the geometry of cutting inserts. These are geometric properties of the cutting tool, tip angles, approach angle, feed, cutting speed, depth of cut, coatings, cooling liquid, chip breaker form, work piece, rigidity of the cutting tool, wiper geometry etc. (Kurt, 2006), (Lin, Lee, et al., 2001). Wiper geometry is assembled by three curves to form a circular arc edge. The nose of wiper provides less profile height on the surface that is formed by the cutting edge, resulting in a smooth turning surface. Insert with wiper has high efficiency when used for finish and semi-finish turning. The surface quality remains the same even at double feed rate. (Stachurski, 2012).

These parameters being selected suitable to the property of workpiece material reduces the cost of manufacturing and the applied energy with lengthening the life of the cutting tool and the surface quality of the manufactured product (Saglam, et al., 2007), (Gokkaya and Nalbant, 2006). When all these factors are taken into consideration, it is obvious that the selection of the cutting parameters in turning is very essential. (Field, et all., 1989).

The machining of stainless steel inherently generates high cutting temperature, which not only reduces tool life but also impairs the workpiece surface quality. (Ay and Basmaci, 2015), (Noordin et al., 2007), (Korkut and Kasap, 2004). One of the stainless steel family materials most commonly used in the production facility is steel with austenitic structure. (Jawahir et al., 2011), (Elbah et al., 2013). The austenitic stainless steels structure is a combination of good mechanical properties and good corrosion resistance. (Grzesik and Wanat, 2006). The three primary factors in turning operation are speed, feed, and depth of cut. Other factors such as kind of material, environment and type of tool have a large influence, so these three are the ones the operator can change by adjusting the controls, right at the machine. (Sheth et al., 2016). It is a challenging task to machine these high strength materials. Although there have been many methods evolved to machine such materials, such techniques are expensive and costly cutting tools are required to machine those materials. (Palanisamy and Senthil, 2016).

In this study, an experimental investigation on cutting forces and surface roughness after machining in turning of 17-4 PH stainless steel using wiper and conventional insert cutting tools were presented. The influences of feed rate, depth of cut, corner radius, dry cutting condition on surface roughness and cutting force were examined. In order to optimize the turning process, Grey Relational Analysis Taguchi optimization method was used. The influence of each parameter on obtained results was determined by using analysis of variance (ANOVA). The relationship between dependent parameters and independent parameters were modelled by regression analysis. The optimal machinability of 17-4 PH stainless steel with coated carbide insert was successfully determined in this study.

2. Materials and Methods

2.1. Materials

The samples used in the experimental study were in the shape of stick. Their length was 130 mm and diameter was 25 mm. Chemical composition of 17-4 PH stainless steel were presented in Table 1. A JOHNFORD TC 35 CNC Fanuc 0T CNC lathe was used.

Table 1. Chemical composition

C	Mn	Cr	Mo	Ni	Co	Cu
0.04	0.78	15.9	0.40	4.69	0.06	3.4

In the experimental study, KENNAMETAL KC5010 PVD TiAlN coated conventional (FF) and wiper (FW) inserts were used. The surface roughness value and hardness on the work-piece obtained after the machining process was measured by MAHR-Perth meter and three measurements were performed on the machined surfaces determine the Ra values. For the force measurements, KISTLER 9121 force sensor, KISTLER 5019b charge amplifier and DynoWare analysis program were used. Schematic drawing of the experimental set up is given in Figure 1.

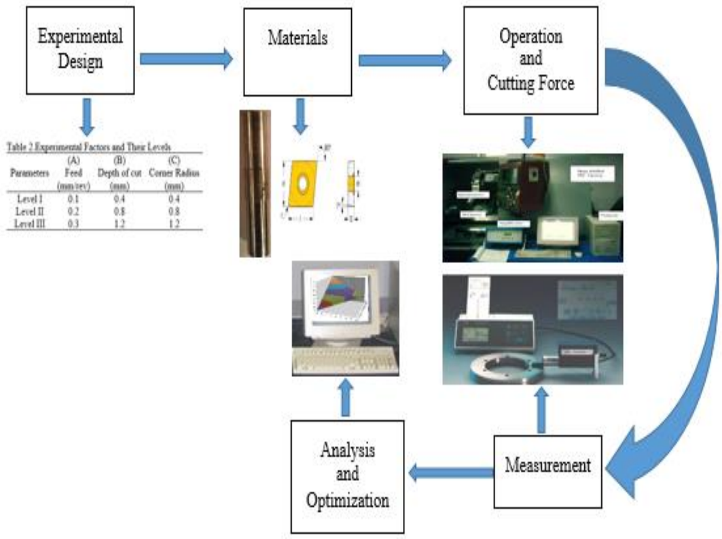


Figure 1. Experimental set up

2.2. Methods

2.2.1. Experimental Design

For the experimental design Taguchi method was employed.

$$S / N(\eta) = -10x \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad \textbf{(1)}$$

Experimental factors and their levels were presented in Table 2 and L9 experiment design in Table 3.

Table 2. Experimental Factors and Their Levels

Parameters	(A) Feed (mm/rev)	(B) Depth of cut (mm)	(C) Corner Radius (mm)
Level I	0.1	0.4	0.4
Level II	0.2	0.8	0.8
Level III	0.3	1.2	1.2

Table 3. Taguchi L9 experiment design

Experiment No.	Variables	(A) f (mm/rev)	(B) d (mm)	(C) r (mm)
1	$A_1B_1C_1$	1	1	1
2	$A_1B_2C_2$	1	2	2
3	$A_1B_3C_3$	1	3	3
4	$A_2B_1C_2$	2	1	2
5	$A_2B_2C_3$	2	2	3
6	$A_2B_3C_1$	2	3	1
7	$A_3B_1C_3$	3	1	3
8	$A_3B_2C_1$	3	2	1
9	$A_3B_3C_2$	3	3	2

3. Taguchi Based Grey Relational Analysis Method

The obtained experimental results and the determined parameters were optimized with Grey Based Taguchi method. Using regression model, researches were carried out calculating an equation between dependent parameters and independent parameters. The Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only.

Experimental design was done using Taguchi method. Hence, it has been possible to reach more comprehensive results with doing less experiment. In this sense, time and money have been used more efficiently. (Yang and Tarng, 1988). While only outcome is optimized in the Taguchi Method, multiple outcomes can be optimized in a Grey Relational Analysis (Venkatesan et al., 2014).

In this study, Taguchi Method was used in the experimental design step, Grey Relational Analysis Method was used in the optimization step.

Grey relational analysis optimization process was carried out in the following three steps. (Kurt et al., 2012).

1.Normalization of experimental results (the lowest-the best)

2.Calculation the Grey Relational Coefficient

3.Calculation of the Grey Relational Degree

4.Determination of optimal experiment parameters

In the normalization step, the experimental results were normalized using the blow equation according to 'the lowest-the best'**.**

$$x_i\,(k)=\frac{\max yi(k)-yi(k)}{\max yi(k)-\min yi(k)} \qquad (2)$$

Where, xi (k) refers to the value at the i series and k row after normalization process, min yi (k) refers to the minimum value at the i series, max yi (k) refers to the maximum value at the i series and yi (k) refers to the original value at the i series and k row.

The step 2, Grey Relational Coefficient was calculated via equation (3);

$$\xi_i\,(k)=\frac{\Delta min+\zeta\,\Delta max}{\Delta 0i\,(k)+\zeta\,\Delta max} \qquad (3)$$

Here, ζ is a distinguishing coefficient between 0 and 1. Δ0i is the amount of deviation between the reference series and the normalization values. Δmin refers to the minimum value of the deviation sequence from the reference series and Δmax refers to the maximum value of deviation sequence from the reference series.

The step 3, Grey Relational Degree was calculated by equation (4);

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi i\,(k) \qquad (4)$$

4. Result And Discussion

Influence of the cutting parameters and the effect of cutting geometry and parameters on surface roughness (Ra) and cutting force (N) on turning of a 17-4 PH stainless steel with KENNAMETAL KC5010 PVD TiAlN coated conventional (FF) and wiper (FW) inserts has been discussed in this section.

4.1. *Optimization of Experimental Results and ANOVA for surface roughness and cutting force*

In the experimental step, Taguchi L9 experiment design, surface roughness, cutting force values were shown in Table 4.

Table 4. Taguchi L_9 experiment design, surface roughness and Cutting force,

Experiment No.	Variables	Surface Roughness, Ra (µm) (FF)	Surface Roughness, Ra (µm) (FW)	Cutting Force (N) (FF)	Cutting Force (N) (FW)
1	$A_1B_1C_1$	1,02	0,81	153,42	178,71
2	$A_1B_2C_2$	0,84	0,68	175,14	260,76
3	$A_1B_3C_3$	0,63	0,55	209,05	342,22
4	$A_2B_1C_2$	1,04	0,87	180,55	216,54
5	$A_2B_2C_3$	1,32	0,95	269,59	370,56
6	$A_2B_3C_1$	1,69	1,37	353,65	373,28
7	$A_3B_1C_3$	1,26	1,02	216,1	272,4
8	$A_3B_2C_1$	2,37	1,75	303,18	348,67
9	$A_3B_3C_2$	1,95	1,29	373,97	390,53

Grey Relational Analysis Method was applied to the experimental results shown in Table 4, and the first step (normalization) results were given in Table 5.

Table 5. Normalization results

Exp.No.	Surface Roughness, Ra (µm) (FF)	Surface Roughness, Ra (µm) (FW)	Cutting Force (N) (FF)	Cutting Force (N) (FW)
1	-0,010	0,349	1,308	1,262
2	0,297	0,571	1,268	1,114
3	0,656	0,793	1,207	0,967
4	-0,044	0,246	1,259	1,194
5	-0,523	0,109	1,098	0,916
6	-1,156	-0,779	0,947	0,911
7	-0,421	-0,010	1,195	1,093
8	-2,318	-1,600	1,038	0,956
9	-1,600	-0,301	0,910	0,880

Then, the deviations from the reference series were calculated and the results were given in Table6.

Table 6. Values of the deviation from the reference value

Exp.No.	Surface Roughness, Ra (μm) (FF)	Surface Roughness, Ra (μm) (FW)	Cutting Force (N) (FF)	Cutting Force (N) (FW)
1	1,010	0,651	-0,308	-0,262
2	0,703	0,429	-0,268	-0,114
3	0,344	0,207	-0,207	0,033
4	1,044	0,754	-0,259	-0,194
5	1,523	0,891	-0,098	0,084
6	2,156	1,609	0,053	0,089
7	1,421	1,010	-0,195	-0,093
8	3,318	2,258	-0,038	0,044
9	2,600	1,472	0,090	0,120

The Grey Relational Coefficients were calculated using the equation 2 and shown in Table 7.

Table 7. The Grey Relational Coefficients

Exp.No.	Surface Roughness, Ra (μm) (FF)	Surface Roughness, Ra (μm) (FW)	Cutting Force (N) (FF)	Cutting Force (N) (FW)
1	0,331	0,434	2,598	2,101
2	0,416	0,538	2,159	1,295
3	0,593	0,707	1,708	0,938
4	0,324	0,399	2,072	1,633
5	0,247	0,360	1,244	0,856
6	0,188	0,237	0,903	0,849
7	0,260	0,331	1,637	1,229
8	0,131	0,181	1,081	0,918
9	0,161	0,254	0,847	0,807

The Grey Relational Degrees related to each experiment result was calculated and the experiments results were ranked in order from highest Grey Relational Degree to present in Table 8.

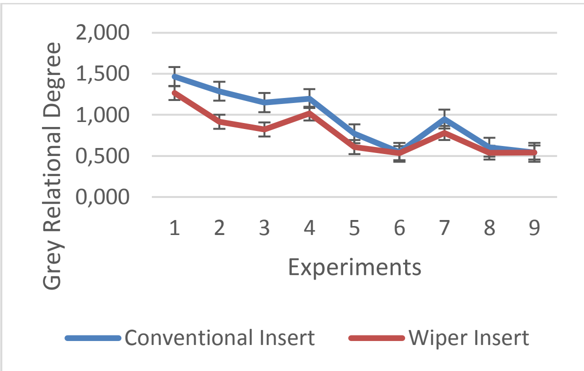


Figure 2. Grey Relational Degrees for each experiments

Table 8. Grey relational degrees of the factor levels for conventional insert tool

Levels	(A) Feed (mm/rev)	(B) Depth of cut (mm)	(C) Corner Radius (mm)
Level 1	**1,301**	**1,204**	0,872
Level 2	0,830	0,880	**0,996**
Level 3	0,686	0,733	0,948

As seen from the Table 8, A1 (feed: 0.1mm/rev), B1 (depth of cut: 0.4mm), and C2 (corner radius: 0.8 mm) were selected as the optimal parameter levels on the results. The optimal parameters levels will represent the lowest surface roughness and cutting force value.

4.1. *Evaluation of surface roughness results*

In general, the obtained roughness value has been between 0.55-2.37 µm, which meets the expectations. The surface roughness values obtained as a result of those 18 experiments are shown in Figure 4.

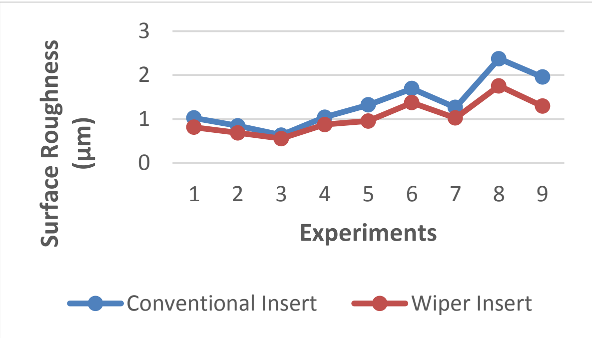


Figure 3. The surface roughness results

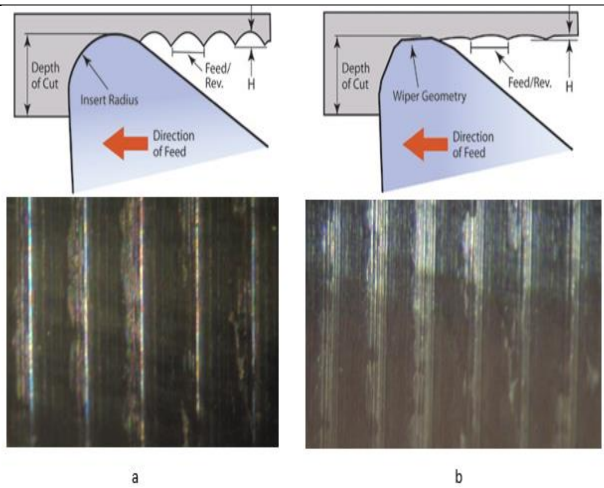


Figure 4. The surface roughness results for (a) conventional and (b) wiper insert

4.2. *Evaluation of Cutting Forces Results*

In general, the obtained cutting force value has been between 153.42- 390.53 N, which meets the expectations. The cutting force values obtained as a result of those 18 experiments are shown in Figure 5.

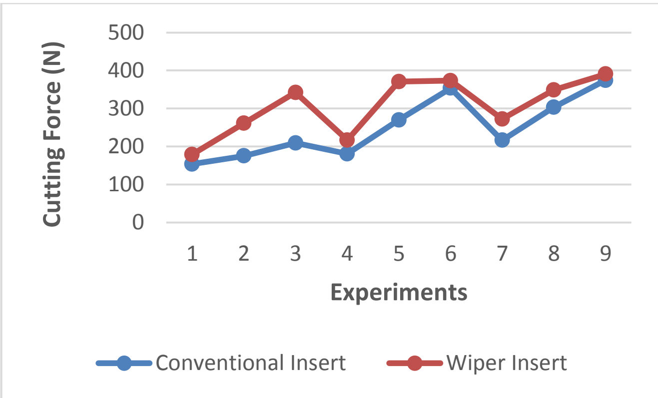


Figure 5. The cutting force results

4.3.Evaluation of ANOVA Results

In turning of 17-4 PH stainless steel, nine experiments have been carried out using three different factors at three different levels and different Ra, and N values have been obtained from each experiment. Whether these differences are only a coincidence or result from the factors and the influence of each factor in this answer will be determined by the analysis of variance.

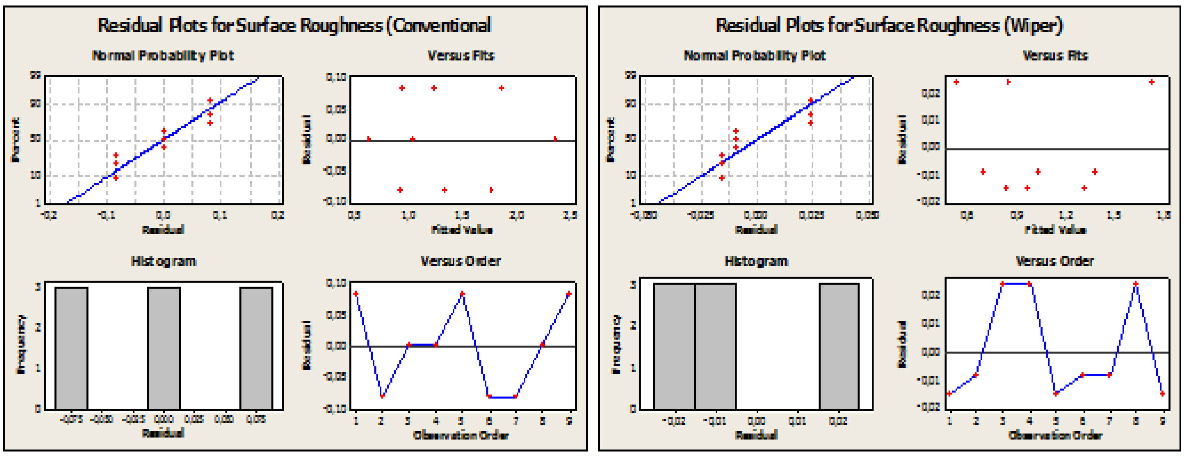
The ANOVA results of the average values of surface roughness are presented in Figure 6, Table 9 and 10. As a result of the machining of 17-4 PH stainless steel with conventional and wiper insert cutting tools, the feed with a proportion of 51.70% and 48.88% has been the most effective factor in the formation of the roughness on the machined surface.

Table 9. ANOVA result Ra for conventional insert

Notations	Degree of freedom	Sum of Squares	Variables	F Ratio	Percentage Ratio (%)
A	2	1.03740	0.51870	20.39	48.88
B	2	0.17407	0.08703	3.42	08.19
C	2	0.87927	0.43963	17.9	42.91
Error (e)	2	0.05087	0.02543		0.02
Total	8	2.14160			100

Table 10. ANOVA versus Ra for wiper insert

Notations	Degree of freedom	Sum of Squares	Variables	F Ratio	Percentage Ratio (%)
A	2	0.75709	0.37854	25.73	51.70
B	2	0.13016	0.06508	4.42	8.88
C	2	0.57696	0.28848	19.61	39.40
Error (e)	2	0.02942	0.01471		0.02
Total	8	1.49362			100



a b

Figure 6. The ANOVA analysis for rate of graphic and feed rate on surface roughness (a) conventional and (b) wiper insert

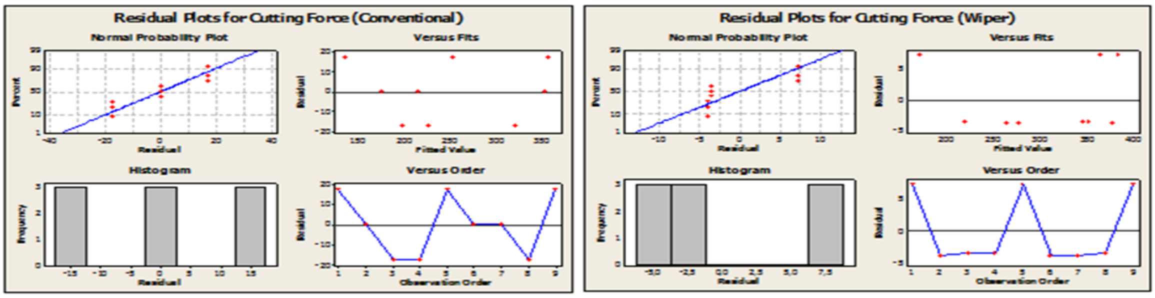
The ANOVA results of the average values of cutting forces are presented in Figure 7, Table 11 and 12. As a result of the machining of 17-4 PH stainless steel with conventional and wiper insert cutting tools, the depth of cut with a proportion of 73.6% and 49.76% has been the most effective factor in the formation of the cutting force on the machining.

Table 11. ANOVA versus cutting forces for conventional insert

Notations	Degree of freedom	Sum of Squares	Variables	F Ratio	Percentage Ratio (%)
A	2	22815.0	11407.5	12.61	45.57
B	2	24914.5	12457.3	13.77	49.76
C	2	2339.6	1169.8	1.29	04.66
Error (e)	2	2339.6	120.1		0.01
Total	8	1809.6			100

Table 12. ANOVA versus cutting forces for wiper insert

Notations	Degree of freedom	Sum of Squares	Variables	F Ratio	Percentage Ratio (%)
A	2	9712.5	4856.2	40.44	21.06
B	2	33957.7	16978.9	141.38	73.64
C	2	2443.6	1221.8	10.17	05.29
Error (e)	2	240.2	120.1		0.01
Total	8	46354.0			100



a b

Figure 7. The ANOVA analysis for rate of graphic and feed rate on cutting force (a) conventional and (b) wiper insert

4.4. Evaluation of Regression Analysis Results

Regression models aim to determine the relationship between variables where a cause and effect relationship is estimated. In this context, in application of the regression model, estimating that there is a conceptual relationship between independent factors and dependent factors is highly important for the model developer. To formulate a predictive equation between the control factors used during chip removal (feed, depth of cut and corner radius) and the result (average surface roughness, cutting force) and to define this relationship, linear regression analysis has been used. A represents the feed rate, B cutting depth and C corner radius. In addition, ε stands for inaccuracy.

Linear regression coefficients were obtained using equations 5 to 8, where ε indicates error. R2 is the coefficient expressing the appropriateness of the equation. Although an acceptable value of R2 can vary depending on the relationships between dependent and independent variables used in each discipline or model, the optimal value is the one that is closest to 1. As R2 gets closer to 1, it is considered that statistical approximation of the regression model to the real relationship increases. A regression model represents the relationship between the dependent and independent variables. According to Pearson coefficient, If R2 has a value of 0.80 and greater, it is considered a strong relationship, while 50-70% is considered to be a moderate relationship. In this case, when the modeled statistical regressions (Equations 5 to 8) are analyzed, it is understood that they are within acceptable limits. There is a particularly strong relationship between the variables in Equation 8. Based on this finding, it is concluded that the factors (independent factors) selected in the experimental study as having a strong effect on dependent variables (surface roughness, cutting force) were accurately estimated. In this case, it is concluded that the regression model provides a good estimation of reality.

The Ra equation formulated for this experimental study is represented below wiper and conventional insert:

Surface Roughness (Wiper Insert) = 0.748 + 0.353 A+ 0.0850 B - 0.285 C+ (ε) (5)

R2 = 0.857

In this equation, the coefficient of determination of the equation is 0.857.

Surface Roughness (Conventional Insert) =1.00+0.415 A + 0.062 B - 0.348 C +(ε) (6)

R2 = 0.833

In this equation, the coefficient of determination of the equation is 0.833.

The cutting force equation formulated for this experimental study is represented below wiper and conventional insert:

Cutting Force (Wiper Insert) = 55,0 + 38,3 A + 73,1 B + 14,1 C +(ε) (7)

R2 = 0.907

In this equation, the coefficient of determination of the equation is 0.902.

Cutting Force (Conventional Insert) = 39,4 + 59,3 A + 64,4 B - 19,3 C +(ε) (8)

R2 = 0.929

In this equation, the coefficient of determination of the equation is 0.929.

5. Conclusion

This study of the machinability of 17-4 PH stainless steel alloy material with KENNAMETAL KC5010 PVD TiAlN coated conventional (FF) and wiper (FW) inserts have produced some useful results. The criteria for the machinability are surface roughness, cutting force and material hardness. Three control factors which were considered to be effective in creating the most suitable conditions for the criteria (feed rate, depth of cut and corner radius) were chosen at three different levels and applied in the experimental study. Below is the summary of the results:

•Based on the analysis of Grey Relational, the optimal cutting parameters were A1B1C2 for surface roughness and cutting force i.e. feed at 0.1mm/rev, depth of cut at 0.4mm and corner radius at 0.8 mm.

•The most effective control factor on the surface roughness value on the machined surface is feed rate. It has also been observed that feed is the most serviceable factor, still depth of cut and cutting speed play a role as well.

•The effective parameters for the increase of cutting forces are depth of cut, cutting speed and feed rate.

•Taguchi method is beneficial for the experimental design of the machinability of 17-4 PH stainless steel alloy material. Having optimized the parameters, it is also fruitful for keeping the response values at required levels.

•The analysis of variance (ANOVA) is helpful in determining which control factor has how much importance in the determination of the results obtained from the experimental study.

•The test results prove the effectiveness of the wiper inserts in providing excellent surface roughness. The results also suggest that the use of the wiper insert is an effective way that significantly increases cutting efficiency without changing the machined surface roughness in high feed turning operations.

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