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MACHINING PARAMETERS OPTIMIZATION IN END MILLING OF Ti6Al4V USING TAGUCHI METHOD

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ABSTRACT

Ti6Al4V has inevitable applications in aerospace industry where high surface finish is required. In this research the endmilling of annealed Ti6Al4V is performed using coated carbide inserts. The study in the effect of tool geometry has great importance in improving the quality of milled product.Cutting speed, feed rate, depth of cut and nose radius of milling cutter is selected as the input parameters. The responses observed are the surface roughness and cutting force. Taguchi method is employed for the design of experiments. L9 orthogonal array is selected for four factors and three levels by using MINITAB software. Each response is separately optimized by using signal to noise ratio analysis(S/N ratio analysis). ANOVA is employed to find out the percentage influence of input parameters on response. Optimum combination of machining parameters isobtained for surface roughness as well as for cutting force by using Taguchi based S/N ratio analysis.

KEYWORDS: Slot Milling, Nose Radius, Taguchi Method, Signal to Noise Ratio Analysis, Grey Relational Analysis, ANOVA

INTRODUCTION

Titanium and its alloys are extensively used in aerospace because of their high specific strength, which is maintained at elevated temperature, their fracture resistant characteristics and their exceptional resistance to corrosion. They are being used increasingly in other industrial and commercial application such as petroleum refinery, nuclear reactors, surgical implants and marine application. They are also being used extensively for aerospace industry, mainly in airframe construction, where maximum ease of formability is desired.However,machining of titanium alloys involves expensive tooling cost at the expense of getting good surface roughness[1]. The main limiting factor in designing aircraft structures that involves dynamic loading is the fatigue property of the materials which is related to the surface quality. Therefore, the importance of surface integrity intitanium alloys milling process should be in consideration. BalakrishnaRao et.al[2] have studied about facemilling of Ti6Al4V using simulations and experiments. This work concludes that the cutting speed has only a little contribution to cutting force and specific cutting energy.Khairi Yusuf and Y Nukman studiedflat end milling process that can produce a flat surface. Here, the rotation of cutter is perpendicular to the work piece of titanium alloys. The flat end milling with the multiple flute end mills, solid tool is used since the center cutting end teeth allows these end mills to drill into work piece to start a machining operation[3].LohithakshaMMaiyaa, Dr.R.Ramanujam, and Dr.J.Jerald[4] have studied the effect of machining parameters on surface roughness and cutting force.It concludes that depth of cut has the most significant effect on cutting force followed by feed rate and cutting speed.The work also reveals that the most influencing parameter on surface roughness is feed rate followed by depth of cut and cutting speed.V Krishnaraja, S Samsudeensadham, R Sindhumathi, P Kuppan[5] have investigated high speed end milling of titanium alloy (Ti–6% Al–4% V) using carbide insert based end mill cutter. Effects of cutting forces during high speed machining of titanium alloys have got higher attention in selecting the optimal cutting conditions to improve the production and tool life. From this study it is found that depth of cut and feed rate have higher effect on cutting forces when compared to cutting speed.In this work,the machining parameters such as cutting speed,feedrate,depth of cut and nose radius are optimized for cutting force and surface roughness in end milling of Ti6Al4V using Signal to Noise ratio analysis. Coated carbideinserts are used in the milling operation [6].

NOMENCLATURE

Vc- cutting speed in m/min

f-feed rate in mm/min

a_p-axial depth of cut in mm

r_E-nose radius in mm

OA-orthogonal array

S/N-signal to noise ratio

GRA-grey relational analysis

Ra-average surface roughness

F_x-force in x direction (in feed force)

F_y-force in y direction (cross feed force)

F_z-force in z direction (thrust force)

F_R-resultant cutting force

$\varphi_i(k)$-grey relational coefficient

δ-distiguishing coefficient

γ_i-grey relational grade

DOF- Degree of freedom

SS -Sum of squares

MS-Variance of each factor

%C -percentage contribution

EXPERIMENTATION

The response values required for the analysis is obtained by conducting nine slot milling operations.Slots of width 25mm were milled for a length of 84mm by considering the parameters such as cutting speed(m/min),feed rate(mm/min),depth of cut(mm) and nose radius(mm) and the measured output parameters are surface roughness and cutting force. The experiments are followed by Taguchi design and S/N ratio analysis. ANOVA is used to find out the percentage influence of input parameters on response.

WORKPIECE USED

Ti6Al4V (Annealed) of size 90x84x10mm rectangular piece is used as workpiece. Similar six pieces are employed in the work for experimentation including confirmation experiments. Holes of diameter 8mm are drilled at the cornersof each work piece according to the top plate dimensions of dynamometer. Two experiments are performed (two slots) in each workpiece.The chemical composition and some mechanical properties of the workpiece material are given in the table 5.1 and 5.2 respectively. Figure 4.1 shows the actual image of the single workpiece. Figure 4.2 shows the dimensions of the workpiece used.

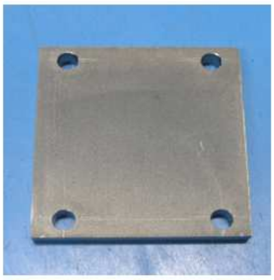

Figure 4.1: Work Piece Used

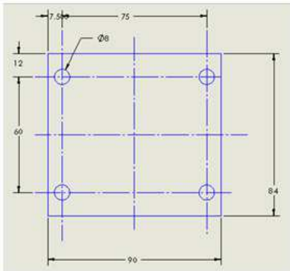

Figure 4.2: Drawing and Dimensions of Work Piece

PROPERTIES OF TI-6AL-4V

Table 5.1: Chemical Composition

Component	Percentage
Ti	89.55
Al	6.40
V	3.89
Fe	0.16
C	0.002

Table 5.2: Mechanical Properties

Hardness (HRC)	36
Yield Strength	900 MPa
Ultimate Tensile Strength	950 MPa
Elongation	14 %
Poisson's ratio	0.342
Modulus of Elasticity	113 GPa
Density	4.43 g/m^3
Thermal Conductivity	6.7 W/m-K

CUTTING TOOL USED

The cutting tool used is coated carbide inserts of grade WSP45S made by WALTER. The inserts used are of positive rhombic in shape and are shown in figure 6.1. Inserts of different nose radius are used for the studies (0.8 mm, 1.2 mm and 1.6 mm) which are ADMT 10 T3 08 R-F56,ADMT 10 T3 12 R-F56,ADMT 10 T3 16 R-F56.Each insert has two cutting edges. Six inserts of each type is used for the experiments.Total eighteen fresh inserts are used for the effective study of nose radius. The above mentioned three typesinsert show variations only in nose radius; all other features are same.The experiment was conducted on a DECKEL CNC 3 axis vertical milling machine and is shown in figure 6.3.

The milling cutter of diameter 25mm is used for the slot milling operations.It holds three inserts. Figure 6.2 shows the milling cutter usedin the study. The specifications of milling cutter used is F 4042 R W 25 .025 Z03 10.

Figure 6:.1Inserts Used (Nose Radius: 0.8 Mm, 1.2 Mm And 1.6 Mm)

Figure 6.2: Millingcutter Used

Figure 6.3: CNC Milling Machine Used

DESIGN OF EXPERIMENTS USING TAGUCHI METHOD

Design of experiments using the Taguchi method is employed to find out the optimum number of runs for the experiments with the combination of the parameters. Four input parameters and three levels are selected for the experiments. So, L9 orthogonal array with combination of input parameters and their levels are obtained using MINITAB software. The factors and levels of parameters are shown in table 7.1.

Table 7.1 Factors and Levels

Factors	-1	0	1
Cutting speed(m/min)	24.7	31.4	39.3
Feed rate(mm/min)	60	120	180
Depth of cut(mm)	1	1.5	2
Nose radius(mm)	0.8	1.2	1.6

Total nine experiments are performed according to the L9 orthogonal array.

EXPERIMENT SET UP

The KISTLER made tool dynamometer is fixed on the machine table.Work pieceis fixed over the tool dynamometer plate using M8 nuts.Tool dynamometer is connected to an amplifier through cables. Amplifier is connected to a computer using cables to record the cutting force data.Coolant applied during the milling operation is HOTCUT 795 H and is supplied in flood mode. The water soluble ratio of the coolant used is 1:9. The experiment setup including the work piece and tool setup, dynamometer and its accessory connections are shown in the figure 8.1 and 8.2.

Figure 8.1: Experiment Setup

Figure 8.2: Amplifier and Computer Used for Force Measurement

CUTTING FORCE AND SURFACE ROUGHNESS MEASUREMENT

Cutting Force Measurement

The force in Xdirection (in feed force), Ydirection (cross feed force) and Z direction (thrust force) are measured using KISTLER made multi component tool dynamometer of type 9257B. The force obtained in each axis is averaged along the time domain between the times of engagement of cutter in the slot to the time of disengagement of the cutter at the end of the slot. The forces F_x(in feed force), F_y (cross feed force) and F_z (thrust force) are used to calculate F_R(resultant cutting force) by using the equation1[7].

$$F_R = \sqrt{F_X^2 + F_Y^2 + F_Z^2} \quad (1)$$

Surface Roughness Measurement

Surface roughness (Ra) is measured using Talysurf roughness tester. Ra in the starting, centre and ending points of each slot are measured and its average is taken as the surface roughness for the experiment.Surface roughness is measured for a sampling length of 4mm and a cut off length of 0.8mm.

RESULTS AND ANALYSIS

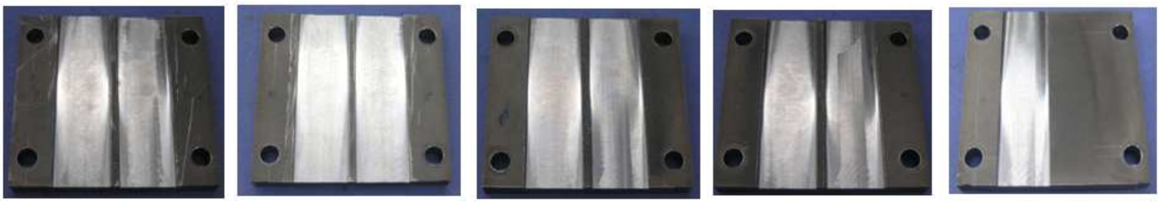

Figure 10.1: Work Pieces after Slot Milling Operations

Table 10.1 Experiment Results

Run	Vc (M/Min)	F (Mm/Min)	Ap (Mm)	r_E (Mm)	Ra (Mm)	F_R (N)
1	24.7	60	1	0.8	0.2318	432.6035
2	24.7	120	1.5	1.2	0.6121	528.9070
3	24.7	180	2	1.6	0.7733	713.5275
4	31.4	60	1.5	1.6	0.2185	487.6598
5	31.4	120	2	0.8	0.2825	500.7595
6	31.4	180	1	1.2	0.4130	551.6736
7	39.3	60	2	1.2	0.2713	544.0877
8	39.3	120	1	1.6	0.3957	490.0413
9	39.3	180	1.5	0.8	0.5874	522.8327

S/N RATIO ANALYSIS

The S/N ratios are derived from the quadratic loss function and are expressed in a decibel scale (dB). Once all of the S/N ratios have been computed for each run of an experiment, Taguchi advocates a graphical approach to analyze the data. In the graphical approach, the S/N ratios and average responses are plotted for each factor against each of its levels.There are three standard types of S/N ratios depending on the desired performance response such as larger the better, nominal the better and smaller the better.Here,Surface roughness and cutting force are optimized using smaller the better relation[8]. The best condition is the one which maximize the appropriate S/N ratio. Table 11.1 shows the S/N ratios calculated for Ra and F_R using the equation 2.

Smaller the better (for making the system response as small as possible):

$$\frac{S}{N_S} = -10 \log \frac{1}{n} \sum_{i=1}^{n} y_i^2 \qquad (2)$$

Table 11.1 S/N Ratios of Responses

Experiment	Ra (Mm)	S/N Ratio Of Ra (Db)	F_R (N)	S/N Ratio of F_R (Db)
1	0.2318	12.6906	432.6035	-52.7218
2	0.6121	4.2633	528.9070	-54.4675
3	0.7733	2.2250	713.5275	-57.0682
4	0.2185	13.2007	487.6598	-53.7623
5	0.2825	10.9550	500.7595	-53.9925
6	0.4130	7.670	551.6736	-54.8336
7	0.2713	11.2996	544.0877	-54.7133
8	0.3957	8.0456	490.0413	-53.8046
9	0.5874	4.6152	522.8327	-54.3672

Figure 11.1: Data Analysis Plot for S/N Ratio of Ra **Figure 11.2: Data Analysis Plot for S/N Ratio of F_R**

From the figure 11.1, the optimized parameters for minimum surface roughness are obtained. Optimized parameters for Ra are cutting speed 31.4m/min, feed rate 60mm/min, depth of cut 1mm and nose radius 0.8mm. The optimized parameters for cutting force obtained are also the same as that of surface roughness.From the figure 11.2the optimized parameters for minimum cutting force are obtained and are cutting speed 31.4m/min, feed rate 60mm/min, depth of cut 1mm and nose radius 0.8mm. The larger nose radius produces high cutting force. So, the smallest nose radius (0.8mm) is the optimized level of nose radius for cutting force.

ANALYSIS OF VARIANCE

ANOVA is done to find out the significant factor on output parameters. The percentage influence of factors can be found out using ANOVA. It is performed with a confidence interval of 95%. The results of analysis are tabulated in table 12.1 and table 12.2. From the table 12.1,it is clear that feed rate is the most influencing factor on surface roughness followed by cutting speed and depth of cut. Noseradius has the least effect on surface roughness.

From table 12.2,it is found that feed rate is the most influencing parameter on cutting force. Depth of cut and nose radius are the other important parameters that affect cutting force.The effect of cutting speed on cutting force is very less.

Table 12.1: Anovafor Surface Roughness

Source	DOF	SS	MS	F	% C
Cutting speed	2	27.9396	13.9698	13.9698	21.94
Feed rate	2	87.2217	43.6108	43.6108	68.50
Depth of cut	2	6.8012	3.4006	3.4006	5.34
Nose radius	2	5.3644	2.6822	2.6822	4.22
Error	0	0.00000			
Total	**8**	**127.3269**		**63.6634**	**100**

Table 12.2: ANOVA for Cutting Force

Source	DOF	SS	MS	F	% C
Cutting speed	2	0.5286	0.2643	0.2643	4.74
Feed rate	2	4.7786	2.3893	2.3893	42.80
Depth of cut	2	3.4565	1.7282	1.7282	30.95
Nose radius	2	2.4015	1.2007	1.2007	21.51
Error	0	0.0000			
Total	**8**	**11.1652**		**5.5825**	**100**

The multiple linear regression model for surface roughness and cutting force are obtained and are shown in equation 3 and 4 respectively.

$$Ra = 0.026 - 0.00761Vc + 0.002923\ f + 0.096a_p - 0.119r_\varepsilon \quad (3)$$

$$F_R=241-2.61Vc + 0.898\ f + 96.2\ a_p+100\ r_\varepsilon \quad (4)$$

Two confirmation experiments for surface roughness and cutting force are performed and the roughness value obtained is 0.2036µmand the cutting force obtained is 414.0475 N and are in in good agreement with the predicted values of regression models.

CONCLUSIONS

Analysis and optimization in end milling of Ti6Al4V is done by considering four machining parameters such as cutting speed, feed rate, depth of cut and nose radius. Taguchi method and ANOVA are used to find out the optimum combination of machining parameters to minimize surface roughness and cutting force.

From this study, it can be concluded that;

- The most influencing parameter on surface roughness is feed rate, which is followed by cutting speed, depth of cut and nose radius.
- Feed rate is the most influencing parameter on cutting force, followed by depth of cut, nose radius and cutting speed.
- The smaller nose radius produces less cutting force.
- The optimal parameters for end milling of Ti6Al4V to reduce surface roughness (cutting speed =31.4m/min, feed rate =60mm/min, depth of cut =1mm, nose radius= 0.8mm) and the optimal parameters to reduce cutting force (cutting speed =31.4m/min, feed rate =60mm/min, depth of cut =1mm, nose radius= 0.8mm) were obtained through this study and the confirmation experiments produced low values of cutting force and surface roughness.

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