An Experimental Analysis of High Speed Turning of Al 7075 using Cemented Carbide Tool for Process Optimisation

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Abstract

Machining of Aluminium is a tedious task due to its tendency of forming built up edge on the cutting tool, leading to deteriorated surface finish. The cutting parameters have to be chosen cleverly so that the problem can be resolved. The present work is an attempt for optimization of the process parameters to provide the best solution to optimize the tool wear, surface roughness and material removal rate during high speed turning of Al 7075 using uncoated cemented carbide insert. The experiments were performed on a CNC lathe. Three levels of cutting speed, feed and depth of cut were taken and Box-Behnken design was chosen to design the experiments. The process performance was analysed in terms of surface roughness produced, tool wear and material removal rate. Regression equations were formed and the factorial graphs along with response surfaces were analysed. It was found that for the selected range of cutting parameters the surface roughness deceased with increase with both speed and feed whereas it first decreased with increase in depth of cut and then started increasing again. Similarly the tool flank wear first decreased and then started increasing again with increase in feed. Also, it deceased with increase in cutting speed. Whereas with increase in the depth of cut, the flank wear increased. The material removal rate always increases with increase in value of process parameters. The cutting parameters were proposed for optimized process performance in terms of surface roughness, MRR and tool wear.

Keywords: Machining, Turning, Surface roughness, Tool wear.

1. INTRODUCTION

High speed machining is increasingly being used in aerospace industry. The quality of the surface finish is an important requirement for the work-pieces in today's manufacturing engineering. In the metal-cutting process the work-piece material is compressed and subjected to a localized plastic deformation. Usually, the material removal witnesses hostile environment with a quite high temperature and pressure in the machining zone. The science of metal cutting is sneeded to be understood to solve practical problems associated with efficient material removal. To achieve this, the principles which govern the cutting process should be clearly understood. Knowledge of these principle is helpful in predicting the practical results of the machining process and, thus, the selecting the optimum cutting conditions for a particular case.

Surface finish is considered as a major manufacturing goal for turning operations by many of the existing research works. The machining process performance is commonly governed by speed, feed rate and cutting depth, which are frequently determined based on the machine performance, however the product characteristics thus generated are not always guaranteed to be acceptable. Therefore, the optimum turning conditions must be accomplished. Parameter optimization for surface roughness is a problem hard to be solved because of the interactions between the parameters. The issue related to the enhancement of the product quality and production efficiency may always be related to the optimization procedures.

Lalwani et al. [1] studied the effect of cutting parameters on cutting forces and surface roughness during turning of hardened steel. Dickinson[2]surveyed about the factors affecting the surface roughness. Grieve et al. [3] also studied the causes affecting surface parameter.

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Fischer and Elrod [4] developed a turning model in which tool nose radius and feed rate are taken into account but the cutting speed is ignored. Yang and Tarng [5] studied on optimal cutting parameters using Taguchi method in turning. Singh and Rao [6] studied the effects of cutting conditions and tool geometry on the surface roughness in the finish hard turning. Choudhury and El-Baradie [7] used RSM and factorial design to estimate the surface roughness during the turning process of high strength steel. Nian et al. [8] investigated the optimization of CNC turning operations by Taguchi method with multiple performance characteristics. On the other hand, Lin et al. [9] developed a network model to estimate the surface roughness and cutting forces. Wang et al. [10] investigated the effect of tool nose vibration on surface roughness during turning theoretically and experimentally. Above works show the strong dependency of process performance on the chosen cutting parameters during machining of various materials. The works also underline the importance of design of experiments and robustness of surface response methodology in predicting the trends of the variations in response variables w.r.t. input parameters.

The objective of the present work is to optimize the material removal rate, surface roughness & tool wear to get an economical production during machining of Al7075 using a coated carbide tool insert. It is proposed to use the Response Methodology Technique for the optimisation of the process. It was decided to perform the turning experiments under dry conditions.

2. EXPERIMENTATIONS

Al 7075 is used in this experiment as work piece. The material was obtained in the form of cylindrical bar of 32 mm as initial diameter and was machined for 50 mm in length. Uncoated carbide insert CNMG120408 was used as cutting tool. The machining was performed in dry condition. The experiments were designed by following Box-Behnken design of

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experiments, considering three main influencing process parameters such as cutting speed, feed rate and depth of cut at three different levels namely Low, Medium and High. In the present work using three-level Box – Behnken experimental design, a three level L-15 array was used to design and conducted the experiments. Table 1 shows the values of various parameters used for experiments.

Table 1

Levels of process variables

S.No.	Process Parameters	Levels		
		-1 (Low)	0 (Medium)	+1 (High)
1	v (m/min)	100	150	200
2	f (mm/rev)	0.1	0.15	0.2
3	d (mm)	0.5	1.0	1.5

The turning experiments were carried out in dry cutting conditions on a CNC lathe machine (Make: Micromatic Controller: FANUC Series Oi Mate-TD). Taylor and Hobson made Surtronic 3-P surface analyser was used to measure the surface roughness of work piece. A Dino-Lite make Optical Microscope available at IIT Kanpur was used for wear measurements. The material removal rate was calculated based on cutting parameters values using the relationship in eqn. (1)

MRR= v.f.d mm^3/s, (1)

Where 'v' is cutting velocity in mm/s., 'f' is feed in mm/rev and 'd' is the depth of cut in mm. After experimentations, the measurements were made and the measured values have been tabulated in table 2:

Table 2

Observation table

Run No.	v (m/min)	f (mm /rev)	d (mm)	MRR (mm^3 /s)	Ra (µm)	Tool wear (mm)
1	100	0.1	1	166.66	3.292	0.225
2	200	0.1	1	333.33	3.974	0.104
3	100	0.2	1	333.33	2.166	0.187
4	200	0.2	1	666.66	2.18	0.082
5	100	0.15	0.5	125	2.656	0.005
6	200	0.15	0.5	250	1.232	0.044
7	100	0.15	1.5	375	1.316	0.218
8	200	0.15	1.5	750	1.218	0.005
9	150	0.1	0.5	125	1.306	0.052
10	150	0.2	0.5	250	1.678	0.224
11	150	0.1	1.5	375	2.5	0.22
12	150	0.2	1.5	750	1.466	0.082
13	150	0.15	1	375	2.576	0.068
14	150	0.15	1	375	2.578	0.067
15	150	0.15	1	375	2.577	0.066

3. REGRESSION ANALYSIS

Study was carried out to analyse the effect of various process variables on MRR, surface roughness and tool wear for a turning operation, based on experimental observations and response surface methodology. The second order response surface representing the surface roughness can be expressed as a function of cutting speed, feed and depth of cut, being the input variables of machining (turning) process. The relationship between the input factors and the performance parameters are expressed by multiple regression equations, which may be used to predict the expected values of the performance parameter for any factor value with in selected range.

If all variables are assumed to be measurable, the response surface can be expressed as $y=f(x_1, x_2, \ldots, x_k)$. The goal is to optimize the response variable y. It is assumed that the independent variables are continuous and controllable by experiments with negligible errors. Usually a second-order model is utilized to find a suitable approximation for the functional relationship between independent variables and the response surface. The functional relationship between independent variables and the response can be given as:

$$y = \beta_o + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_i \sum_j \beta_{ij} x_i x_j + \varepsilon \quad (2)$$

Where ε is the random error.

In matrix form, $y = \beta X + \varepsilon$ (3)

The solution of Eq. (2) can be obtained by the matrix approach[11].

$$\beta = (X^T X)^{-1} X^T Y \quad (4)$$

Second order RSM representing the relationship of each of the output parameters i.e. surface roughness, MRR and tool wear with the input process parameters namely cutting speed, feed rate and depth of cut were generated using the values of the experimental data and are given below-

$$Ra(\mu m) = 1.36 - 0.0169v - 12.4f + 8.57d + 3.9\times10^{-5}v^2 + 92f^2 - 4.27d^2 - 0.067v.f + 0.0133v.d - 14.1f.d \quad (5)$$

$$MRR(mm^3/s) = 375.0 - 2.5v - 2500f - 375d + 16.67v.f + 2.5v.d + 2500f.d \quad (6)$$

$$Toolwear(mm) = 0.091 + 6.3\times10^{-4}v - 6.44f + 0.941d + 2\times10^{-6}v^2 + 31.19f^2 - 0.0139d^2 + 1.58\times10^{-3}v.f - 2.520\times10^{-3}v.d - 3.260f.d \quad (7)$$

Where, v = Cutting speed (m/min)
f = Feed rate (mm/rev)
d = Depth of cut (mm)

4. RESULTS AND DISCUSSION

4.1 Factorial Plots

Factorial plots are used to create main effects and interactions plots to show the graphical relationship between response and input parameters independently. The factorial plot between various response and input parameters taken in consideration in this project has been shown in figure1 ,2 and 3.

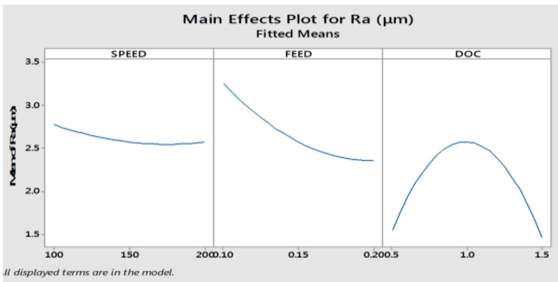

Fig 1. The variation of surface roughness

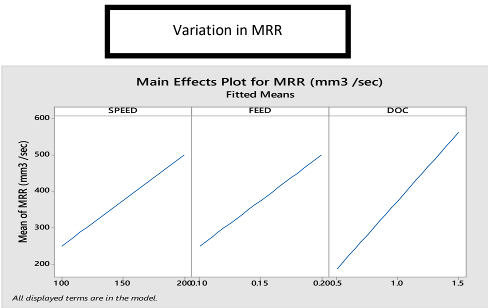

Fig 2. Variation in MRR

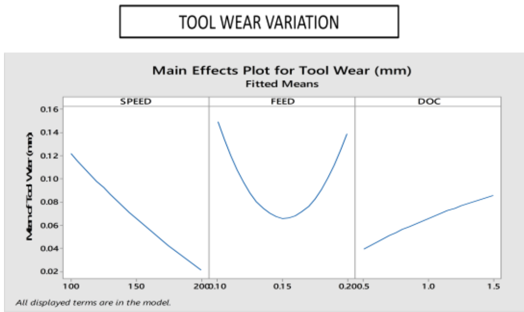

Fig 3. The variation of tool wear

The variation of surface roughness is shown in the figure 1. From the plot it can inferred that the surface roughness reduced with increase in cutting speed. It also reduced with increase in feed value which is against the expected theoretical result. Because in case of aluminium (ductile material), at low speed and feed tool chip friction causes portion of chip to adhere to the rake face of the tool and microchips get deposited at the machined surface of the work piece due to which surface finish deteriorates and surface finish gets better at high feed value due to burnishing effect during machining. Theoretically surface roughness value should increase with increase in depth of cut but in case of aluminium, at higher depth of cut surface roughness decreases due to burnishing effect and work piece looks shinier. Fig.2 shows that the variation of MRR with respect to speed, feed and depth of cut is linear which is as expected.

From fig. 3 it is evident that tool wear decreased with increase in speed and increased with increase in depth of cut while for feed it is first decreasing and then increasing. As cutting speed increases, there are less possibilities of built up edge formation which results into low tool wear. At low feeds there may be more ploughing of metal instead of cutting due to which surface finish is not good. As feed increases the cutting is more predominant, so better surface finish is encountered. As feed is increased further the surface finish again deteriorates due to feed marks and higher groove formation.

4.2 Response Surface Analysis

3-D surface plots were drawn for different combination of parameters to analyze the trend of variation of response within the selected range of input parameters and also influence of each parameter over the other parameters. Fig. 4 shows variations of Surface roughness. It shoes that surface roughness deceases with cutting speed and feed whereas with depth of cut it first increases and then decreases, this may be due to reduction in built up edge generation which is a common citing in machining of Aluminium alloys. The tool wear is found to be decreasing with cutting speed which may be due to low BUE generation that results in low tool wear (Fig. 5). With increase in depth of cut the tool wear increases which may due to high chip load resulting into higher temperature and pressure that are the driving factors of BUE formation.

4.3 Optimization of the Parameters

Multi-objective optimisation has been aimed at to achieve better quality coupled with higher productivity. Accordingly optimisation criteria for each response were selected with their objective as given in table 3. This involves an optimality search model, for the various process variables conditions for maximizing the response after designing of experiments and determination of the mathematical model with best fits. The optimization is done numerically and the desirability and response cubes are plotted.

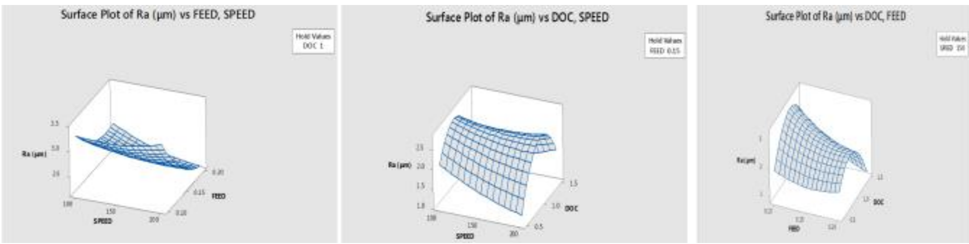

Fig 4. Surface roughness variation surface plot

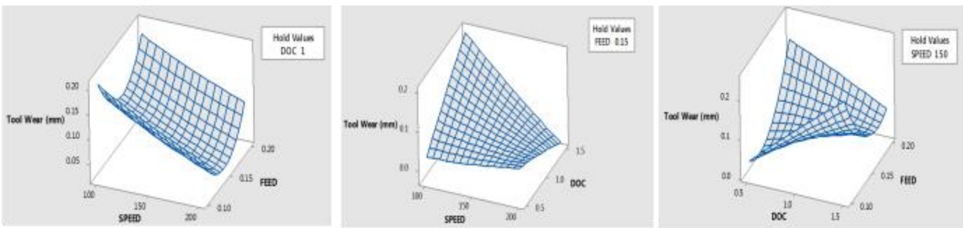

Fig 5. Tool Wear variation surface plot

Table 3

Optimization Table

Response	Goal	Variable	Constraint	Lower	Upper
Ra (µm)	Minimize	Speed (m/min)	Constrain to region	100	200
MRR (mm^3/s)	Maximize	Feed (mm)		0.1	0.2
Tool Wear (mm)	Minimize	Depth of Cut (mm)		0.5	1.5

Best Solution satisfying the above criteria was obtained using the 'MINTAB' software, which is given in figure 6 and it has the overall desirability of 1. The optimized value considering maximum material removal rate along with minimum surface roughness and tool wear obtained using MINI TAB software is given in table 4.

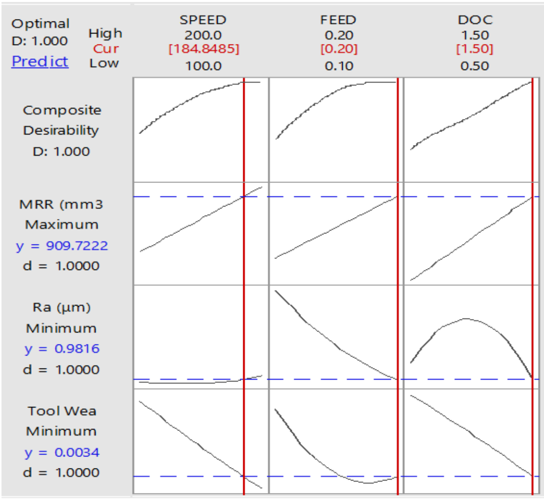

Fig 6. Optimized graph

Table 4

Value of parameters suggested after optimisation

v (m/min.)	f (mm/ rev)	d (mm)	MRR (mm^3/s)	Ra (µm)	Tool Wear (mm)
184.848	0.2	1.5	909.722	0.981	0.0034

When machining AL7075 using coated carbide tools, above optimised cutting parameter values would provide the minimum surface roughness and tool wear along with maximum MRR.

5. CONCLUSIONS

The experimental study was conducted to analyze the effect of input parameters (Cutting Speed, Feed and Depth of cut) on the surface roughness, MRR and tool wear while machining Al 7075 using coated carbide inserts. Data was collected and models were developed using Box-Behnken design of experiments. The following conclusions could be drawn:

- Surface roughness goes down with increase in cutting speed and feed. Whereas it first increased and then decreased with depth of cut.
- The tool wear also deceased with increase in cutting speed and depth of cut where as with increase in feed it first increase and then decreases.
- Response Surface Methodology effectively optimized the machining process.
- For the minimum surface roughness and tool wear and maximum MRR, the recommended cutting parameters for turning of AL 7075 are 184.84 m/min, 0.2 mm/rev feed & 1.5 mm depth of cut with uncoated carbide insert under dry machining conditions.

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