Investigating the Effect of Machining Parameters on Surface Roughness and MRR of Ti-6Al-4V Titanium Alloy in End Milling

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Abstract **- Titanium alloys are considered as one of the best engineering metal due to their strength, low mass and good corrosion and temperature resistance and very good biocompatibility which makes this material very interesting for biomedical applications. Due to its material properties titanium alloy poses a challenge for machining operations. A sound understanding of the alloy behavior during the machining process is essential to achieve shape and dimensions tolerances of the product with minimum costs and machining times. The objective of this work is to optimize the end milling of Ti-6Al-4V, which is focused towards maximize the MRR(material removal rate) induced during machining and to reduce the surface roughness of the machine parts. Machining parameters like cutting speed, feed and depth of cut are considered in this work. The optimization procedure includes the application of Taguchi method and ANOVA for designing the experiments and for validating the experimental results.**

Index Terms-Ti-6Al-4V; DOE; Surface roughness; MRR; Taguchi; ANOVA; Optimization

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I. INTRODUCTION

Today, manufacturing industry needs surface quality and productivity. The current state of economy and consequent market pressure has forced manufacturers to simultaneously decrease the surface roughness and increase the metal removal rate so that they can meet the quality and time constraints. Mainly, the surface roughness affects wear resistance, ductility, tensile, fatigue strength, etc., for machined parts and cannot be neglected in designing any component. The imperative objective of the science of metal cutting is the solution of practical problems associated with the efficient and precise removal of metal from work piece.

Milling process is used in the experimentation. Milling is one of the common metal cutting operations used for machining parts in manufacturing industry. It is usually performed at the final stage in manufacturing a product. The demand for high quality and fully automated production focuses attention on the surface condition of the product, especially the roughness of the machined surface, because of its effect on product appearance, function, and reliability.

In the present work an experimental investigation of machining parameters on Ti -6Al-4V Titanium alloy with carbide coated tool in end milling is carried out and the effect of different cutting parameters like speed, depth of cut , feed rate on the surface roughness and MRR is studied because one can relate quality with surface roughness and productivity with MRR. Application of coolant tends to reduce tool wear and minimize adhesion of the work material on the cutting tool during machining and also improves the surface finish.

Obtained experimental readings are analyzed with the help of Taguchi method and ANOVA. Results obtained from both these analysis are closely matching with each other.

II. METHODOLOGY

DOE techniques enable designers to determine simultaneously the individuals and interactive effects of many factors that could affect the output results in any design. There are three input parameters and three level. Full factorial experimental design will give rise to total 33=27 experiments which is time consuming and lengthy procedure.

Taguchi found out new method of conducting the design of experiments which are based on well defined guidelines. This method uses a special set of arrays called orthogonal array. This standard array gives a way of conducting the minimum number of experiments which could give the full information of all the factors that affect the response parameter instead of doing all experiments. ANOVA was developed by Sir Ronald Fisher in 1930 and can be useful for determining influence of any given input parameter for a series of experimental results by design of experiments for machining process and it can be used to interpret experimental data. ANOVA is statistical based objective decision making tool for detecting any differences in average performance of groups of items tested. While performing ANOVA degrees of freedom should also be considered together with each sum of squares. In ANOVA studies a certain test error, error variance determination is very important. Obtained data are used to estimate F value of Fisher Test (F-test). Variation observed (total) in an experimental attributed to each significant factor or interaction is reflected in percent contribution (P), which shows relative power of factor or interaction to reduce variation.

Fig 1: End- milling operation

III. MATERIALS AND METHODS

The work piece material used is Ti-6Al-4V titanium alloy of 200mm long, 22mm width and 5mm thickness in the form of slab. The mechanical properties and composition of Ti-6Al-4V are shown in Table 1 and table 2respectively. Milling operation was carried out on SINGER UNIVERSAL MILLING MACHINE by using TIALN coated solid carbide end mill cutter.

Table 1 Properties of Ti-6Al-4V Titanium Alloy

TENSILE TEST			BHN	
Ultimate Stress	Yield Stress	Modulus Of Elasticity	For 500 Kg	Density
(N/mm2)	(N/mm2)	(GPa)		(gm/cm3)
950	850	113	340	4.43

Table 2 Composition of Ti-6Al-4V Titanium Alloy

Elements	C	Fe	N	Al	V	H	Ti
%	0.05	0.09	0.01	6.15	4.40	0.005	balance

Work piece was inserted in the jaw on the work bed and was tightened in the jaws until they fixed the work piece such that top surface of the work piece will be perfectly perpendicular to the tool axis. The milling was carried out for 9 different work pieces. For each workpiece, all the three parameters, viz. cutting speed, depth of cut and feed rate, were varied as shown in Table 3.

Table 3 Machining parameters and levels

Machining Parameters	Level 1	Level 2	Level 3
Cutting speed (Rev/min)	130	186	220
Feed rate (mm/min)	32.09	18.4	13.8
Depth of cut(mm)	0.1	0.2	0.3

The surface roughness of each specimen was tested on the surface roughness tester (Mitutoyo Roughness tester SJ-400) for cut off value of 4.0 mm distance. The Ra value was generated by the tester for each work piece.

IV. RESULTS AND DISCUSSION

Table 4 shows experimental design matrix and surface roughness value (Ra) Ti-6Al-4V Titanium Alloy, S/N ratio is calculated using Lower the better characteristics.

Table 4 Experimental Design Matrix and Results for surface roughness

MILLING PARAMETERS						
EXPT. NO.	SPEED (RPM)	FEED RATE (mm/min)	DEPTH OF CUT (mm)	SURFACE ROUGHNESS (µm)	S/N RATIO	MEAN
1	130	32.09	0.1	0.55330	5.1407	0.55330
2	130	18.4	0.2	0.65666	3.6539	0.65666
3	130	13.8	0.3	0.50330	5.9634	0.50330
4	186	32.09	0.2	0.46660	6.6211	0.46660
5	186	18.4	0.3	0.43330	7.2642	0.43330
6	186	13.8	0.1	0.49666	6.079	0.49666
7	220	32.09	0.3	0.42330	3.553	0.42330
8	220	18.4	0.1	0.51000	5.8485	0.510000
9	220	13.8	0.2	0.38000	8.4043	0.38000

Responses for Signal to Noise Ratios of Smaller is better characteristics is shown in Table 5. Significance of machining parameters (difference between max. and min. values) indicates that speed is significantly contributing towards surface roughness as difference gives higher values. Plot for S/N ratio shown in Figure 1 explains that there is less variation for change in depth of cut where as there is significant variation for change in speed.

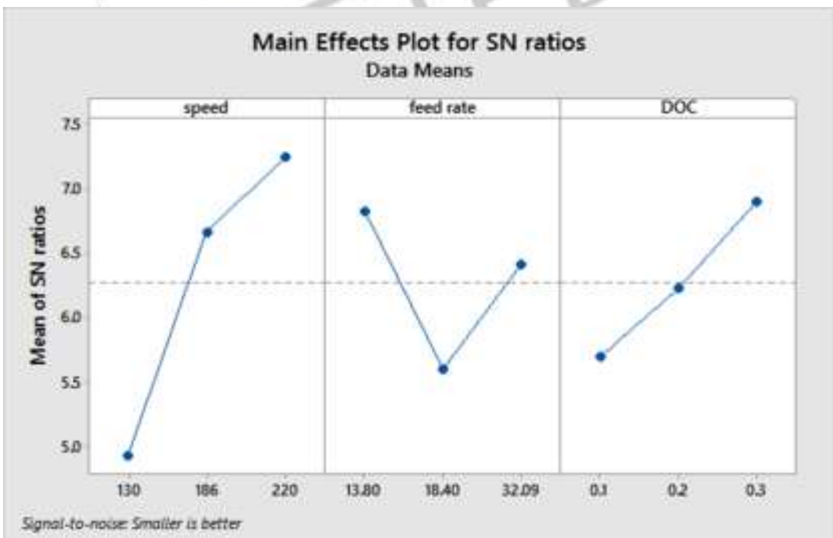
Table 5 Response Table for a) Signal to Noise Ratios and (b) means

(a)

Level	Speed	Feed	Depth of Cut
1	4.919	6.816	5.689
2	6.655	5.589	6.226
3	7.240	6.410	6.898
Delta	2.321	1.227	1.209
Rank	1	2	3

(b)

Level	Speed	Feed	Depth of Cut
1	0.5711	0.4600	0.5200
2	0.4655	0.5333	0.5011
3	0.4378	0.4811	0.4533
Delta	0.1333	0.0733	0.0667
Rank	1	2	3



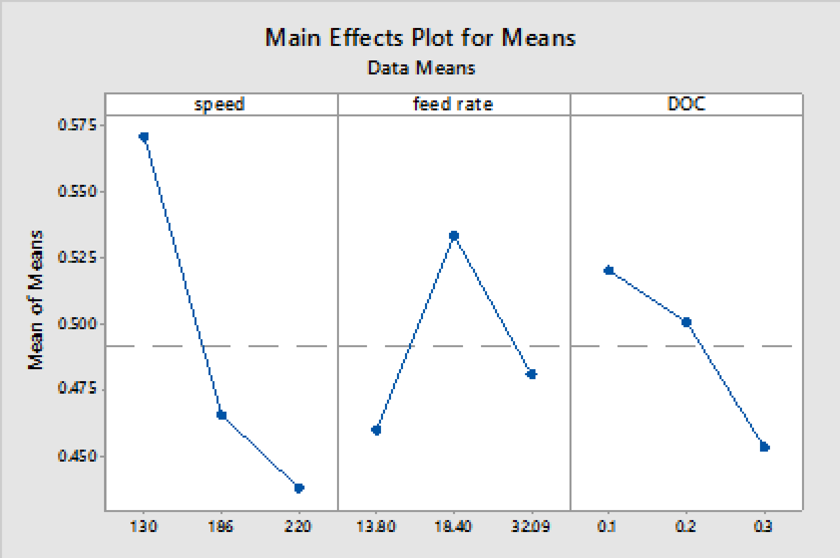


Fig. 2 Effect of cutting speed, Depth of cut and Feed rate on surface finish

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Taguchi method cannot judge and determine effect of individual parameters on entire process while percentage contribution of individual parameters can be well determined using ANOVA. MINITAB software of ANOVA module was employed to investigate effect of process parameters cutting speed, Depth of Cut and Feed rate.

Table 6 Analysis of variance for surface roughness

Source	SS	DOF	MSS	F ratio	% contribution
Speed	0.02969	2	0.014844	3.87	56.34
Feed	0.008533	2	0.004276	0.58	16.19
Depth	0.007088	2	0.003544	0.47	13.45
Residual error	0.007	0			
	37.7902	8			

The value of F ratio (3.87) from the table 6 indicates that Speed is the most contributing parameter on surface roughness followed by feed rate and depth of cut.

Fig 3 Pie chart with Percentage contribution of each factor on surface roughness

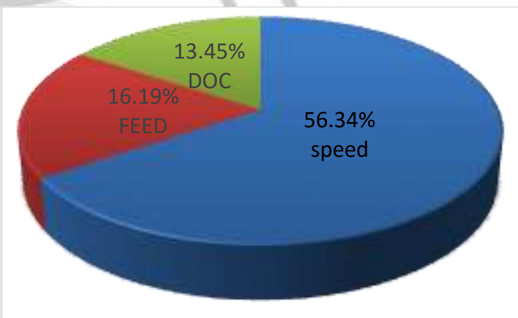

Fig 4 Specimen photograph for smooth and rough surface

Cutting speed, 130 rev/min; Depth of cut 0.1 mm; Feed, 18.40 mm/min

Cutting speed, 220 rev/min; Depth of cut 0.3 mm; Feed, 13.80 mm/min

Table 7 shows experimental design matrix and MRR value (Ra) Ti-6Al-4V Titanium Alloy, S/N ratio is calculated using Larger the better characteristics.

Table 7 Experimental Design Matrix and Results for surface roughness

EXPTNO.	SPEED(RPM)	FEED(MM/MIN)	DEPTH OF CUT(MM)	CHANGE IN WEIGHT(gms)	MRR BY WEIGHT (mm3/min)	S/N RATIO	MEAN
1	130	32.09	0.1	0.251	79.0592	37.9590	79.059
2	130	18.4	0.2	0.3652	65.9503	36.3843	65.950
3	130	13.8	0.3	0.465	62.9796	35.9840	62.980
4	186	32.09	0.2	0.359	113.076	41.0674	113.076
5	186	18.4	0.3	0.476	85.9593	38.6859	85.959
6	186	13.8	0.1	0.258	34.9435	30.8673	34.944
7	220	32.09	0.3	0.476	149.929	43.5177	149.929
8	220	18.4	0.1	0.249	44.9661	33.0577	44.966
9	220	13.8	0.2	0.287	38.8713	31.7926	38.871

Responses for Signal to Noise Ratios of larger is better characteristics is shown in Table 8. Significance of machining parameters (difference between max. and min. values) indicates that feed rate is significantly contributing towards MRR as difference gives higher values. Plot for S/N ratio shown in Figure 5 explains that there is less variation for change in depth of cut where as there is significant variation for change in speed.

Table 8 Response Table for a) Signal to Noise Ratios and (b) means

(a)

Level	Speed	Feed	Depth
1	36.78	32.88	33.96
2	36.87	36.04	36.41
3	36.12	40.85	39.40
Delta	0.75	7.97	5.43
Rank	3	1	2

(b)

Level	Speed	Feed	Depth
1	69.33	45.60	52.99
2	77.99	65.63	72.63
3	77.92	114.02	99.62
Delta	8.66	68.42	46.63
Rank	3	1	2

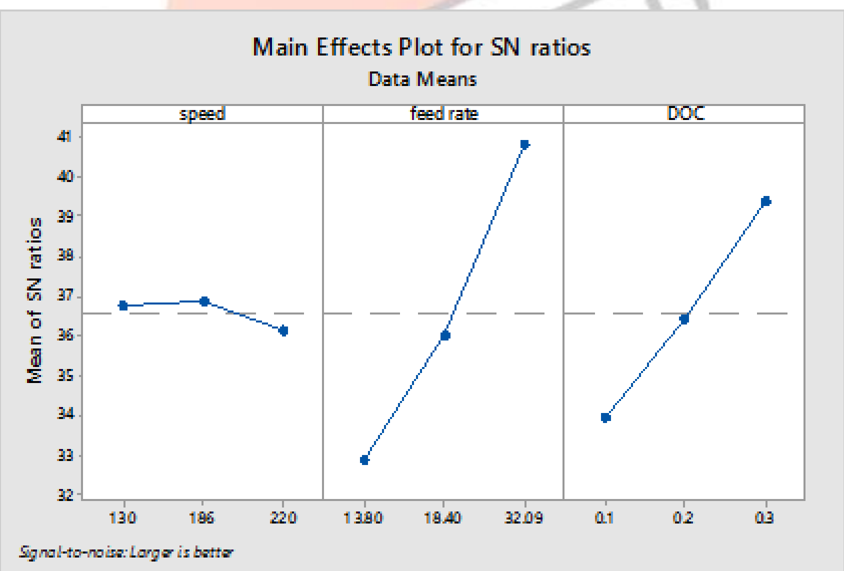

Fig. 5 Effect of cutting speed, Depth of cut and Feed rate on MRR

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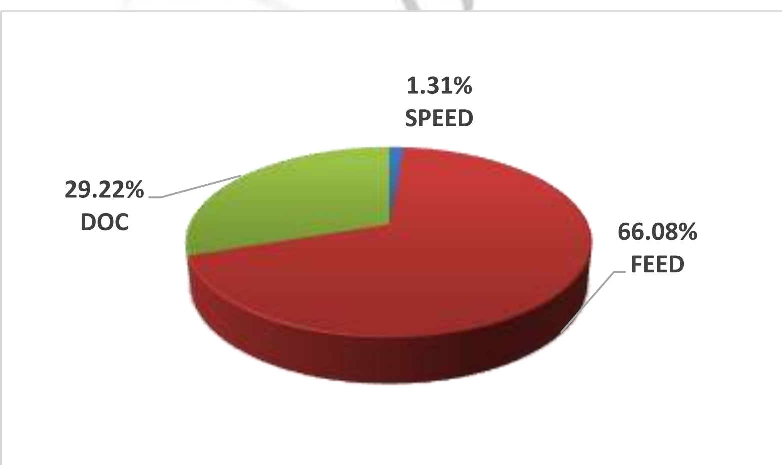
Taguchi method cannot judge and determine effect of individual parameters on entire process while percentage contribution of individual parameters can be well determined using ANOVA. MINITAB software of ANOVA module was employed to investigate effect of process parameters cutting speed, Depth of Cut and Feed rate.

Table 9 Analysis of variance for MRR

Source	SS	DOF	MSS	F ratio	% contribution
Speed	0.0029	2	0.001459	0.04	1.31
Feed	0.14569	2	0.7285	5.85	66.084
Depth	0.06442	2	0.03221	1.24	29.22
Residual error	0.007	0			
	0.22046	8			

The value of F ratio (5.85) from the table 8 indicates that feed rate is the most contributing parameter on MRR followed by depth of cut and speed.

Fig 6 Pie chart with Percentage contribution of each factor on MRR



V. CONCLUSION

Taguchi method of experimental design has been applied for investigating the effect of machining parameters on surface roughness. Results obtained from Taguchi method closely matches with ANOVA. Best parameter found for surface finish are: Cutting speed, 130 rev/min; feed, 18.40 mm/min; depth of cut, 0.1 mm. The parameter found for rough surface are cutting speed, 220 rev/min; depth of cut, 0.3 mm; feed, 13.80 mm/min. Also parameter for the higher MRR are cutting speed, 186 rev/min; feed, 32.09 mm/min; depth of cut, 0.3 mm .and parameter for the lowest MRR are cutting speed 220 rev/min, feed rate 13.80 mm/min and depth of cut 0.1 mm.Thus Feed Rate is most influencing parameters corresponding to the quality characteristics of MRR and Speed is most influencing parameter to surface roughness.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

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