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Comparative Performance Analysis of Insert Geometry by CNC turning of HSS (M2) and Taguchi Method

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Abstract:
In this research work the effect of variation of geometric parameter of insert such as nose radius on surface roughness and material removal rate (MRR) in a CNC turning operation for HSS (M2) are studied by using the Taguchi method. The experimental trials are conducted under varying process parameters including cutting speed, feed rate, depth of cut and insert nose radius. An L9 orthogonal array, the signal-to-noise (S/N) ratio are employed to the study the performance characteristics in the CNC turning of HSS (M2) usingTNMG160404,TNMG160408 and TNMG16-0412 Tin coated carbide inserts on CNC turning center. The conclusions revealed that the feed rate and nose radius are the most influential factors on the surface roughness and material removal rate (MRR) in CNC turning process.

Key words -Insert, Taguchi, S/N ratio, HSS (M2), MRR, Surface Roughness, Nose radius.

1. INTRODUCTION

The turning process is fundamental machining process and every industry consists of this process therefore is important one. In the present time the technology of CNC turning machine is improved significantly. Tool geometry parameters play a important role in determining the overall machining performance, including cutting forces, tool wear, surface finish and chip formation. The significance of optimizing tool geometry is highlighted recently to be of huge economic significance in maximizing tool life in machining. Various angles are vital when introducing the cutting tool's edge into a spinning work piece. These angles include the angle of inclination, rake angle, effective rake angle, lead or entry angle, and tool nose radius.

On the strength of the exhaustive review of work done by previous investigators [1- 9], it is found that a very little work has been found in use of inserts with different nose radius as a parameter for optimizing the surface properties. The study demonstrates detailed methodology of the proposed optimization technique which is based on Taguchi technique .Material removal rate of a turned product along with surface finish of work piece have been optimized.

2. DESIGN OF EXPERIMENT

In the present study, the method employed while designing experiments is Taguchi Method. It is oldest method for optimization. It is flexible and simple method to apply for industrial optimization problems. It is industrial accepted method for optimization. In the present study, the orthogonal matrix is designed by Minitab 14 software. The selection of particular orthogonal matrix from the standard orthogonal array depends on number of process parameters considered in study. In the present study cutting speed,feed rate, depth of cut and nose radius these four process parameters have used and number of levels equal to 3 and total degree of freedom (DOF) for 4 parameters are equal to 4 × (3-1) = 8. Therefore, minimum number of experiment equal to total DOF for parameters +1 = 8 + 1= are 9. In this research work, the interactions between factors are not considered. So, $L_9\,(3^4)$ orthogonal array of Taguchi is selected.

3. EXPERIMENTATION PHASE

3.1 Process parameters and levels use

The CNC turning lathe is programmed by cutting speed, feed, depth of cut and insert nose radius. The process parameters selection and their level finalization is very important initial stage of Taguchi optimization technique .The parameters and levels used in the experiment are shown in Table 1. In the present research work, the actual running part such as twist drill is taken for trials therefore the levels are fixed by referring actual condition available at work station.

Levels	Control factors			
	Cutting speed	**Feed rate**	**Depth of cut**	**Nose radius**
L1	150	0.15	0.5	0.4
L2	220	0.22	0.75	0.8
L3	300	0.28	0.8	1.2

Table 1: Process parameters and levels

3.2 Design of orthogonal matrix

In the present work there are three levels and four factors. According to Taguchi approach L9 has been selected. So, according to Taguchi L9 array design matrix of variables are formed.

Exp.No.	Cutting speed (m/min) A	Feed rate (mm/rev) B	Depth of cut (mm) C	Nose radius (mm) D
1	150	0.15	0.5	0.4
2	150	0.22	0.75	0.8
3	150	0.28	0.8	1.2
4	220	0.15	0.75	1.2
5	220	0.22	0.8	0.4
6	220	0.28	0.5	0.8
7	300	0.15	0.8	0.8
8	300	0.22	0.5	1.2
9	300	0.28	0.75	0.4

Table 2: Design of orthogonal matrix

3.3 Selection of cutting tools and work piece material size

The cutting tool selected for present work is Tin coated carbide inserts. The inserts (ISO coding) used in present work are TNMG160404, TNMG160408, and TNMG160412. All inserts has zero clearance angle. The tool holder used is HCLNL 2525M0904.The work piece material used for present experimental work is HSS (M2) circular bars (ϕ 18mm x 120mm).

3.4 Chemical compositions of HSS (M2) and properties of work piece

The chemical composition of HSS (M2) is as shown in Table 2. The properties of material depend up on the chemical composition of material. The HSS (M2) material is generally used for manufacturing taps, broaches, reamers, twist drills. It is cutting tool material.

Element	Symbol	%
Carbon	C	0.86/0.96
Chromium	Cr	3.8/4.5
Molybdenum	Mo	4.9/5.5
Tungsten	W	6.0/6.75
Vanadium	V	1.7/2.2
Cobalt	Co	Nil

Table 3: Chemical composition of HSS (M2) [12]

The properties of work piece is given as, Density = 8.028×10^{-3}g/mm^3, Melting point = 4680^0 , Hardness = 62/65 HRC, Compressive yield strength = 3250 Mpa, Poisson's ratio = 0.27/0.30 and Elastic modulus = 210Gpa.

3.5 Experimental unit and procedure

The trials are conducted on CNC turning centre for HSS (M2) materials that is shown in Figure1. ACE Designers Ltd. CNC turning centre with Fanuc Oi-mate-TDcontroller is used to carry out the trials.

Figure1: Experimental unit

The specification of experimental unit is as shown in Table 1. The all trials are conducted in dry environment and at 2800 Rpm spindle speed. The factors such as tool wear, tool vibration are not considered in present study.

Parameters	Value
Max.turning diameter	300 mm
Max.turning length	400 mm
Max.spinde speed	3500 rpm
Supply voltage	380 v/4.5v
Number of axis	2
Control voltage	24 VDC
Back up fuse	63
Rated current	24/22 Amps
Environment	Dry

Table 4: Specification of CNC turning center [11]

The CNC machine is programmed as per design of matrix and one by one two sets of nine trials are conducted for two response values such as material removal rate and surface roughness. Initial and final weights of work pieces are noted using digital weighing machine. Machining time is also recorded. Following equations are used to calculate the response material Removal Rate:

$$MRR = \frac{Wi - Wf}{\rho s X Cycletime} mm^3 / \sec$$
(1)

Where, W_i = Initial weight of work piece in *gm*
W_f = Final weight of work piece in *gm*
t = Machining time in seconds
ρs = Density of HSS steel
= ($8.028 x 10^{-3}$ *gm/mm³*)

The surface roughness value is recorded with help of Make–Strumentazione, Model RT10G, and L.C.0.001µm.
The top view of surface roughness tester is shown in Figure 2.

Figure2: Surface roughness tester

The S/N ratio are calculated using equation (2) and (3). The results for S/N ratio calculations are shown Table5.
The conditions of S/N ratio used to find out minimum surface roughness, maximum material removal rate are given as follows:

1. Condition of S/N ratio for surface roughness : smaller is better

$$S/N = -10 * log(\Sigma(Y^2)/n))$$
(2)

2. Condition of S/N ratio for Material removal rate : larger is better

$$S/N = -10 * log\ (\Sigma(1/Y^2)/n)$$
(3)

A	B	C	D	Ra	S/N	MRR	S/N
150	0.15	0.5	0.4	2.3	-7.2	208.9	46.3
150	0.22	0.75	0.8	2.6	-8.4	318.0	50.0
150	0.28	0.8	1.2	2.3	-7.3	368.9	51.3
220	0.15	0.75	1.2	0.7	2.5	225.6	47.0
220	0.22	0.8	0.4	3.3	-10	314.5	49.9
220	0.28	0.5	0.8	3.4	-10	369.3	51.3
300	0.15	0.8	0.8	1.3	-2.5	225.0	47.0
300	0.22	0.5	1.2	1.2	-1.9	311.0	49.8
300	0.28	0.75	0.4	3.8	-11	341.5	50.6

Table 5: Response Table of Ra and MRR along with S/N Ratio

4. OPTIMUM RESPONSE VALUE CALCULATION

The optimal settings and the predicted optimal values for surface roughness and MRR are found out individually by Taguchi's approach. The optimum response value can be calculated using following formulation. Let T' = average results for 9 runs of response factor

$$T' = \frac{\sum_{i=1}^{9} M}{9}$$
(4)

Response $factor_{optimum}$ = T'+ (A_{n1} – T') + (B_{n2} – T') + (C_{n3} – T') + (D_{n4} – T')
(5)

Where A_{n1} , B_{n2} ,C_{n3}, D_{n4} are corresponding mean values of response factor.
Table 8 shows these individual optimal values and its corresponding settings of the process parameters for the specified performance characteristics. It is observed that the feed is most significantly influences the surface roughness and material removal rate followed by nose radius. The mean values for both response factors are calculated by Minitab 14 software (see Table 6 and 7).

Levels	Mean value of MRR			
	A	B	C	D
L1	298.6	219.9	296.4	288.3
L2	303.2	314.5	295.1	304.2
L3	292.6	360.0	302.8	301.9

Table 6: Means of MRR at different levels

Levels	Mean valu	
	A	B
L1	2.430	1.445
L2	2.497	2.420
L3	2.135	3.197

Table 7: Means of Ra at dif

The optimum response values are calculated by equation (5). The final optimum results with their levels are shown in Table 8.

Response factors	Units	Optimum parameters level	Optimum predicted value
MRR	mm^3/sec	A2 B3 C3 D2	375.842
Ra	µm	A3 B1 C2 D3	0.350

Table 8: Predicted optimal values and setting of process parameters

5. RESULTS AND DISCUSSIONS

The graphs are developed using Minitab 14 software. These results are analyzed using S/N ratio for the purpose of identifying the significant factors which affect the surface roughness and material removal rate. The graphs shows the variation of individual response with the four parameters i.e. cutting speed, feed, depth of cut and nose radius separately. In the plots, the x-axis shows the value of each process parameter at three level and y-axis the response value. Figure3shows the main effect plots for MRR. It is observed that the maximum MRR is obtained at the 220 m/min. of cutting speed, 0.28mm/rev of feed, 0.80mm depth of cut and 0.8 mm nose radius. Figure4 shows the main effect plot for surface roughness. It is observed that the maximum surface finish or minimum roughness is obtained at the 300 m/min of cutting speed, 0.15mm/rev of feed, 0.75mm depth of cut and 1.2mm nose radius.

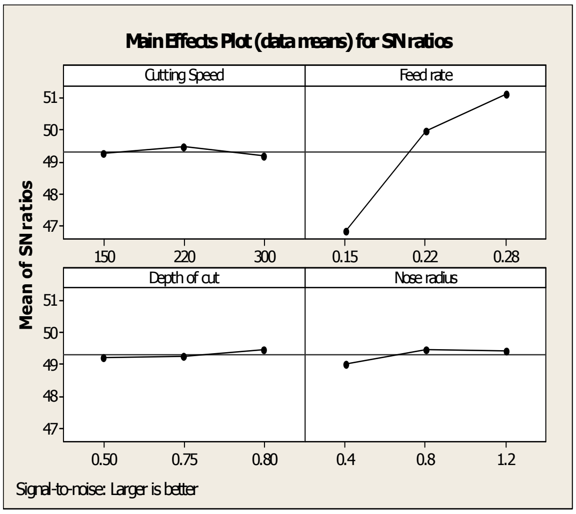

Figure3: Main effect plots for MRR

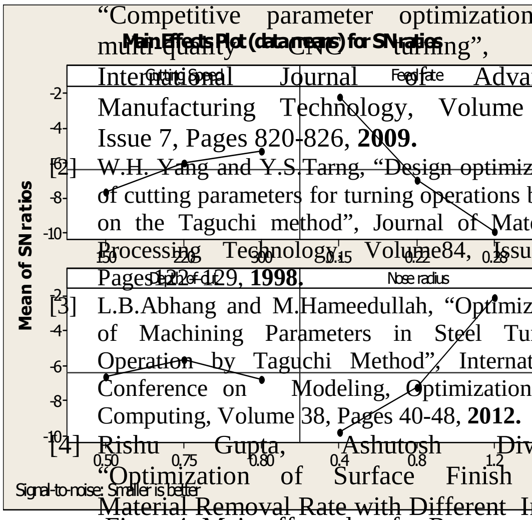

Figure4: Main effect plots for Ra

6. CONCLUSIONS

The turning tests are performed on HSS (M2) work piece using three different Tin coated carbide insert of varying nose radius on CNC machine. The effect of cutting speed, feed rate, depth of cut and nose radius are studied on the machined surface roughness and material removal rate (MRR). Based on the results obtained, the following are the conclusions drawn:

I. The analysis of the experimental observations highlights that MRR and Ra values in CNC turning process is greatly influenced by feed rate and nose radius.

II. The optimal level of process parameters for optimum value of surface finish (0.312 µm) is cutting speed 300 m/min, feed rate 0.15mm/rev, depth of cut 0.75mm, nose radius 1.2mm.

III. The optimal level of process parameters for optimum value of material removal rate (379.67mm^3/sec) is cutting speed 220m/min, feedrate 0.28mm/rev, depth of cut 0.80mm, nose radius 0.8mm.

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