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Parametric Optimization of Lathe Turning for Al-7075 Alloy Using Taguchi: An Experimental Study

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Abstract: *Turning is a machining process in which a cutting tool, commonly a non-rotary tool bit, exhibits a helical path on work piece material. The conventional metal removal process always influenced by the parameters such as, material machinability, cutting tool material, cutting speed and spindle speed, depth of cut, feed rate, tool geometry, and coolant. Optimizing these parameters is a daedal thing so that, Signal to noise (S/N), Analysis of variance (ANOVA) and Taguchi method using statistical software MINITAB are striving to solve these problems in the present scenario. The present paper is aimed at investigating parametric optimization of turning of 7075 Aluminium alloy using Taguchi L_{27} orthogonal array was employed for both Design of Experiment (DOE) and Signal to noise ratio (S/N) to analyze the effects of the selected parameters. The result demonstrates there are different effects of cutting parameters on cutting force, surface roughness and temperature for two samples and compared the samples. Furthermore, surface morphology of the machined specimen is obtained through SEM analysis. This work can be use full to determine the optimum cutting parameters for better machinability.*

Keywords: *Al-7075 alloy, DOE, Optimization, Parameters, Taguchi method, S/N Ratio*

I. Introduction

Turning is a form of machining, which is used to create rotational parts by cutting away unwanted material. Turning is used to produce rotational, typically axi-symmetric, parts that have many features. In turning, the speed and motion of the cutting tool is specified through several parameters. These parameters are selected for each operation based on the work piece material, tool material, tool size, and more. There are several optimization techniques in order to determine optimum parameters for better machining such as, Box-Behnken design, ANOVA, RSM, Taguchi, Regression analysis, FFD, Grey relational analysis, Factorial DOE., etc.

Taguchi method and the Response Surface Methodologies (RSM) were used for reducing the burr height and irregularity in the surface in hole making operation of Al-7075, research carried out by Kilickap et al. [1]., more over they considered Taguchi as a powerful tool to optimize design quality and used to find out optimal cutting parameters. Authors also reported that, the combination of low cutting speed, low feed rate and high point angle were mandatory to overcome burr height, finally lower cutting speeds and feed rates yielded best outcomes of surface roughness at higher point angles.

Wang and Lan [2] considered four parameters as cutting speed, depth of cut, feed and tool nose radius. Theses parameters used for optimizing three responses such as surface roughness, tool wear and material removal rate (MRR) in precision turning on an ECOCA-3807 CNC lathe by using Orthogonal array of Taguchi paired with the Grey Relational Analysis (GRA). They made analysis on optimization approaches using orthogonal array and GRA and aided a satisfactory technique for improving the multiple machining performances in precision CNC turning.

Taguchi and RSM were used for reducing the surface roughness in turning of Discontinuously Reinforced Aluminum Composite (DRAC), composite made with Al-6061 as matrix and 15 vol.% of SiCp of mean diameter 25 µm via pressurized steam jet approach by Shetty et al. [3]. They also reported that, the effect of cutting parameters on surface roughness was evaluated and determined optimum cutting condition to minimize the surface roughness.

Sahin [4] has chosen cutting speed, feed rate and tool hardness as cutting parameters and compared the tool life of Cubic Boron Nitrate (CBN) and Ceramic inserts in turning hard steel using Taguchi method, more over determined the effect of cutting parameters on tool life using orthogonal array, signal to noise ratio and variance analysis.

In this work, turning operation performed on Al-7075 alloy by using High Speed Steel (HSS) cutting tool. Cutting force, surface roughness and temperature are considered as responses, optimization of process parameters are carried out using Taguchi, and developed design matrix for two samples, and done comparisons. Scanning Electron Microscopy (SEM) also performed simply to show surface morphology.

II. Experimental procedure

The experimentation was performed on the Al-7075 alloy, widely used in in mold tool manufacturing, transport applications…etc., due to its high strength and low density. The chemical composition has shown in table 1, the dimensions of work piece shown in fig. 1. The turning operation was done on TURN MASTER 350 Lathe which is shown in Fig. 2. (b), lathe tool dynamometer attached with strain gauge is shown in Fig. 2. (c) Used to measure the cutting force(s) is based on three principles. They are following as i). Measurement of elastic deflection of a body subjected to the cutting force, ii). Measurement of elastic deformation (strain induced by the force) and iii). Measurement of pressure developed in a medium by the force. While machining takes place the temperature raise measured by using Infrared Pyrometer (Non-contact infrared temperature measuring gun) which is shown in Fig. 2. (d), after completion of each trial the surface roughness calibrated with Mitutoyo Surface Roughness tester (SJ-201P) with display of LCD matrix, stylus material as Diamond has shown in Fig. 2. (e), and finally surface morphology has studied via Scanning Electron Microscope (CarlZeiss model EVO MAIS at S. V. University).

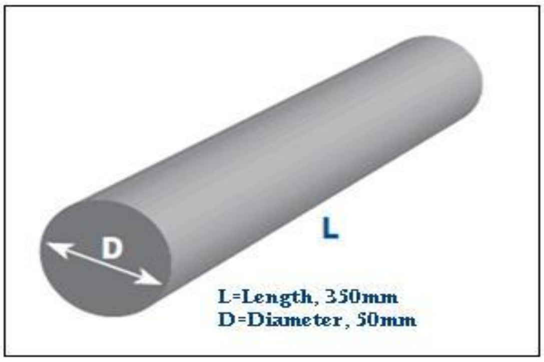


Fig. 1. Dimensions of the work piece.

Table 1: Chemical composition, in wt. % of Al-7075 alloy

Component	Wt. %	Component	Wt. %	Component	Wt. %
Al	87.1-91.4	Mg	2.1-2.9	Zn	5.1-6.1
Cr	0.18-0.28	Mn	Max 0.3	Other each	Max 0.05
Cu	1.2-2	Si	Max 0.4	Other total	Max 0.15
Fe	Max 0.5	Ti	Max 0.2		

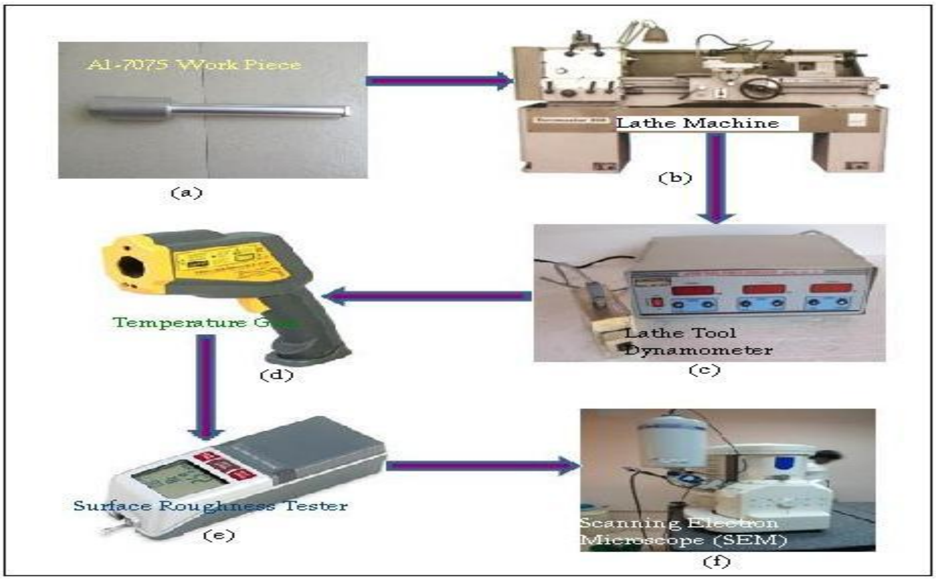


Fig. 2. Experimental Sequence

III. Experimental design

The conventional experimental design methods are too complicate and difficult to use. In addition, huge number of experiments have to be carried out when the number of machining parameters increase.

3.1. Design of Experiments (DOE)

Within the theory of optimization, an experiment is a series of tests in which the input variables are changed according to a rule, in order to identify the reasons for the changes in the output response. Montogomery [5]. The choice of suitable DOE technique depends also on the aim of the experimentation. If a more precise computation of the main and some interaction effects must be accounted for, a factorial or a full factorial method is better. There are three aspects of the process that are analyzed by a designed experiment:

- **Factors** or inputs to the process. Factors can be classified as either controllable or uncontrollable variables. Noise Factor is an uncontrollable which causes variability under normal conditions, but can be controlled during the experiment using blocking and randomization.
- The DOE technique and the number of **levels** are to be selected according to number of experiments which can be afforded. This mean the number of different values a variable can assume according to its discretization.
- **Response** is the output of the experiment, determining where to set the influential controllable variable so that the response is almost always near the desired optimal value, so that the variability in the response is small, so the effects of uncontrollable variables are minimized.

Hence, 27 experiments $n^p=3^3=27$, [where n= number of levels, p= number of parameters] have been conducted on two sample work pieces at different machine speed, feed and depth of cut, but conducting 27 experiments is really a costlier process and it is not economic. So, there is a need for optimizing the number of experiments to be conducted. Therefore the process parameters are optimized using Design of Experiments. In Design of Experiments there are different methods of optimization. Among those, Taguchi Design is selected for finding the relative significance of various parameters.

3.2. Taguchi Method and Experimental Design

The Taguchi method was developed by Genichi Taguchi in Japan to improve the implementation of off-line quality control. The method is related to finding the best value of the controllable factors to make the problem less sensitive to the variations in uncontrollable factors. Signal to noise ratio and orthogonal array are two significant tools used in vigorous design.

Taguchi method treats optimization problem in two categories they are i). Static problems, ii). Dynamic problems. Moreover Static problems concern of determining the best control factor levels, when output considered as the target value. Signal to noise (S/N) ratio is the familiar approach conventionally applied to study the effects of the parameters. The significant factor can be determined by calculating the average of S/N ratio Adesta et al. [6]. There are three Signal to Noise ratios of common interest for optimizing of Static problems.

The S/N ratio characteristics can be divided into three categories given by Eqs. (1)–(3), when the characteristic is continuous [7] as following:

- smaller-the-better

$$\text{SNR} = -10\ log_{10}\frac{1}{n}\left(\sum y^2\right) \qquad \text{eqn. (1)}$$

- larger-the-better

$$\text{SNR} = -\ log_{10}\frac{1}{n}\left(\sum \frac{1}{y^2}\right) \qquad \text{eqn. (2)}$$

- nominal-the-best

$$\text{SNR} = 10\ log_{10}\left(\sum \frac{\bar{y}}{S_y^2}\right) \qquad \text{eqn. (3)}$$

In the experimental analysis the Al-7075 alloy samples were prepared with uniform dimensions shown in fig. 1, the sample 1 and sample 2 were machined with pre-defined values of three cutting parameters shown in table 2.

Table 2: Cutting Parameters

Code	Cutting parameters	Level 1	Level 2	Level 3
A	Cutting speed (rpm)	280	450	710
B	Feed rate (mm/rev)	0.06	0.1	0.14
C	Depth of cut (mm)	0.4	0.8	1

Twenty seven (27) readings were taken by three levels of speed, feed and depth of cut for both sample 1, and sample 2. Experimental Design matrix obtained, which is necessary for construct orthogonal array matrix in Taguchi procedure, moreover experimental results for 27 runs with three (3) replications obtained for both samples.

IV. Results and discussion

The following tables exhibit the results of the S/N average ratios for three pre-defined responses such as, Cutting force, Temperature and Surface roughness. The rank 1 represents most influencing one, rank 2 and rank 3 are the sub sequent followers of the rank 1.

Table 3: Response table based on S/N Ratio for sample-1

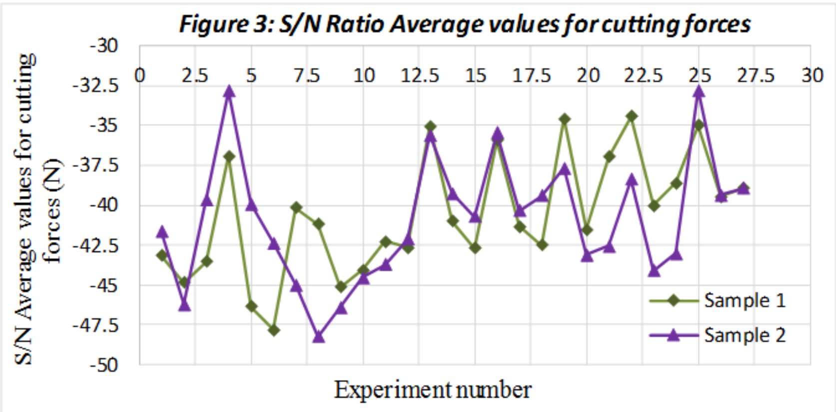
Parameters	***S/N Average values***	***DELTA(∆)=S/N(max)-S/N(min)***			***Rank***
		Cutting forces			
Velocity	S/NA1	-43.244	∆ 1	5.531	1
	S/NA2	-40.844			
	S/NA3	-37.711			
Feed	S/NB1	-41.509	∆ 2	1.547	3
	S/NB2	-40.331			
	S/NB3	-39.961			
Depth of cut	S/NC1	-37.686	∆ 3	4.420	2
	S/NC2	-42.009			
	S/NC3	-42.106			
		Cutting Temperatures			
Velocity	S/NA1	-32.133	∆ 1	0.658	2
	S/NA2	-31.474			
	S/NA3	-32.108			
Feed	S/NB1	-31.789	∆ 2	0.180	3
	S/NB2	-31.958			
	S/NB3	-31.969			
Depth of cut	S/NC1	-31.536	∆ 3	0.734	1
	S/NC2	-31.908			
	S/NC3	-32.2713			
		Surface roughness			
Velocity	S/NA1	10.530	∆ 1	1.946	2
	S/NA2	11.009			
	S/NA3	9.063			
Feed	S/NB1	13.009	∆ 2	6.319	1
	S/NB2	10.904			
	S/NB3	6.689			
Depth of cut	S/NC1	9.975	∆ 3	1.406	3
	S/NC2	11.017			
	S/NC3	9.610			

Table 4: Response table based on S/N Ratio for sample-2

Parameters	***S/N Average values***	***DELTA(∆)=S/N(max)-S/N(min)***			***Rank***
		Cutting forces			
Velocity	S/NA1	-42.374	∆ 1	2.789	2
	S/NA2	-39.585			
	S/NA3	-40.660			
Feed	S/NB1	-42.493	∆ 2	2.496	3
	S/NB2	-40.131			
	S/NB3	-39.996			
Depth of cut	S/NC1	-38.208	∆ 3	4.502	1
	S/NC2	-42.710			
	S/NC3	-41.702			
		Cutting Temperatures			
Velocity	S/NA1	-31.837	∆ 1	0.635	1
	S/NA2	-32.193			
	S/NA3	-32.473			
Feed	S/NB1	-32.333	∆ 2	0.441	3
	S/NB2	-31.891			

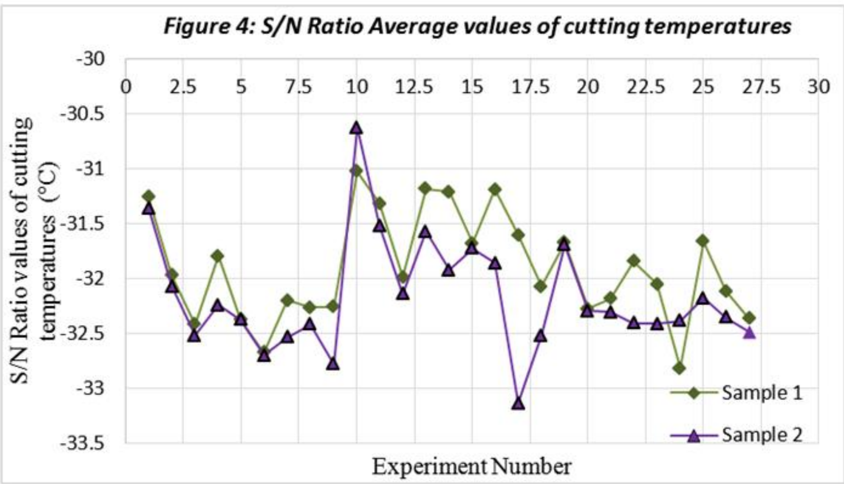
	S/NB3	-32.278			
Depth of cut	S/NC1	-31.830	Δ 3	0.564	2
	S/NC2	-32.277			
	S/NC3	-32.395			
Surface roughness					
Velocity	S/NA1	9.347	Δ 1	0.367	3
	S/NA2	9.714			
	S/NA3	9.501			
Feed	S/NB1	10.799	Δ 2	1.927	1
	S/NB2	8.872			
	S/NB3	8.891			
Depth of cut	S/NC1	10.508	Δ 3	1.668	2
	S/NC2	9.216			
	S/NC3	8.839			

Experiment numbers and mean of the cutting forces obtained through the experiment are plotted as a response graphs considering response (cutting force) along the ordinate and experiment runs along abscissa respectively are shown in Fig. 3.



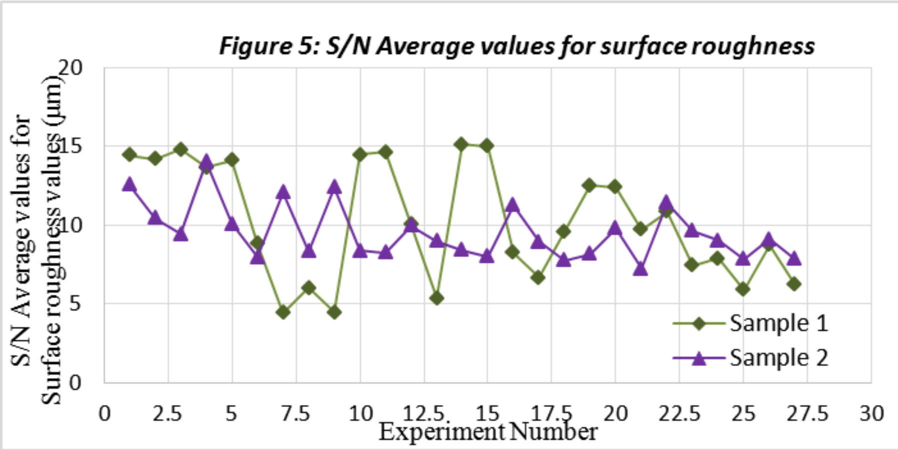
The peak value in Fig. 3 indicates the increase in value of S/N ratios of cutting force due increase in the speed (710 rpm) and the value corresponding to force is -47.838 N. The lowest value indicates the decrease in the S/N ratios of cutting force due to decrease in cutting speed (280 rpm) and the value the value is -38.945 N.

Experiment numbers and mean of the cutting Temperatures obtained through the experiment are plotted as a response graphs considering response (cutting temperature) along the ordinate and experiment runs along abscissa respectively are shown in Fig. 4.



The peak value in Fig. 4 indicates the increase in value of S/N ratios of cutting temperature due increase in the depth of cut (1mm) and the value corresponding to temperature is -32.816 °C. The lowest value indicates the decrease in the S/N ratios of cutting temperature due to decrease in depth of cut (0.4mm) and the value the value is -31.984 °C.

Experiment numbers and mean of the surface roughness obtained through the experiment are plotted as a response graphs considering response (surface roughness) along the ordinate and experiment runs along abscissa respectively are shown in Fig. 5.



The peak value in Fig. 5 indicates the increase in value of S/N ratios of surface roughness due increase in feed (0.14 mm/rev) and the value corresponding to surface roughness is 14.787 μm. The lowest value indicates the decrease in the S/N ratios of surface roughness due to decrease in feed (0.06 mm/rev) and the value the value is 4.426 μm.

Figure 6 shows those SEM images, which depicts the following points:

- Abrasive elements presented in Al 7075 composition causes more were on cutting tool so that flank wear of the cutting tool had been increased, due to which the surface roughness increased on the machined Al 7075.
- Apart from the tool wear, the adhesion properties of the cutting tool and work piece appeared as major factor for influence of surface roughness.
- In-sufficient cooling of Zinc leads to the Zinc Segregation which causes high surface roughness exhibited closely in 5000 X magnification in Fig. 6. (iv).

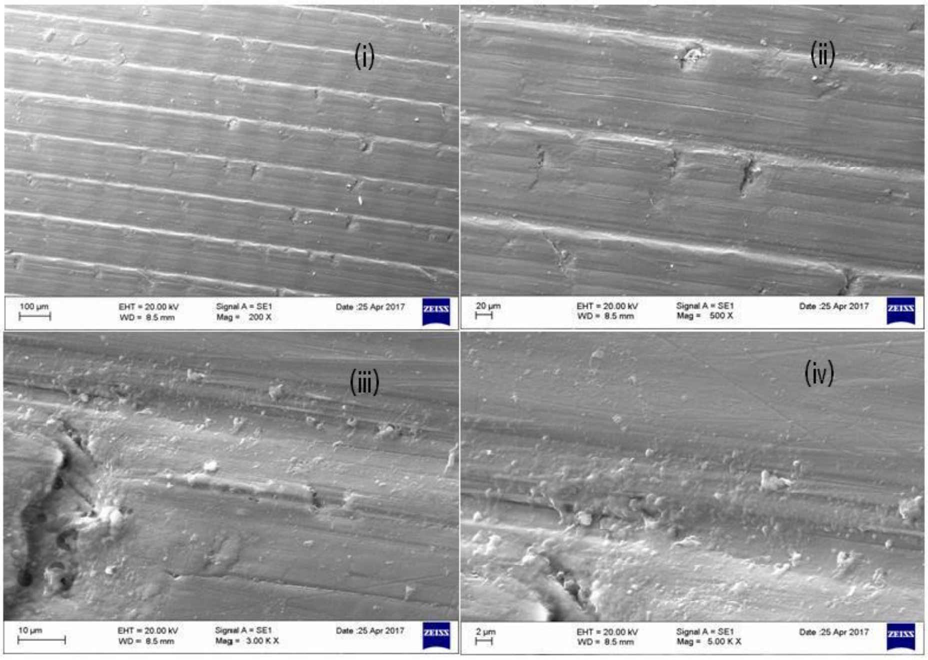


Fig. 6. The SEM of machined surfaces for surface roughness profiles of 7075 alloy specimens 200 X magnification (i), 500 X magnification (ii), 3000 X magnification (iii) and 5000 X magnification (iv).

V. Conclusions

Aluminum 7075 alloy turned with HSS tool and considered Machine Force, Surface Roughness and Temperature as responses. Optimization of process parameters is carried using DOE and Taguchi technique. SEM images are presented to study surface morphology. In the illumination of results the following conclusions can be drawn:

– Depth of cut influences the cutting temperature:
- The maximum temperature attained is 44.7 °C at a depth of cut of 1 mm, speed of 710 rpm and feed of 1mm.
- The minimum temperature attained is 35.5 °C at a depth of cut of 0.4 mm, speed of 280 rpm and feed of 0.4 mm.

– Machine speed influences the cutting force:
- The maximum cutting force attained is 255.52 N at a speed of 710 rpm, feed of 0.14 rpm and depth of cut of 1mm.
- The minimum cutting force attained is 86.551 N, at a speed of 280 rpm, feed of 0.06 rpm and depth of cut of 0.4 mm.

– Feed influences the surface roughness:
- The maximum surface roughness attained is 0.67 μm at a feed of 0.14 mm/rev, speed of 710 rpm and depth of cut of 1mm.
- The minimum surface roughness attained is 0.2 μm at a feed of 0.06 mm/rev, speed of 280 rpm and depth of cut of 0.4 mm.

– Further work is needed to study the influence of other parameters such as, tool geometry, cutting fluids and the influence of cutting parameters on cutting forces and power consumption.

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