INVESTIGATION OF THE EFFECTS OF CONVENTIONAL AND WIPER COATED CARBIDE TOOLS WITH DRY CUTTING ON CUTTING FORCES, SURFACE ROUGHNESS, AND MATERIAL HARDNEES IN TURNING 17-4 PH STAINLESS STEEL

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Abstract: In this study, an experimental investigation on cutting forces, surface roughness and the hardness of material after machining 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, cutting force and material hardnesswere examined. In order to optimize the turning process, Taguchi optimization method has been 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: Anova, Taguchi method, wiper and conventional tools, Surface roughness, cutting force, Hardness,

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 some factors which determine them. The cost of cutting tools and the cost of the work-piece can be considered as the two important factors in question. Thus, to lower the manufacturing cost and buy the product on cheap, 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 producing the work-piece 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 work-piece have been searched by the scientists. The researches have revealed the fact that there are a number of parameters and conditions in turning, which affect the above-mentioned points (Shaw,1984, Cakır,2000). 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 etc (Shaw,1984, Cakır,2000, Kurt,2006, Lin,2001). These parameters' being selected suitable to the property of work-piece 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 (Lin, 2001, Saglam, 2007, Gokkaya, 2006, Field,1989). When all these are taken into consideration, it is obvious that the selection of the cutting parameters in turning is very essential.

The machining of stainless steel inherently generates high cutting temperature, which not only reduces tool life but also impairs the workpiece surface quality (Kumar, 2006, Noordin, 2007). Obtaining the desired surface quality is very important for the functional maintenance of a part. One of the stainless steel family materials most commonly used in the production facility is steel with austenitic structure. The austenitic stainless steels structure is a combination of good mechanical properties and good corrosion resistance (Korkut, 2004, Elbah, 2013, Grzesik, 2006).

In this study, an experimental investigation on cutting forces, surface roughness and the hardness of material 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, cutting force and material hardness were examined. In order to optimize the turning process, 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.

Materials and Methods

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.

Figure 1. Experimental set up

Experimental Design

For the experimental design Taguchi method was employed.

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

Experimental factors and their levels were presented in Table 2 and L9 experiment design in Table 3. Schematic drawing of the experimental set up is given in Figure 1.

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 L_9 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

Results and Discussion

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 2.

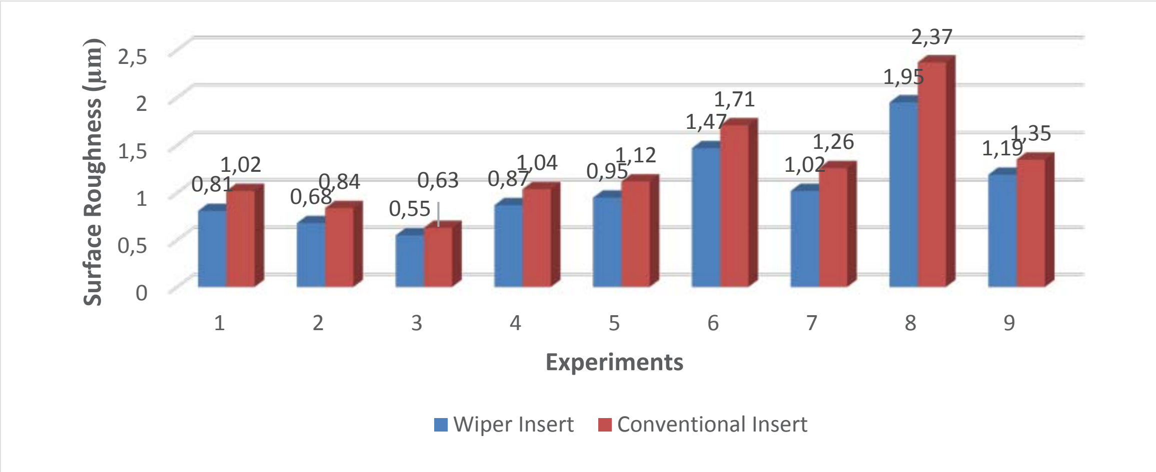

Figure 2. The surface roughness results

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 3.

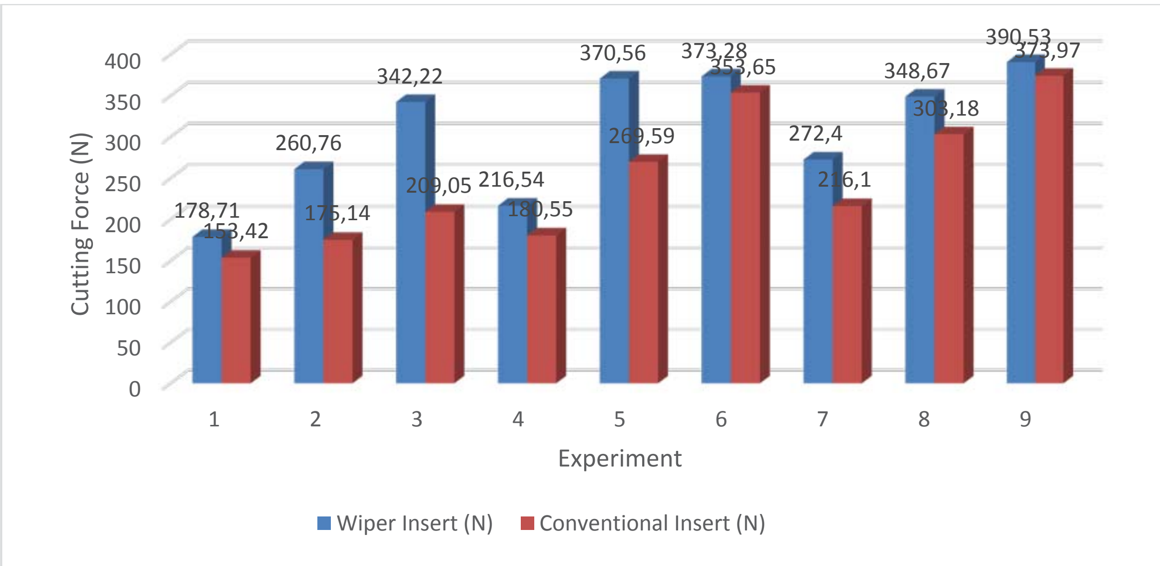

Figure 3. The cutting force results

Evaluation of Hardness Results

In general, the obtained hardness value has been between 32.17- 39.67 HRC, which meets the expectations. The material hardnessvalues obtained as a result of those 18 experiments are shown in Figure 4.

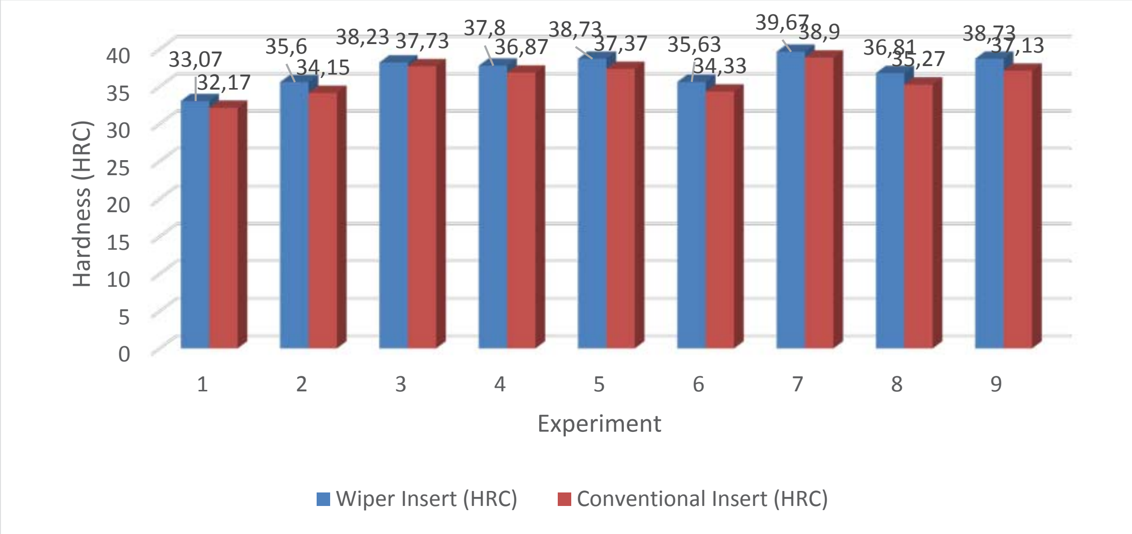

Figure 4. The material hardness results

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, N, and HRC 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 Table 4 and 5. As a result of the machining of 17-4 PH stainless steel with wiper and conventional 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 4. 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

Table 5. ANOVA versus 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

The ANOVA results of the average values of cutting forces are presented in Table 6 and 7. As a result of the machining of 17-4 PH stainless steel with wiper and conventional 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 6. 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

Table 7. 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

The ANOVA results of the average values of material hardness are presented in Table 8 and 9. As a result of the machining of 17-4 PH stainless steel with wiper and conventional insert cutting tools, the corner radius with a proportion of 62.48% and 71.58% has been the most effective factor in the formation of the material hardness on the machined surface.

Table 8. ANOVA versus material hardness for wiper insert

Notations	Degree of freedom	Sum of Squares	Variables	F Ratio	Percentage Ratio (%)
A	2	11.7807	5.8903	11.48	35.30
B	2	0.7406	0.3703	0.72	02.21
C	2	20.8588	10.4294	20.32	62.48
Error (e)	2	1.0263	0.5131		0.01
Total	8	34.4063			100

Table 9. ANOVA versus material hardness for conventional insert

Notations	Degree of freedom	Sum of Squares	Variables	F Ratio	Percentage Ratio (%)
A	2	8.9384	4.4692	4.75	25.66
B	2	0.9606	0.4803	0.51	02.75
C	2	24.9444	12.4722	13.25	71.58
Error (e)	2	1.8827	0.9413		0.01
Total	8	36.7261			100

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 rate, depth of cut and corner radius) and the result (average surface roughness, cutting force, material hardness) and to define this relationship, linear regression analysishas 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 2 to 7, where ε indicates error. R^2 is the coefficient expressing the appropriateness of the equation. Although an acceptable value of R^2 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 R^2 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 R^2 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 2 to 7) are analyzed, it is understood that they are within acceptable limits. There is a particularly strong relationship between the variables in Equation 6. 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, material hardness) 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) (2)

$R^2 = 0.857$

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) (3)

$R^2 = 0.833$

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) (4)

$R^2 = 0.907$

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) (5)

$R^2 = 0.929$

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

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

Material Hardness (Wiper Insert) = 30,0 + 1,39 A + 0,342 B + 1,85 C +(ε) (6)

$R^2 = 0.954$

In this equation, The coefficient of determination of the equation is 0.954.

Material Hardness (Conventional Insert) = 29,1 + 1,21 A+ 0,208 B + C +(ε) (7)

$R^2 = 0.924$

In this equation, The coefficient of determination of the equation is 0.924.

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:

- 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.
- The most effective control factor on the surface material hardness is in the direct proportion with corner radius and wiper insert.
- 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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