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THE STUDY OF PARAMETERS OF TITANIUM ALLOY USING TAGUCHI METHOD

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ABSTRACT

The present work is focused on the machinability study of Titanium (Grade-5) alloy using the CBN cutting tool inserts. Taguchi method has been used for planning experiment and data analysis. An orthogonal array L_9, the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) are used to investigate the cutting characteristics of Titanium alloy (grade-5) using CBN cutting tool. Three cutting parameters namely cutting speed, feed rate and depth of cut each at three levels are optimized with considerations of coefficient of friction and specific wear rate as machinability criteria. For the elaboration of experiments plan the method of Taguchi for three factors at three levels is used, being understood by levels taken by the factors. The array chosen was the L_9 which have 9 rows corresponding to the number of tests. Orthogonal array experiment also minimizes the number of test runs due to pairwise balancing property with three factors and each at three levels. There are 3^3 possible combination and would require 27 trial runs for factorial experiment. Taguchi method reduces it to only 9 experiment which save time and cost.

***Index Terms*—**Machinability, Orthogonal array, Roughness, Taguchi technique.

INTRODUCTION

Titanium is a d block element having 22 atomic number and 47.867 atomic mass discovered in 1791 by William Gregor in Britain. Titanium and its alloys have poor thermal properties and its thermo-mechanical properties due to which its alloys are classified as difficult-to-machine. These properties limit their usage especially in the markets where cost is much more of a factor other than in aerospace. Machining is a basic manufacturing process in almost all industries because it is involved if precision is required and is the most effective process for production. Low machinability of titanium alloys makes us difficult to select the machining conditions and parameters. It is most challengeable task to machine titanium to overcome the short tool life that typically prevents machining people at high cutting speeds.

Metals that contain a mixture of titanium and other chemical elements are termed as Titanium alloys. They have very high tensile strength and toughness [1]. They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures. However, their cost is high both for raw materials and processing thus used in military applications, aircraft, spacecraft, medical devices, highly stressed components such as connecting rods on expensive sports cars and some premium sports equipment and consumer electronics [2-4]. For most applications titanium is alloyed with small amounts of aluminum and vanadium, typically 6% and 4% respectively, by weight [5]. It has a solid solubility which varies dramatically with temperature, allowing it to undergo precipitation strengthening. The heat treatment process is carried out after the alloy has been worked into its final shape before use, allowing much easier fabrication of a high-strength product [6].

Grade 5: In this research, we are using grade 5 Titanium alloy having applications in Aero-engine components, Airframe components, Marine equipment, Offshore oil & gas equipment, Power generation industry, Auto sport components and Medical equipment, with description Ti-6Al-4V(Grade5), also classed as an alpha-beta alloy, is the most widely used of the high strength titanium alloys. The alloy combines its good mechanical strength and low density(4.42kg/dm^3) with excellent corrosion resistance in many media. Grade 5 titanium is fully heat treatable (solution heat treatment plus aging) in sections up to 25mm and can be employed up to around 400°C. This confers improved ductility and fracture toughness with some reduction in mechanical strength. Uses include fracture critical airframe structures and for offshore tubulars. Titanium and its alloys resist a wide range of acid conditions being highly resistant to oxidizing acids, possessing useful resistance to reducing acids and offering good resistance to most organic acids at lower concentrations and temperatures. Titanium should not be used with red fuming nitric acid and is rapidly attacked by hydrofluoric acid. The addition of 0.05% palladium (grade24), 0.1% ruthenium (grade29) or 0.05% palladium and 0.5% nickel (grade25) significantly increases corrosion resistance in reducing acid chloride and sour environments, raising the threshold temperature to over 200°C.

EXPERIMENTAL DETAILS

A. Materials

The objective of the experimental investigation is to establish a relationship between the machining parameters and the machinability performance, including cutting force and surface roughness. The cutting performance tests were performed on Titanium (Grade-5) alloy in the form of round bars. The hardness of the bar is 35 HRC. The mechanical characteristics of Titanium (Grade-5) alloy are such as ultimate tensile strength- 950MPa; percentage elongation14% and shear strength- 550MPa. The chemical composition of (Grade-5) alloy is given in Table 1.

It has atomic properties which give it useful macroscopic properties. These properties make titanium and its alloys effective materials for use in machining and other applications.

Table 1 Chemical composition of titanium alloy.

Al	V	Fe	O	Ti
6 %	4 %	0.25 %	0.2 %	89.75 %

B. Turning process

Automated and flexible manufacturing systems are used for that purpose with the help of computerized numerical control (CNC) machines that can achieve high accuracy and very low processing time. Turning is the most common method for cutting and for the finishing machined parts. In turning process parameters, such as cutting speed, feed rate, depth of cut is selected; it is an important to select these parameters for achieving cutting performance. The desired cutting parameters are determined based on experience or by using handbook. However, this does not ensure that the selected cutting parameters have optimal cutting performance for a machine and environment.

In a turning, it is an important task to select cutting parameters for achieving high cutting performance. The desired cutting parameters are determined based on experience or by use of a handbook. However, this does not ensure that the selected cutting parameters have optimal or near optimal cutting performance for a machine and environment.

C. Experimental setup

The experiments were carried out under dry machining condition on a SPRINT 16 CNC turning centre A turning dynamometer was used to measure the cutting forces. The cutting conditions used are given in Table 2. The length of cut for each test was 20 mm. The dynamometer was rigidly held on tool post so that cutting force Fc could be measured. Force signals obtained from the dynamometer were transferred to PC by means of the data acquisition card and were evaluated by using XKM software. A Roughness tester was used to measure Ra after each cutting operation.

Table 2 Levels and factors for this study

	Control Factor	**Levels**			
		I	II	III	Units
A	Cutting Speed	45	55	65	m/min
B	Feed Rate	0.15	0.20	0.25	mm/rev
C	Depth of cut	0.2	0.3	0.4	mm

D. Machining performance

In the present work the effect of variation of the various cutting parameter (Fc, feed rate and depth of cut) on surface roughness and cutting forces (Fc) of the work piece have been studied. There are various simple Ra amplitude parameters used in industry, such as roughness average (Ra), root-mean-square (rms) roughness (Rq), and maximum peak-to-valley roughness (Ry). The average roughness (Ra) is the area between the roughness profile and its mean line or the integral of the absolute value of the roughness profile height over the evaluation length.

TAGUCHI METHOD

Taguchi method is very popular for solving optimization problems in the field of production engineering. Taguchi method is a statistical method or robust design method, developed by Genichi Taguchi to improve the quality of manufactured goods, and applied to engineering, [7] biotechnology, marketing and advertising. The Taguchi method reduces the variation in a process through robust design of experiments

[8-9]. This is a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning [10]. It uses orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows the collection of the necessary data to determine factors that mostly affect product quality with a minimum amount of experimentation, thus saves time and resources [11-18].

The machinability of titanium alloys is difficult due to their low thermal conductivity and elastic modulus, high hardness at elevated temperature, and high chemical reactivity [19]. Several strategies have been used with some success in the development of machinability of titanium alloys like the optimization of cutting parameters, chip breaking, tool vibration, cryogenic cooling, high pressure coolant, and others [20-21]. Titanium and its alloys present low machinability due to their low thermal conductivity, high reactivity, low elastic modulus, high hardness and strength at elevated temperature, and peculiar work hardening. The tools used for machining of titanium alloys are generally carbide, diamond and CBN. They have high wear resistance, heat resistance, thermal conductivity, adhesive resistant temperature, oxidization resistant temperature and hardness compared to that of high speed steel tools and thus used for machining of hard materials. CBN can be used at high cutting speeds in the range 30-130m/min.

DESIGN OF EXPERIMENTS

In this work, experimental work has been designed in several steps to ensure that data is obtained in a way that its analysis will lead to valid statistical results. This type of research methodology is called as DESIGN OF EXPERIMENT (DOE) methodology. DOE using Taguchi approach attempts to extract maximum important information with minimum number of experiments [22-23]. Taguchi technique is experimental design optimization technique which uses standard Orthogonal Arrays for forming a matrix of experiments. Using an OA to design the experiment helps the designer to study the influence of multiple controllable factors in a fast and economic way. OA's screens out few important main effects from the less

Run	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	Surface Roughness (µm)	S/N Ratio
1.	45	0.15	0.2	1.55	-3.80663
2.	45	0.20	0.3	2.11	-6.48565
3.	45	0.25	0.4	0.55	5.19275
4.	55	0.15	0.2	1.22	-1.72720
5.	55	0.20	0.3	1.14	-1.13810
6.	55	0.25	0.4	1.51	-3.57954
7.	65	0.15	0.2	3.01	-9.57133
8.	65	0.20	0.3	1.41	-2.98438
9.	65	0.25	0.4	2.43	-

					7.71213

important ones. It allows us to estimate interaction effects if any and determine their significance [24]. In the present machining of Titanium alloy of Grade 5 system three operating parameters, each at three levels, are selected. Based on Taguchi method, the L9(33)-OA was constructed. The reason for using L9-OA is to evaluate the significance of terms, means the influence of an operating variable on the effect of another operating variable [25]. The experimental Design will be three factor(Parameters) and three level design for this research which will require 33=27 runs. There will be transformations of experimental observations into S/N ratio.

Ƞ = -10 log (mean sq. deviation).

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The plan for experiments are:

The first column will be assigned to cutting speed (A), the second column feed rate (B) and the third column depth of cut (C) and the remaining columns will be used to estimate experimental errors. After assigning appropriate level settings, the S/N analysis is needed to evaluate experiment results.

RESULTS AND DISCUSSION

A. Analyses of experimental results

The use of an orthogonal array to reduce the number of cutting experiments for design optimization of the cutting parameters is found. Results of the cutting experiments are studied in this chapter using the S/N ratio and ANOVA analyses. Using S/N ratio and ANOVA analyses, optimal settings of the cutting parameters for surface roughness and cutting force are obtained considering nose radius of cutting tool 0.4mm.

The experimental data for surface roughness is shown in Table 3 for tool nose radius 0.4 mm, the overall mean for the S/N ratio of the surface roughness are found to be –3.535 dB. The analyses of the experimental data are carried using the software MINITAB 17 used for design of experiment applications in engineering. The mean response refers to the average values of the performance characteristics for each parameter at different levels i.e. of surface roughness.

Fig.1 show the graphically the main effect plot of S/N ratio of the three control factors on surface roughness. Analysis of these results leads to the conclusion that the factors gives minimum surface roughness.

Table 3. Experiment design using L_9 array

A. ANOVA and factor's effects

To understand the impact of various control factors on the response of experimental data we required to develop the analysis of variance (ANOVA) to find the significant factors. ANOVA allows analyzing the influence of each variable on the total variance of the results. The last column of table shows the percentage contribution (P) of each variable in the total variation indicating the influence on the surface roughness.

Table 5(b) shows the results of ANOVA for surface roughness. It is observed that the Cutting speed, feed rate and depth of cut are the significant cutting parameters for affecting surface roughness.

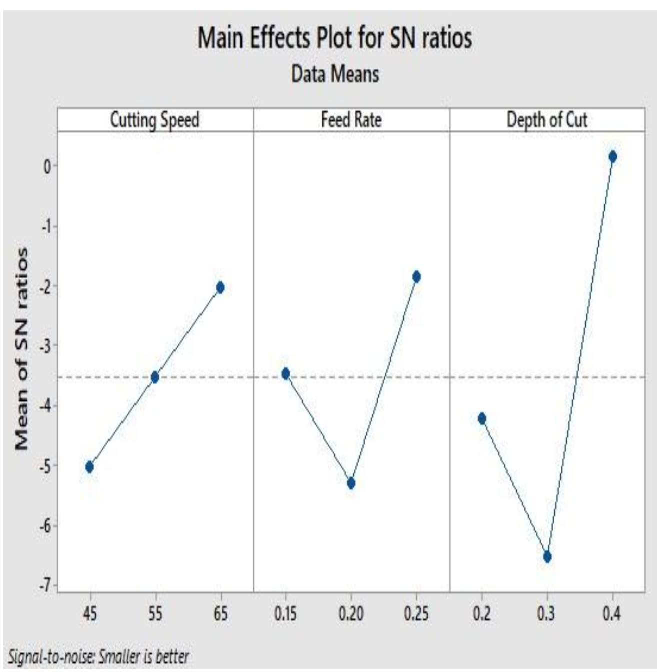

Fig. 1 Main effect plot of S/N ratios for surface roughness

Table 4 Experiment design using L_9 array for cutting force

Run	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	Cutting Force (N)	S/N ratio (dB)
1.	45	0.15	0.2	72	-37.1466
2.	45	0.20	0.3	139	-42.8603
3.	45	0.25	0.4	204	-46.1926
4.	55	0.15	0.2	138	-42.7976
5.	55	0.20	0.3	120	-41.5836
6.	55	0.25	0.4	128	-42.1442
7.	65	0.15	0.2	86	-38.6900
8.	65	0.20	0.3	142	-43.0458
9.	65	0.25	0.4	125	-41.9382

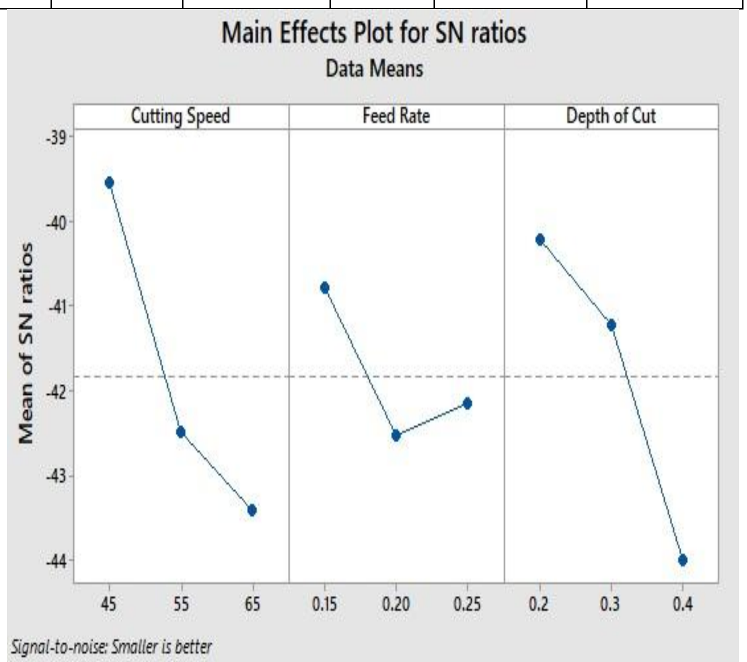

Fig. 2 Main effect plot for S/N ratios for cutting force

However, the contribution order of the cutting parameters for surface roughness is feed rate (P=0.837%), depth of cut (P=0.794 %).

Table 5(a) shows the S/N ratio for surface roughness, it is observed that the feed rate has major impact on surface roughness followed by depth of cut and cutting speed.

Table 5(b) Result of the ANOVA for surface roughness

ANOVA result	**DOF**	**Seq SS**	**Adj SS**	**F**	**P**

A	2	47.00	23.498	0.68	0.597
B	2	13.52	6.759	0.19	0.837
C	2	18.08	9.041	0.26	0.794
Error	2	69.56	34.780		
Total	8	148.16			

Table 5(a) S/N response for surface roughness

Symbol ratio (db)	**Mean S/N**				
	Level i	Level ii	Level iii	Delta	Rank
A	-5.0351	-3.5360	-2.0330	3.0021	3
B	-3.4569	-5.3083	-1.8389	3.4694	2
C	-4.2190	-6.5455	0.1604	0.1604	1

To understand the impact of various control factors and interaction on the response of experimental data it is desirable to develop the analysis of variance (ANOVA) to find the significant factors as well as interactions. ANOVA allows analyzing the influence of each variable on the total variance of the results. The last column of table shows the percentage contribution (P) of each variable in the total variation indicating the influence on the cutting force. The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is too accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error.

Table 6(b) shows the result of ANOVA for cutting force the approach angle, feed rate and depth of cut are cutting parameter mainly effecting cutting force. The contribution order of the cutting parameters for cutting force is cutting speed (P= 0.934%) and depth of cut (P= 0.819%). From the analysis of ANOVA and response, it is found that the cutting speed and depth of cut have major impact on cutting force.

Table 6(a) shows S/N ratio for cutting force, it is observed that the cutting speed has major impact on cutting force followed by depth of cut and feed.

Table 6(a) S/N response for cutting force

Symbol ratio (db)	**Mean S/N**				
	Level i	Level ii	Level iii	Delta	Rank
A	-39.54	-42.50	-43.43	3.88	1
B	-40.78	-42.53	-42.16	1.75	3
C	-40.22	-41.23	-44.01	3.79	2

Table 6(b) Result of the ANOVA for cutting force

ANOVA result	**DOF**	**Seq SS**	**Adj SS**	**F**	**P**
A	2	1.624	0.8120	0.07	0.934
B	2	24.632	12.3159	1.07	0.484
C	2	5.110	2.5551	0.22	0.819
Error	2	23.106	11.5531		
Total	8	54.472			

CONCLUSIONS

It is observed that Taguchi design of experiment and analysis is successfully used for optimizing machining for Titanium alloy (grade-5) for CBN cutting tool insert in this research. Taguchi ‘s orthogonal array design is suitable to analyze the surface roughness and cutting force problem as mentioned in this study. It is found that the experimental design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the cutting parameters. The design of experiment using Taguchi method is sufficiently efficient compared to other statistical methods and tools available. By choosing proper level combination of various independent variables, the number of experiments is reduced considerably. At the same time, there is no loss of any information, duplicity and redundancy due to reduction of number of experiment. Taguchi target was minimizing the variation around the target and improve the quality, using and learning the technique for engineers, scientists and researchers, time need in researches is become less

- The experimental results show that the feed rate and depth of cut are the main parameters among the three controllable factors (depth of cut, feed rate and cutting speed) that influence the surface roughness in turning of Titanium alloy. Per tool the result shows 0.837% contributed by the feed on the surface roughness. It is found that cutting speed 45 m/min, feed rate 0.20 mm/rev and depth of cut 0.2 mm are the optimum cutting parameters for surface roughness.

- In case of cutting force main parameters are cutting speed and depth of cut as compared to other parameters. The results show the 0.934% and 0.819% contributed by the cutting speed and depth of cut on the cutting force. It is found that cutting speed 45 m/min, feed rate 0.15 mm/rev and depth of cut 0.2 mm are the optimum cutting parameters for cutting force.

- Deviations between actual and predicted S/N ratio for surface roughness and cutting force are small each parameter.

- Cutting force increase with increase feed rate and depth of cut. Surface roughness increase with increase feed rate.

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