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Influence of Turning Process Parameters on Surface Roughness and Tool wear in Machining DIN1.2714 tool steel

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Abstract In this study, hard turning of hot work steel, Din 1.2714, using coated carbide tools was done in order to explore the effects of different turning process variables, such as cutting speed, feeding rate, and depth of cut, on surface roughness and tool wear. The L9 orthogonal array in a CNC lathe has been put through tests. By using Taguchi's design of experiments technique and fuzzy logic methodology, the output quality parameters of surface roughness and tool wear were enhanced. The results indicated that tool wear and surface roughness may be precisely identified by multi-response analysis employing fuzzy logic and the Taguchi Technique. The least amount of surface abrasion and tool wear was produced when cutting at a speed of 100 m/min and a depth of 1.5 mm.

Keywords: Tool Wear, Surface Roughness, Hard Turning, Fuzzy, Taguchi, Anova.

I. INTRODUCTION

Machining of prehardened tool steel where hardness is high became difficult with conventional methods, only possible with grinding after hardening process. In last years the tool manufacturers developed different new cutting tool materials and tool coatings which able to machine the work piece where hardness is quite high and classified in the term of hard turning.

The machining of steel with a hardness of at least 45 HRC is referred to as "hard turning" [1, 2], Coated and uncoated carbides are widely used in the metal working industry and provide the best substitute for most turning operations. [3]. Hard turning is now gradually replacing the grinding for finishing operations, the improvement in wear resistance coated carbide inserts remarkably increase in cutting speed which tends to improved productivity at the machine shop floor. And today, 70% of the cemented carbide tools used in the industries are coated [4,5].

Increase the hardness of workpiece effects on tool life and machined surface accuracy; it has a tendency to accelerate tool wear, which immediately lowers the quality of surface roughness and significantly affects machining costs and productivity. There are different kinds of wear occurs in cutting tool such crater wear, flank wear, chipping …etc. The types of tool wear depend on the workpiece, cutting conditions, tool material, and machining process [5, 6]. Two areas of the cutting tool are subject to gradual wear. Figure 1 depicts crater wear on the top rake face and flank wear on the flank face (side of tool).

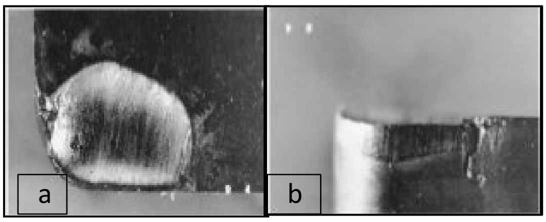

Fig.1. Cemented carbide tool photographic:
a-crater wear, b-flank wear [7].

During machining of steel, crater wear occurs as a combination of abrasion and dissolution-diffusion wear [8-10] whereas flank wear occurs due to the abrasive action of the work material. The tool can be used unless the average value of flank wear is larger than 0.3 mm, according to ISO 3685 (1993). This rising value of tool flank wear is a clear indication that the tool's life is coming to an end. [12].

Optimization procedures can always be related to increases in product quality and manufacturing efficiency. For continuous improvement of output quality features, numerous optimization methods such as factorial design, response surface methodology (RSM), fuzzy logic, neural network, and Taguchi method are increasingly frequently employed. [13-16].

This study aims to identify the best input process parameter combinations to minimize tool wear and surface roughness while turning hardened hot work steel DIN 1.2714 using coated carbide tools. The Taguchi approach is used for the experimental work, and a fuzzy logic model is built to enhance the output machined performance parameters. Finally, the accuracy of the model prediction is assessed by comparing the experimental and predicted values.

II. EXPERIMENTAL TECHNIQUES AND WORK

This study investigated how the machining parameters cutting speed (Vc), feed rate (f), and depth of cutting (a) impact tool wear (VB) and surface roughness (SR) while dry machining 1.2714 tool steel.

A. Workpiece material and cutting tool

In this job, round bars with a 50 mm diameter and a 40 mm cutting length produced of 1.2714 prehardened tool steel (42 HRC) are used for turning operations. The chemical composition of the workpiece is shown in Table 1.

Table 1. Chemical Composition of tool steel 1.2714

Component	Content
Carbon	0.55%
Chromium	1.10%
Molybdenum	0.50 %
Nickel	1.70%
Vanadium	0.10%

The cutting tool was SANDVIK "Ti(C,N)/$\mathbf{Al_2O_3}$/TiN" CVD coated carbide cutting inserts known as GC2015 (CNMG 12-04-08-PM).

B. Cutting parameters & conditions

The values of the input process parameters for the turning operation are as in the table2.

Table 2.cutting parameters of the turning operation

Factors	Level 1	Level 2	Level 3
Depth of cut (mm)	1.0	1.5	2.0
Feed (mm/rev)	0.1	0.25	0.4
Cutting Speed (m/min)	80	100	120

Turning experiments were conducted on a CNC Lathe (Make: HWACHEON Ltd., Korea; Model: Hi-ECO 31A), at the production & training center, in janzor city. Photographs of CNC Lathe and experimental system are shown in Fig.2 and Fig.3, respectively.

Fig.2.CNC lathe HWACHEON Hi-ECO 31A

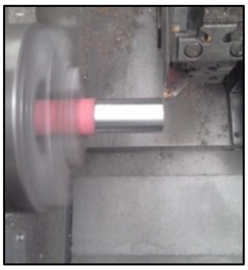

Fig.3. Magnified view of the tool and workpiece

C. Design of experiment

Taguchi DOE is an effective approach for designing high-quality systems. Taguchi presented a set of orthogonal arrays by conducting a small number of tests to examine the impact of parameters on certain quality criteria and to discover the best parameter combination. The MINITAB 17 Software was used to assign the factors in this experiment. The three process parameters in turning each taken in three levels as shown in Table-3 are represented in an L9 orthogonal array.

Table 3. Design of Experiment with L9 orthogonal array

n	Vc [m/min]	a [mm]	f [mm/rev]
1	80	1	0.1
2		1.5	0.25
3		2	0.4
4	100	1	0.25
5		1.5	0.4
6		2	0.1
7	120	1	0.4
8		1.5	0.1
9		2	0.25

D. Experimental data

Surface roughness and tool wear were measured after the machining process. Roughness parameters such as the arithmetic surface roughness average Ra were utilized to define the work surface. Ra was measured using the ALPA-SM Roughness Tester. In Fig.4, the measurement is displayed.

Fig.4 measuring of (SR) by Roughness Tester.

The measurements were made three times in different locations for each sample, and the average value was calculated. In order to quantify tool wear, an optical method was employed (VB). A CCD camera and an optical microscope are used in the system to directly detect the wear area.

The experimental test results of tool wear (VB) and surface roughness (Ra) are tabulated in Table 4.

Table 4. Experimental results.

Nr.	Surface roughness [Ra in µm]	Tool wear [VB in mm]
1	1.354	0.06
2	2.432	0.04
3	1.946	0.12
4	1.102	0.04
5	2.138	0.05
6	2.128	0.04
7	3.774	0.06
8	0.978	0.07
9	3.100	0.22

E. Methods for Identification of Optimal Parameters

Taguchi, fuzzy logic and ANOVA are selected as a analysis tools to for identifying the optimal parameter combination.

1. Taguchi method

In this technique, the signal-to-noise (S/N) ratio is used to represent output quality characteristics. There are three types of S/N ratios: the smaller the better, the bigger the better and the nominal the better. Smaller-the-better is selected as performance and expressed as:

$$S/NRatio = -log_{10}(1/n)\sum_{i=1}^{n} y_{ij} \quad [1]$$

2. Fuzzy logic

One of today's most successful techniques for developing sophisticated control systems is fuzzy logic. Fuzzy logic replicates human decision making by generating exact answers from specific or approximate information. MATLAB software was used to develop Fuzzy Logic to determine the output parameters. Fuzzy systems make judgments based on linguistic variables for inputs and outputs [11]. A fuzzy logic unit is made up of 5 components. The defuzzifier turns the fuzzy predicted value into a Multi Performance Characteristics Index (MPCI) response, which may be used to determine the MPCI's output correctness. Fig.5 depicts the structure constructed for this investigation, which is a three-input-one-output fuzzy logic unit.

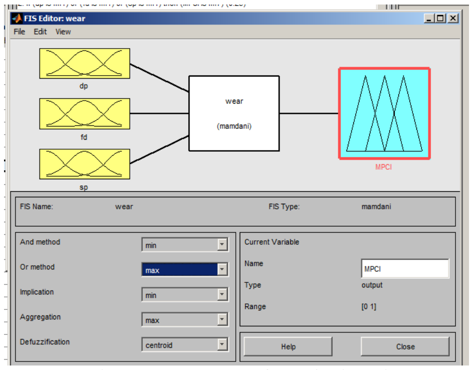

Fig. 5. Input-output fuzzy logic unit

3. Analysis of Variance (ANOVA).

The ANOVA method is mainly employed to identify the machining variables that significantly affect performance parameters. This is performed by dividing the overall variability of the MPCI, determined as the sum of the squared deviations from the MPCI's total mean, into contributions from each process parameter and the error.

In order to determine tool wear and surface roughness, MINITAB17 Software performs an ANOVA analysis on the data.

III. Analysis and Discussion of Results

Experimental data was analyzed according to Taguchi Design & analysis of variance (ANOVA) by using Minitab 17. The fuzzy logic analysis was successfully performed by using Matlab R2014.

A. Taguchi technique

The obtained results were analyzed are shown in the tables 5, 6 and fig. 6, 7.

Table 5. Mean S/N Ratios for SR.

Level	a	f	Vc
1	-4.987	-1.164	-5.373
2	-4.715	-6.122	-2.833
3	-5.563	-7.979	-7.060
Delta	0.848	6.814	4.227
Rank	3	1	2

Table 6. Mean S/N Ratios for VB.

Level	a	f	Vc
1	25.61	25.16	23.60
2	25.69	23.02	27.31
3	19.84	22.96	20.23
Delta	5.85	2.21	7.08
Rank	2	3	1

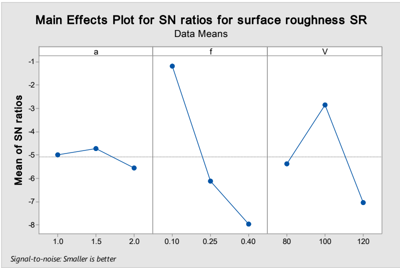

Fig.6. Main Effects Plot for S/N ratios for SR.

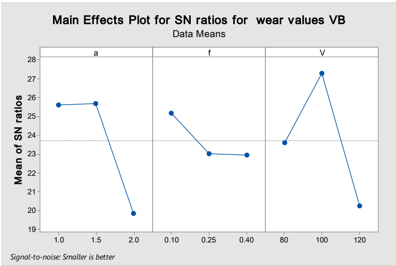

Fig.7. Main Effects Plot for S/N ratios for VB.

The following are the ideal turning parameter values for surface roughness and tool wear based on Tables 5,6 and Fig. 6,7:

- Cutting speed Vc: 100 m/min;
- Feed rate f: 0.1 mm/rev;
- Cut depth a: 1.5 mm.

B. Fuzzy logic

For the input process parameters in this investigation, triangular membership functions were employed. The fuzzy logic controller was of the Mamdani type and featured a rule basis to predict the MPCI. The rules were based on knowledge of experimental data. The predicted values of MPCI are shown in table 8.

Table7. Fuzzy predicted data of MPCI.

N.	Speed Vc [m/min]	Feed f [mm/rev]	Depth a [mm]	Predicted MPCI
1	80	0.1	1	0.63
2	80	0.25	1.5	0.53
3	80	0.4	2	0.51
4	100	0.25	1	0.52
5	100	0.4	1.5	0.63
6	100	0.1	2	0.54
7	120	0.4	1	0.52
8	120	0.1	1.5	0.53
9	120	0.25	2	0.52
10	100	0.1	1	0.65
11	100	0.25	1.5	0.56
12	100	0.4	2	0.49
13	120	0.25	1	0.52
14	120	0.4	1.5	0.45
15	120	0.1	2	0.52
16	80	0.4	1	0.62
17	80	0.1	1.5	0.66
18	80	0.25	2	0.53
19	120	0.1	1	0.53
20	120	0.25	1.5	0.52
21	120	0.4	2	0.51
22	80	0.25	1	0.51
23	80	0.4	1.5	0.57
24	80	0.1	2	0.54
25	100	0.4	1	0.62
26	100	0.1	1.5	0.76
27	100	0.25	2	0.52

Greater values depict the low SR and low VB.
Table 7 shows the best turning parameters values for surface roughness and tool wear:

- Cutting Speed Vc: 100 m/min
- Feed rate f: 0.1 mm per revolution;
- Cut depth a: 1.5 mm

C. Analysis of variance(ANOVA)

Analysis of variance (ANOVA) was used as shown in Tables 8 and 9 to assess the impact of process parameters and interactions on the chosen machining characteristic.

Table8. Analysis of variance for surface roughness.

Source	DF	Adj SS	Adj MS	F	P	%Contr
Vc	2	2.05049	1.02524	1.03	0.494	27.05
a	2	0.09416	0.04708	0.05	0.955	1.24
f	2	3.43576	1.71788	1.72	0.368	45.33
Error	2	1.99902	0.99951			26.38
Total	8	7.57942				100

Table9. Analysis of variance for tool wear.

Source	DF	Adj. SS	Adj. MS	F	P	%Contr.
V	2	2.008156	0.004078	1.35	0.425	29.38
a	2	0.010756	0.005378	1.79	0.359	38.75
f	2	0.002822	0.001411	0.47	0.681	10.17
Error	2	0.006022	0.003011			21.7
Total	8	0.027756				100

According to the ANOVA results, cutting speed (Vc), depth of cut (a), and feed rate (f) had respective percentage contributions of 27.05%, 1.24%, and 45.33% and 29.38%, 38.75%, and 10.17% that affected surface roughness and tool wear, respectively.

D. Response Surface Methodology, RSM

An approach to improve the response(s) when two or more quantitative elements are present is also referred to as (Response Surface Modeling). In order to provide experimenters an indication of the form of the response surface they are studying, response surface technique allows them to estimate interactions. RSM is a typical optimization technique. In general, the response surface can be visualized graphically. The graph is helpful to see the shape of a response surface [17]. As a result, the following function is used:

$$Y = f(x1, x2) + error \qquad [2]$$

1. Influence of turning parameters on VB

To investigate how cutting parameters interact and affect tool wear, the 3D surface response plots were plotted Fig. 8. It is observed that modifying the (Vc*a, Vc*f, or a*f) at low and moderate levels, which lead to the lowest VB, has no appreciable impact on tool wear. On the other hand, there is a noticeable difference in tool wear with increasing cutting speed at the deepest level of cut, which increases significantly at the greatest level of Vc and a. When the depth of cut is smaller than 1.5 mm, a minimum of tool wear may be obtained at any level of cutting speed, indicating the optimal combination of cutting speed and depth of cut. It can be seen that the worst tool wear values are achieved at the highest cutting speed and the medium feed. VB is improved but with low feed rate. For the interaction a*f, the lower tool wear is always attained in the region constrained up to the medium level of cut depth. The tool wear is quite sensitive to changes in feed rate at high cut depths. The lowest level of feed combined with the deepest cut results in the least amount of tool wear, whereas the highest depth of cut combined with the intermediate level of feed rate results in the most amount of tool wear. Therefore, according to Fig. 8, it can be concluded that the moderate level of the [Vc] and [a], and the lowest level of [f] is an ideal combination which always produce the best values for tool wear during the hard turning operation.

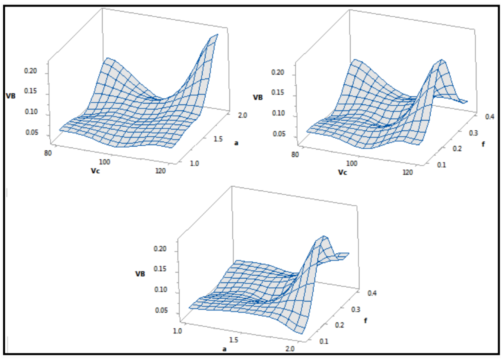

Fig. 8: 3D Surface plots of Tool wear versus (a, f, Vc).

2. Influence of Turning parameters on SR

The 3D Surface plots of surface roughness vs various combinations of cutting parameters are displayed in Fig. 9 to study the interaction effects of cutting parameters on surface roughness. According to the interaction (Vc *a), changing the cutting speed has no effect on surface roughness at large depths of cut. When the lowest cutting speed and depth of cut are combined, a fine surface is generated. Poor surface roughness obtained with fast cutting speed at any depth of cut except the center. It is evident that a combination of high cutting speed and high feed rate results in high surface roughness, and when the cutting speed decreases, SR improves, but only with a low feed rate, indicating that the feed rate has the greatest influence, as previously documented by investigators. When the fastest cutting speed and lowest feed rate are combined, the best surface roughness is obtained. Surface roughness has a tendency to fluctuate significantly with decreasing feed rate at the shallowest depth of cut. The moderate depth of cut and the lowest and intermediate levels of feed rate produced the best surface roughness. The surface roughness rose noticeably with an increase in feed, according to the 3D surface response plots. It can be inferred that the best combination for providing an acceptable surface roughness in hard turning operations is a moderate cutting speed and depth of cut along with the lowest feed rate.

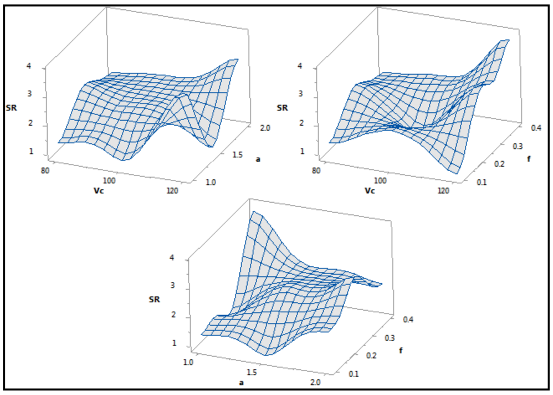

Fig. 9: 3D Surface plots of (SR) versus (a, f, Vc).

IV. Confirmation Test

A confirmation test performed as the last step in the process of validating the best parameters. The results matched those of Taguchi and fuzzy approaches.

In this study, we performed a confirmation test using the optimal parameter levels and received the best results as follows: Ra is 0.858 m and VB is 0.038mm.

V. Conclusions

The following conclusion may be reached based on the experimental results and the confirmation test:

- The ideal parameters have been achieved in terms of DOE approaches namely Taguchi utilizing MINITAB software.
- A fuzzy model was created based on the results of the experiments to get the best predicted parameters..
- The optimal parameters for turning 1.2714 tool steel are Vc=100 m/min, f=0.1 mm/rev, and a=1.5 mm.
- The confirmation test gave results consistent with the optimal parameters obtained by the used techniques.
- To forecast the ideal machining settings, the Taguchi method and fuzzy logic technique are both practical and cost- effective.
- The ANOVA% contribution showed that the feeding rate had the greatest impact on surface roughness, while the depth of cut had the greatest impact on tool wear.
- A moderate cutting speed and depth of cut, combined with a low feed rate, is a perfect combination for producing an acceptable surface roughness in a hard turning operation.

- The optimal combination that consistently yields the best tool wear values during the hard turning operation is a moderate level of cutting speed, depth of cut and lowest level of feed rate.

VI. ACKNOWLEDGMENT

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