Academic Journal of Science,
CD-ROM. ISSN: 2165-6282 :: 1(3):89–97 (2012)

RESEARCH OF THE EFFECT OF CUTTING PARAMETERS ON TOOL LIFE IN TURNING OPERATIONS BY USING OF STATISTICAL PROCESS ANALYSIS

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In this study, we present experimental studies to research the effect of cutting parameters (cutting speed, feed rate and depth of cut) on tool life during the machining of AISI 304 stainless steel by using multi-coated carbide tool on CNC turning machine tools.

High corrosion resistance, ductility and tension strength are the essential properties of stainless steels. Stainless steel is an alloy which has chrome, nickel and molybdenum elements and their machinability is negatively affected. For this reason, the machining of stainless steels is very difficult. In this study, the machining tests were carried out by using coated cutting tools. The tests were performed without coolant at various feed rates, cutting speeds and depth of cuts. Tool life, surface roughness and cutting forces have been determined experimentally. The effect of cutting parameters on the tool life has been researched.

The relationship between cutting parameters and tool life was modeling with surface response methods and analyzed by using SPSS. The results show that cutting speed, feed rate and depth of cut are affected by tool life. Cutting speed is the dominant parameters on the tool life.

Keywords: Cutting parameters, Tool life, SPSS, Turning.

1. Introduction

The machinability of steel usage has been increasing rapidly in daily life and the studies of improvement of its features have continued constantly. Especially, steel, which has various kinds, is increasing the importance of these studies and improvements that supports its features where it is to be used in relationship of maximum efficiency with minimum cost. The machinability in producing materials that fit this purpose has become one of the main points.

One of the main factors in producing is that this high quality, low cost and functional products are machinability. The studies on machinability of materials have continued by gaining great acceleration recently. As a result, these studies are not only beneficial for machinability but also they are beneficial for development of new tools, for increasing tool life, for improvement of surface quality and for creating new types of materials. In this aspect, many studies have been carried out by aiming maximizing the provided quality and functionality while minimizing the cost. The new improvements on materials, surface quality, tool design and life are not only creating a positive effect on machinability but also they are beneficial for development of many branches of manufacturing technologies.

In this study, the machinability of AISI 304 stainless steel has been examined by evaluating tool life, surface roughness, machining time and existed force values measured. After material is machined with various cutting parameters, the aim is that it is determined the most suitable cutting parameters at every aspect.

The change of machining parameters has been examined related to the change of feed rate, cutting speed and the quantity of removed materials parameters.

2. Literature Review

In this study carried out by Bülent Kaya, Cüneyt Oysu and Hüseyin M.Ertunç (2011), a predicted system for force-torque based linear tool friction has been improved by using artificial neural nets in the CNC milling of inconel 718 materials. In this study, as a main factor in the milling of inconel 718 super that alloys an online team observation system was created. Also, it is stressed that artificial neural nets way is an effective and efficient system at the free surface friction of tool.

Balkrishna Rao, Chinmaya R. Dandekar and Yung C. Shin (2011) made an experimental and numerical study on frontal milling of Ti-6Al-4V alloy and they evaluated the surface linearity. In this study, the way of finite components was used in order to analyze exactly. In the 3D FEM simulations, cutting forces that have small dispersions and temperature were observed at the first cutting field. In the experimental analyze, a relationship was reached by focusing on dimensionality of tool performance, surface linearity and cutting energy. A tool friction model was created and parameterized by creating a FEM system based on tool-swarf touching point temperature, touch pressure and swarf speed.

In the study that was prepared by Jukka Paro, Hannu Hanninen and Veijo Kauppinen (2006), and named as “The Tool Friction and Machinability of Austenitic Stainless Steel”; it was seen that the stainless steels having high nitrogen are stronger. While the breaking tension of a normal X5 CrMnN 18 stainless steel is 660 Mpa, the breaking tension of nitrogen added stainless steel increases about 3000 Mpa. It was determined that nitrogen made an obstacle against movement of dislocation in the existed structure.

Kambiz Haji Hajikolaei, Hamed Moradi, Gholomreza Vossoughi and Mohammad R. Movahhedy (2010) made a study on adaptable force distribution and the distribution of shaft speed in order to decrease the vibrations which are renewed in turning operations. Two control strategies were used for adaptable force control and shaft speed change control. In process of orthogonal turning, in the modeling of free surface friction between work material and tool free surface, single independence degree dynamic system was used. The modeling of shaft speed distribution was configured with three sinusoidal signals at average speed. Optimum amplitudes of speed changes were minimized with an algorithm of turning process entrance energy by using a general algorithm. As a secondary control strategy, an adaptive supervisor was designed which reacts small surges under determined system conditions. At this stage, provided external forces were accepted as entrance variables. The results were obtained for every control strategy. In this approach that contains both control strategies, it was determined that the case was suppressed without existing any vibration and surge simultaneously. As a result, both system eliminated the uncertainties of existing process and made the system performance more healthful. As the friction of tool which increased the signal efficiency, this case improved the stability of system at the aspect of system efficiency.

3. Material and Methods

3.1. Specifications of experiment specimens

In this study, AISI 304 cylindrical austenitic stainless steel with 350mm length and 110mm diameter was used as experimental sample. Chemical composition of that material was presented as indicated below.

Table 3.1. Chemical composition of experimental sample.

AISI	C %	Si %	Mn %	Cr %	Mo %	Cu %	Ni %	Co %	P %	S %	N %
304	0,017	0,54	1,78	18,40	0,48	0,46	8,14	0,100	0,029	0,029	0,086

In the machining researches, TT9215 brand and TaeguTec T-Tinox carbide series tool was used. T9215 tool is coated with CVD and has high friction resistance. T9215 can work at high speeds and has high friction resistance in constant turning of stainless steel. By means of superior CDV coating method applied this tool, breaking of cutting edge, consistence of agglomerate and the friction between the swarf and touch surface was decreased.

3.2. Experimental Setup

Cylindrical AISI 304 austenitic stainless steel work material was attached to CNC (Mori Seiki NL 2500MC) machine tool and a designed apparatus with a dynamometer (KSTLER 9257BA) was attached to tool keeper.(Fig.3.1) Prior to the experiments, possible curvatures on the surface of work material were eliminated by cutting a height of 0.5mm with a new cutting tool. Coolant was not used in experiments. Exact factorial designs were based on creating of experiments and the used levels are seen at Table 3.2. Experimental plan was created for 9 main experiments and 2 repeat experiments in exact factorial system (Table 3.3). Surface roughness values were recorded in every experiment. Mitutoya brand surface roughness measurement device was used for measuring surface roughness. (Yontar, A.Ahmet 2011)

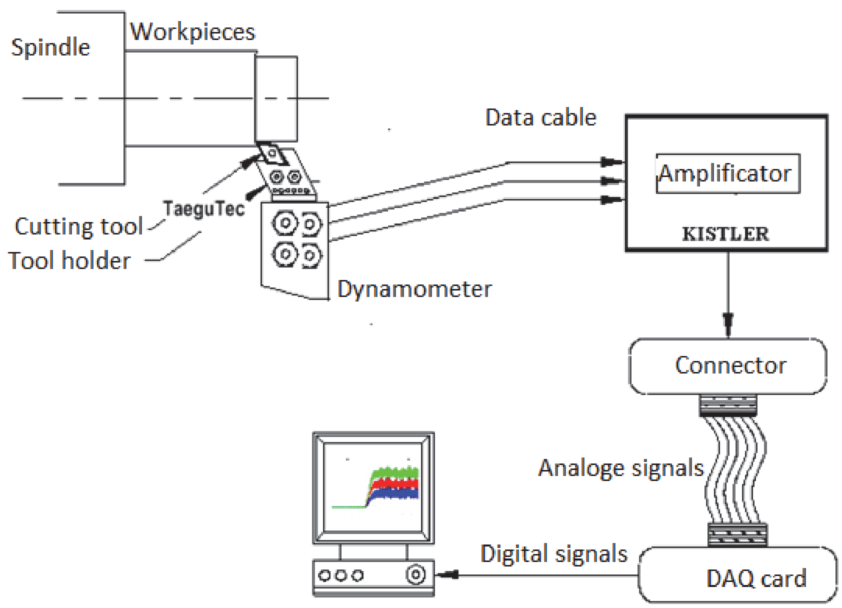

Figure 3.1. Experimental setup.

Table 3.2. Experiment parameters with their values for three levels.

Experiment Levels			
	+1	0	-1
v (m/min)	225	150	100
f (mm/rev)	0,35	0,19	0,1
a (mm)	2	1,4	1

Table 3.3. Experimental plan.

No	v (m/min)	f (mm/cycle)	a (mm)
1	100	0,1	1
2	225	0,1	1
3	100	0,35	1
4	225	0,35	1
5	225	0,35	2
6	100	0,35	2
7	225	0,1	2
8	100	0,1	2
9	150	0,19	1,4
10	150	0,19	1,4
11	150	0,19	1,4

3.3 Experiment results

Table 3.4. Experimental values.

Exp. No	V(m/min	f (mm/rev)	a (mm)	Ra (μm)
1	100	0,1	1	0,44
2	100	0,1	2	1,55
3	100	0,35	1	3,52
4	100	0,35	2	3,80
5	225	0,1	1	0,32
6	225	0,1	2	0,42
7	225	0,35	1	3,72
8	225	0,35	2	4,04
9	150	0,19	1,4	1,39
10	150	0,19	1,4	1,39
11	150	0,19	1,4	1,39

4. The Improvement of Tool Life, Cutting Forces and Prediction Models of Surface Roughness By Means of Response Surface Method

Response surface method was used for the representation with mathematics model of surface roughness and cutting variables. In the light of cutting parameters, design matrix indicated below was created in order to determine the equation of surface roughness.

$$D = \begin{bmatrix} -1 & -1 & -1 \\ -1 & -1 & +1 \\ -1 & +1 & -1 \\ -1 & +1 & +1 \\ +1 & -1 & -1 \\ +1 & -1 & +1 \\ +1 & +1 & -1 \\ +1 & +1 & +1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

After design matrix is obtained, general equation for model is formulated as indicated below:

$$y = \beta_0 + \sum_{i=1}^{f} \beta_i X_i + \sum_{i=1}^{f} \beta_{ii} X_i^2 + \sum_{i=1}^{f} \sum_{j=1}^{f} \beta_{ij} X_i X_j + \varepsilon$$

y: Experiment result
X_i: Factors effecting equation

β_0 ,β_i ,β_{ii} ,β_{ij} : Coefficients of model
□ : Random, zero averaged and constant variance free experimental error

- Coefficients of β_0 ,β_i ,β_{ii} ,β_{ij} can be predicted with method of smallest squares. For solution of this model with the assistance of the equation as indicated below, matrix procedures were applied.

$$y = X\beta + \varepsilon$$

- The X matrix needed for model was used for predicting y respond matrix and β vector. These matrices are as indicated below.

$$y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \\ y_8 \\ y_9 \\ y_{10} \\ y_{11} \end{bmatrix} \qquad X = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1D \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \qquad \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} \qquad B = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \end{bmatrix}$$

The X matrix that is our main reference in all calculations is given below.

$$X = \begin{bmatrix} +1 & -1 & -1 & -1 \\ +1 & -1 & -1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & -1 & +1 & +1 \\ +1 & +1 & -1 & -1 \\ +1 & +1 & -1 & +1 \\ +1 & +1 & +1 & -1 \\ +1 & +1 & +1 & +1 \\ +1 & 0 & 0 & 0 \\ +1 & 0 & 0 & 0 \\ +1 & 0 & 0 & 0 \end{bmatrix}$$

After X matrix was created, the equation indicated below which is used in smallest squares method was used for solution of B vector.

$$B = (X'X)^{-1} X' y$$

For the prediction of surface roughness equation:

$$Ra = C_{Ra} * v^{p} * f^{r} * a^{s}$$
$$\ln Ra = \ln C_{Ra} + p \ln v + r \ln f + s \ln a$$
$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$$

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3$$

By using $B = (X'X)^{-1} X' y$ equation, coefficients can be predicted. For Ra surface roughness, y matrix:

$$y = \begin{bmatrix} -0,82 \\ 0,44 \\ 1,26 \\ 1,34 \\ -1,14 \\ -0,87 \\ 1,31 \\ 1,40 \\ 0,33 \\ 0,33 \\ 0,33 \end{bmatrix}$$

By putting the matrix $(X'X)^{-1}$ in its place in the equation of $B = (X'X)^{-1} X' y$, result is obtained.

$$B = \begin{bmatrix} 0.356 \\ -0.190 \\ 0.963 \\ 0.213 \end{bmatrix}$$

The model of the equation which was established for surface roughness Ra:

$$Y = 0,356 - 0,190 X_1 + 0,963 X_2 + 0,213 X_3$$

$$Ra = 1,43 * v^{-0,190} * f^{0,963} * a^{0,213}$$

obtained as stated above.

5. Variance Analysis

Two-way analysis of variance was developed by using SPSS software in order to determine the joint effects of the cutting variables and tool life, cutting forces and surface roughness as a result of the relationship and interactions with each other.

The results obtained from SPSS are given below.

Table 5.1. Two-way analysis of variance for tool life.

Tests of Between-Subjects Effects

Dependent Variable: T

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	20687,167[a]	8	2585,896	618,303	0,002
Intercept	11193,245	1	11193,245	2676,372	0,000
V	4249,867	1	4249,867	1016,168	0,001
F	4256,231	1	4256,231	1017,690	0,001
A	3201,680	1	3201,680	765,541	0,001
v * f	2094,210	1	2094,210	500,738	0,002
v * a	2282,717	1	2282,717	545,811	0,002
f * a	2257,181	1	2257,181	539,705	0,002
v * f * a	2061,205	1	2061,205	492,846	0,002
Error	8,364	2	4,182		
Total	31755,091	11			
Corrected Total	20695,531	10			

a. R Squared = 1,000 (Adjusted R Squared = ,998)

When examining the variance table belonging to the T tool life; cutting speed, feed rate, cutting depth values can be determined the most effective values for the value of T tool life as taking into account the Sig. (P) cut-off values in the table.

The Sig values which calculated based on these three parameter is the same (0.001) and smaller than 0.05 at the same time. When examining the combined effects; the relationship between cutting speed, feed rate and cutting depth is the most important effect on the T tool which can be seen from the table.

The Analysis was performed as 5% significance level and 95% confidence levels. The effect of each factor on the total variation is indicated on the last column of the charts.

5. Conclusion and Evaluation

In the machining of stainless steels, when the effect of cutting parameters on surface roughness created with mathematics prediction model, response surface method is researched;

For the small values of cutting parameters, surface roughness decreases and the cutting speed shows the least effect. The effects of cutting parameters on quality of surface increase respectively cutting speed, depth of cut and feed rate respectively.

The relationship between cutting parameters and tool life are analyzed by using SPSS. The results show that cutting speed, feed rate and depth of cut are affected by tool life. Cutting speed is the dominant parameters on the tool life.

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