OPTIMIZATION OF MACHINING PARAMETERS OF DIE TOOL STEEL FOR HARD TURNING USING COATED AND UNCOATED CARBIDE TOOL

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Abstract

Hard turning process is a single point cut of hardened workpiece ranging within 2 microns and hardness between 58-70HRC, aimed at turning hardened steel with good surface quality. In this study, an attempt has been made to examine the effect of machining parameters (cutting speed, feed rate, depth of cut and tool nose radius) on tool wear and surface roughness in finish hard turning of H13 tool steel using coated and uncoated carbide tool. CNC lathe machine were used for this purpose.The machining experiments were conducted based on Taguchi method. A comprehensive analysis of variance (ANOVA) was used to fully identify the most influential parameters, and the adequacy of both fitted second order regression models were checked. The SR increase by increasing the cutting speed, feed rate and depth of cut. The depth of cut and feed rate are the most influential factors for increasing SR respectively. Mathematical models for tool wear and SR were developed by using Design L-9 software. Surface roughness were measured by surface roughness tester. Tool wear is measured by optical microscope. Coated tool is more efficient than uncoated tool in case of flank wear.

Keywords: Hard turning, Surface roughness [SR], Tool wear, Taguchi method

1.Introduction

The development of any country mainly depends on growth of its manufacturing industries. Hence, improvement in manufacturing technology, especially machining of hardened steel has been revolutionized many branches of industry such as automotive, die and mould sectors. The application of hard turning has been proved extremely advantageous in producing bearings, gears, cams, shafts, axels, and other mechanical components since the early 1980s **[3].** In turning operation, tool wear and the quality of the surface finish are important requirement for many turned work pieces. Tool wear initiates structural changes to the surface of a work piece. Thus, many researchers focused their studies on the prediction of the tool wear and tool life during high speed machining. Flank wear is the wear that occurs on the flank surface or flank faces of the cutting tool. This occurs due to direct mechanical abrasion and friction between the flank surface and the work piece during the operation. The width of the wear land is a straight forward measure of the flank wear. The width is denoted as VB. The tool life is conventionally considered to be over when the average flank wear land V_B reaches 300 μm or the maximum flank wear land VB_{max} becomes 600 μm**. Choudhury and Srinivas [22]** found that cutting speed and diffusion coefficient index have the most notable effect on the flank wear, followed by feed and depth of cut. Crater wear is the wear that takes place on the rake face or the top face of the cutting tool. It occurs parallel to the principal cutting edge. This type of erosion occurs due to the rubbing of the chip on the rake face during machining. According to **Kalpakjian and Schmid [21]** the most notable factors that affect the crater wear phenomena are temperature occurring at the chip-tool interference and the chemical affinity between the tool and work materials at the elevated temperatures encountered during machining. Factors affecting flank wear also influence crater wear. **B.V. Manoj Kumar, J. Ram Kumar and Bikramjit Basu [23]** found out during the dry machining of boiler steel using TiCN-Ni-WC cermet inserts that crater wear increases significantly with cutting speed and feed. The aim of this work was to optimize the process parameters for surface roughness and tool wear using Taguchi method. **[3]**

For attaining superior tribological properties the productivity enhancement of manufacturing processes imposes the acceleration of design and evolution of improved cutting tools. Turning with coated carbide tools has several benefits such as reduction of processing costs, increased productivity and improved mechanical properties. Selection of optimum machining parameters is very important in controlling quality. **[1,2]**

2. Design of Experimentation

In the traditional one-variable-at-a-time approach, only one variable at a time is evaluated keeping remaining variables constant during a test run. This type of experimentation reveals the effect of the chosen variable on the response under certain set of conditions. The major disadvantage of this approach is that it does not show what would happen if the other variables are also changing simultaneously. This method does not allow to study the effect of the interaction between the variables on the response characteristic. The interaction is the failure of one factor to produce the same effect on the response at different levels of another variable. On the other hand, full-factorial designs require experimental data for all the possible combinations of the factors involved in the study; consequently a very large number of trial need to be performed. Therefore, in the case of experiments involving relatively more number of factors, only a small fraction of combinations of factors are selected that produces most of the information to reduce experimental effort. This approach is called fractional-factorial design of experiment. The analysis of results in this approach is complex due to non-availability of generally accepted guidelines .The Taguchi method provides a solution to this problem.

3. Material Selection

The AISI H13 is selected for the workpiece material.

Table 3.1Chemical composition

Carbon %	0.32 – 0.45
Manganese %	0.20 – 0.50
Silicon %	0.80 – 1.20
Chromium %	4.75 – 5.50
Nickel %	0.3
Molybdenum %	1.10 – 1.75
Vanadium %	0.80 – 1.20
Copper %	0.25
Phosphorous %	0.03
Sulphur %	0.03
Iron %	Balance

Table 3.2Mechanical Properties

Density (×1000 kg/m^3)	7.76
Poisson's Ratio	0.27-0.30
Elastic Modulus (GPa)	190-210

4. Loss Function and S/N Ratio for Taguchi Techniques

The heart of Taguchi method is its definition of nebulous and elusive term '*quality*' as the characteristic that avoids loss to the society from the time the product is shipped. Loss is measured in terms of monetary units and is related to quantifiable product characteristics. Taguchi defines quality loss via his 'loss-function'. He unites the financial loss with the functional specification through a quadratic relationship that comes from Taylor series expansion [Roy (1990)].

$$L(y) = k(y - m)^2$$

Where, L = loss in monetary unit

m = value at which the characteristic should be set

y = actual value of the characteristic

k = constant depending on the magnitude of the characteristic and themonetary unit involved.

$$L(y) = \{k(y_1 - m)^2 + k(y_2 - m)^2 + \dots\dots + k(y_n - m)^2\} \quad \dots\dots\dots\dots\dots (4.1)$$

Where y_1, y_2, ……y_n = values of characteristics for units 1,2,…..n respectively

n = number of units in a given sample

k=constant depending upon the magnitude of characteristic and the monitory unit involved

m = Target value at which characteristic should be set.

Equation (4.1) can be written as:

$$L(y) = k(MSD)$$

Where, MSD denotes mean square deviation, which presents the average of squares of all deviations from the target value rather than around the average value.

1. Larger the better:

$$\left(S/N\right)_{HB} = -10\log(MSD_{HB}) \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

where

$$MSD_{HB} = \frac{1}{R}\sum_{j=1}^{R}(1/y_j^2)$$

2. Smaller the better:

$$\left(S/N\right)_{LB} = -10\log(MSD_{LB}) \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.3)$$

Where $MSD_{LB} = \frac{1}{R}\sum_{j=1}^{R}(y_j^2)$

3. Nominal the best:

$$\left(S/N\right)_{NB} = -\log(MSD_{NB}) \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.4)$$

where

$$MSD_{NB} = \frac{1}{R}\sum_{j=1}^{R}(y_j - y_o)^2$$

R = Number of repetitions

5. Experimentation and Data Collection

After selection of machining parameters and their ranges the turning experiments were performed according to the designof experiments. Various precautionary measures were taken during experimentation such as each set of experiment was repeated three times to reduce error, each set of experiments was performed at room temperature. The next step is to design the matrix experiment and define the data analysis procedure. The experiment is performed against each of the trial conditions of the inner array. Table 6.1 and Table 6.2 shows the results of surface roughness and tool wear with coated and uncoated carbide tools. The cutting speed, feed rate, and depth of cut parameters were programmed into the CNC program. The tool inserts were changed as needed in each set. The surface roughness measurement process included the use of surface roughness tester, as well as all the necessary hardware to align the stylus motion perpendicular to the axis of the turned part during the measurement. The tool wear is measured with the help of optical microscope.

Table shows the various results obtained according to the design matrix L9 of Taguchi technique during turning of AISI H13 die tool steel with coated tool.

Table 5.1 Parameters, Codes and Level Values Used for the Orthogonal Array

Parameter	Code	Level 1	Level 2	Level 3
Cutting Speed (m/min)	A	140	170	200
Feed Rate (mm/rev)	B	0.05	0.1	0.15
Depth of Cut (mm)	C	0.75	1.50	2.25

6. Result and Discussion

Table 6.1Results of Surface Roughness with coated Carbide Tools

S. No.	Cutting Speed (m/min)	Feed Rate (mm/min)	Depth of Cut(mm)	Surface Roughness with Coated Tool (micrometer)	Flank Wear (micrometer)
1	140	0.05	0.75	1.50	100.1
2	140	0.1	1.50	1.96	104.5
3	140	0.15	2.25	2.47	115.5
4	170	0.05	1.50	1.42	97.5
5	170	0.1	2.25	2.87	96.5
6	170	0.15	2.25	1.69	107.2
7	200	0.05	2.25	1.69	101.2
8	200	0.1	0.75	2.38	100.8
9	200	0.15	1.50	3.90	99.5

Table 6.2Results of Surface Roughness with uncoated Carbide Tools

S. No.	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut(mm)	Surface Roughness with Uncoated Tool(micrometer)	Flank Wear (micrometer)
1	140	0.05	0.75	1.69	204.12
2	140	0.1	1.50	2.18	221.5
3	140	0.15	2.25	2.81	290.5
4	170	0.05	1.50	1.89	228.5
5	170	0.1	2.25	3.11	244.5
6	170	0.15	0.75	3.43	269.8
7	200	0.05	2.25	1.83	308.4
8	200	0.1	0.75	2.59	237.5
9	200	0.15	1.50	1.50	253.6

7.Data Analysis

The experiment was carried by using the parametric approach of the Taguchi method. A number of methods have been suggested by Taguchi for analyzing the data: observation method, ranking method, column effect method, ANOVA, S/N ratio, plot of average responses, interaction graphs, etc. In the present analysis, various methods are used.

1. ANOVA for S/N data
2. Plot of average response curves

Table 7.1 shows that the cutting speed, feed, and depth of cut are responsible and have influence on surface roughness height R_a while turning coated carbide inserts. The influence of feed is the most significant as according experimentation. And the influence of depth of cut is significant and cutting speed is less influencing factor as compare to other on the surface roughness height *Ra* during turning of AISI H13 steel.

Table 7.1Response Table for Signal to Noise Ratios: Smaller is better

Level	A	B	C
1	-5.740	-3.708	-6.960
2	-7.344	-7.511	-6.904
3	-7.970	-9.834	-7.190
Delta	2.230	6.126	0.286
Rank	2	1	3

7.1 Plots for coated carbide tool

The S/N ratio and Ra effects data plotted in these graphs can be used to determine the optimal set of parameters from this experimental design. The graphs indicate the levels at which the S/N ratio and Ra effects are at their optimal magnitudes; that is, the S/N ratio effect is at its highest magnitude, and the Ra effect is at its lowest magnitude. The optimized levels of each of the other three parameters were included in the confirmation run.
As seen in Table 5.1 for coated carbide insert, the selected cutting speed speed was at level 2 (170 m/min), the optimal feed rate was at level 3 (0.15 mm\rev), and the optimal depth of cut was at level 2 (1.50 mm).

Main Effects Plot for SN ratios

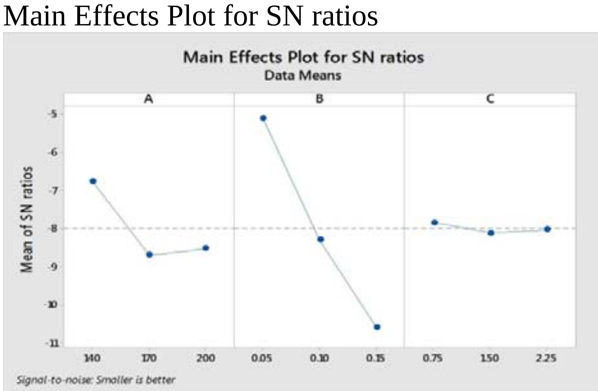

Figure 7.1 Signal to Noise Ratio for the response

Table 7.2 Response Table for Means

Level	A	B	C
1	2.227	1.803	2.570
2	2.810	2.627	2.693
3	2.810	3.417	2.583
Delta	0.583	1.613	0.123
Rank	2	1	3

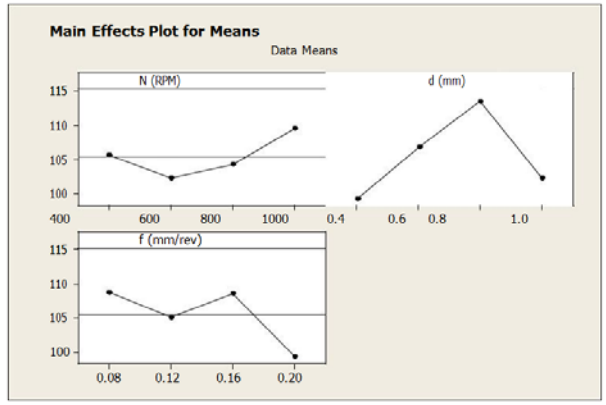

Figure 7.2 Mean effect plot for Flank Wear

7.3 Analysis for Un-Coated Carbide

This table show the S/N ratio for three levels and shows the smaller one is better.

Table 7.3 Response Table for Signal to Noise Ratios

Level	A	B	C
1	-6.767	-5.112	-7.843
2	-8.697	-8.297	-8.120
3	-8.526	-10.581	-8.026
Delta	1.930	5.469	0.277
Rank	2	1	3

7.4 Plots for Uncoated Carbide Tool

The S/N ratio and Ra effects data plotted in these graphs can be used to determine the optimal set of parameters from this experimental design. The graphs indicate the levels at which the S/N ratio and Ra effects are at their optimal magnitudes; that is, the S/N ratio effect is at its highest magnitude, and the Ra effect is at its lowest magnitude. The optimized levels of each of the other three parameters were included in the confirmation run.
As seen in Table 5.1 for coated carbide insert, the selected cutting speed speed was at level 2 (170 m/min), the optimal feed rate was at level 3 (0.15 mm\rev), and the optimal depth of cut was at level 2 (1.50 mm).

Figure 7.3 Signal to Noise Ratio for the response

The Table 7.4 show the response for the mean values.

Table 7.4 Response Table for Means

Level	A	B	C
1	2.227	1.803	2.570
2	2.810	2.627	2.693
3	2.810	3.417	2.583
Delta	0.583	1.613	0.123
Rank	2	1	3

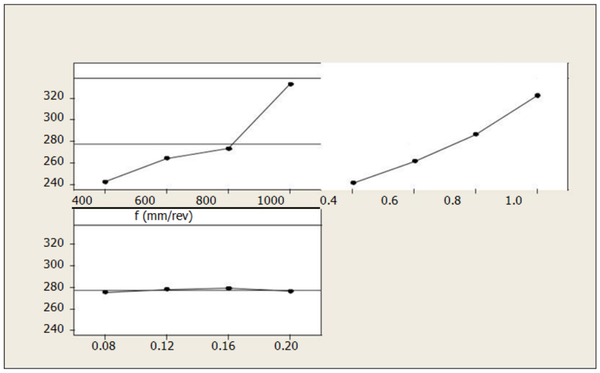

Figure 7.4 Main effect plot for flank wear

8.Comparison between Coated Carbide and uncoated Insert Performance:

The performance of both coated and Un-coated carbide insert can be seen from Fig.4.5. It can be concluded from the figure that coated carbide insert is a better option for the selected range of the control factors.

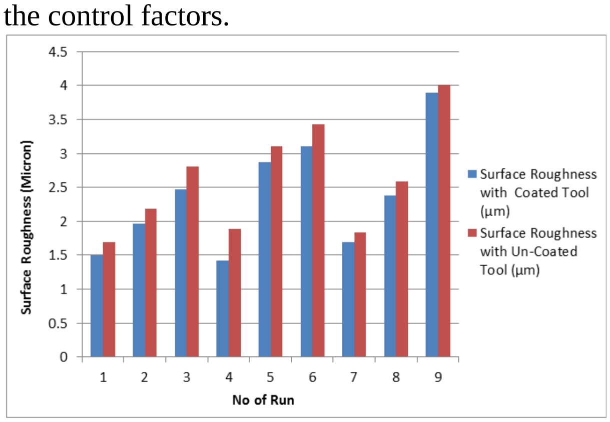

Figure 8.1 Comparison Graph for surface roughness

9. Comparison For tool wear between coated and un-coated tools.

Performance of coated and un-coated tool it is observed that performance of coated tool in case of flank wear and surface roughness is more efficient than un-coated tool. The minimum value of flank wear for coated tool and un-coated tool is 99.5 µm and 253.6 µm respectively, the minimum value of surface roughness for coated and un-coated tool is 3.90 µm and 1.50 µm respectively. The results indicate that turning of AISI H13 using coated tool possess good surface finish with less flank wear. The result indicates that the performance of single layered (AlTiN) coated tool is better than multi layered (TiN, Al_2O_3, TiCN, TiN) CVD coated tool (Chinchanikar and Choudhury, 2013).

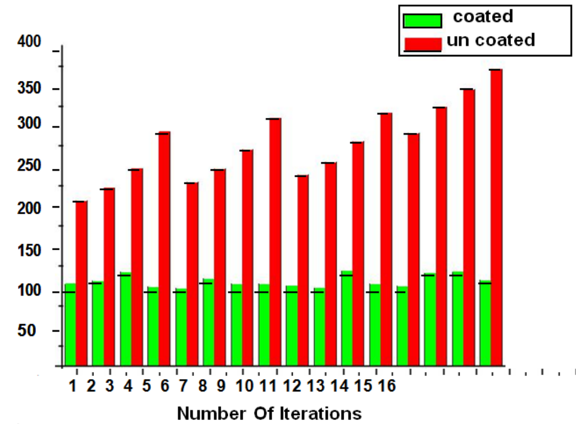

Figure 8.2 Comparison Graph for Flank Wear

10. Prediction of Mean:

After determination of the optimum condition, the mean of the response at the optimum condition was predicted. This mean was estimated only from the significant parameters. The ANOVA identified the significant parameters. The optimum value of Ra was predicted at thes elected level of significant parameters cutting speed (A3), Feed rate (B3), and Depth of cut (C3) for coated carbide insert and cutting speed(A2),feed rate (B3) and depth of cut(C3) for Un-coated carbide insert.

Experiments	Cutting speed	Feed rate	Depth of cut
Optimum levelsfor coated carbideInsert	200m/min	0.15mm/rev	2.25mm
Optimum levelsfor Un-coatedcarbide insert	170m/min	0.15mm/rev	1.50mm

11. Conclusion:

The present study was to evaluate the optimum machining parameters for surface roughness and tool wear during turning of AISI H13 die tool steel with coated and uncoated carbide tools. The study presented an efficient method for determining the optimal turning operation parameters for surface finish under varying conditions through the use of the Taguchi parameter design process. For optimizing the machining parameters Taguchi L9 design of experiments have been used. The use of the L9 (3^3) orthogonal array, with three control parameters allowed this study to be conducted with two different carbide insert. The study found that the various factors have different effects on the response variable such as feed rate have the most influential effects while turning with both carbide insert. The Optimum parameter setting for surface roughness for coated carbide inserts are at a cutting speed of 200 m/min, feed rate 0.15 mm/rev. and depth of cut 2.25 mm and for uncoated inserts are at a cutting speed of 170 m/min, feed rate 0.15 mm/rev. and depth of cut 1.50 mm. Coated tool is more efficient than uncoated tool in case of flank wear.

12. SCOPE FOR FUTURE WORK

This study presented an efficient method for determining the optimum parameter of die tool with coated and uncoated carbide tool for increasing the surface roughness and decreasing the tool wear under varying condition through the use of the Taguchi experimental design. The process parameter were cutting speed, feed rate and depth of cut.

For future scope, this process can be done with more process parameter like tool nose radius and also can be done for increasing the tool life and study about material removal rate.

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