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Investigation of Effect of Parameters on Cutting Force while Turning Ti-6Al-4V (ELI)

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Abstract— Ti-6Al-4V, extra low interstitial (ELI) is an important Titanium alloy, which is highly used in aerospace, marine and biomedical applications. It fall under the category of difficult to cut materials. In this study the investigation of cutting force is carried out. Effects of four parameters namely cutting speed, feed depth of cut and tool nose radius are investigated. The cutting force is taken as output response. ANOVA test is performed to find significance of parameters. The mathematical model for prediction of cutting force is developed. The comparison of actual and predicted values of cutting force is also done.

Keywords— Titanium alloy, turning, ANOVA, Cutting Force, tool nose radius

I. Introduction

Titanium alloys are considered as difficult to cut materials because of their limitations such as low thermal conductivity and rapid tool wear. Selection of proper cutting parameters is always challenging for researcher. The input parameters in turning process like cutting speed, feed and depth of cut are having high influence on output responses like cutting force, surface roughness, tool wear, vibration etc. Tool nose radius is also an important parameter of tool geometry. Its effect on surface roughness, cutting force and cutting temperature is an important area of investigation.

The high cutting temperature is an issue which requires high attention as it is responsible for poor machinability.[1] Ti-6Al-4V and Ti-6Al-4V ELI (Extra Low Interstitial) are basically developed to be used as structural material but it found wide application as implant material also[2]. The extra low interstitial (ELI) grade of Ti-6Al-4V exhibits higher ductility and improved fracture stiffness than grade5 Ti-6Al-4V. This is because of controlled interstitial element of iron and oxygen. The investigation on diffusion bonding of Ti-6Al-4V ELI was also carried out, which revealed that it is possible to have super-plastic forming and diffusion boding at lower temperature than conventional Ti-6Al-4V [3]. The components to be used in aerospace field are expected to have better surface integrity and higher reliability.

The investigation by authors [4] revealed that the surface integrity is more affected by feed and tool nose radius while machining Ti-6Al-4V ELI. In order to understand fatigue behavior of implant, the investigation on the relation between fatigue damage and mechanical properties of Ti-6Al-4V ELI was carried out by researchers [5]. To evaluate the oxygen effect on processing of Ti-6Al-4V, the shapes of stress-strain curves, the kinetic parameters, and the processing maps obtained and have been compared for two grades of material [6]. Titanium alloys are used as implant materials for bio medical and dental application because of their corrosion resistance and good bio-compatibility. The corrosion behavior of titanium alloys like Ti-6Al-4V ELI and Ti–6Al–7Nb in simulated body fluids have also been investigated [7].Turning is highly significant manufacturing process, in which single point cutting tool removes material from cylindrical work-piece while it is rotated.

There are three cutting forces produced during turning namely thrust force, which acts in direction of cutting speed, feed force in the direction of feed and radial force which is produced in the direction normal to cutting speed. Effect of parameters on cutting power has been investigated by researchers [8].Many researchers have contributed their work on optimization of process parameters in order to improve machinability of titanium alloys. Significance of cutting parameters on Tool life and surface roughness of Ti-6Al-4V ELI was investigated [9]. The findings showed that feed rate and cutting speed are highly influencing factors for surface roughness. Tool nose radius also affects the surface properties of the product [10].

II. Methodology

A Round bar of 50 mm diameter of Ti-6Al-4V (ELI) is used for experimentation work. The cutting inserts which have been utilized are coated cemented carbide inserts with ISO designation as TNMG 160404, TNMG 160408 and TNMG 160412 with nose radius 0.4mm, 0.8mm and 1.2mm, respectively. Three levels of four parameters are chosen as shown in Table-1. Total 81 experiments were performed and the cutting force was measured using lathe tool dynamometer. The measured values and design of experiment is not shown here for space management. Non linear quadratic equation, as shown in equation (1) is formulated for the prediction of cutting force from experimental results using MINITAB 17.

TABLE-1 LEVEL OF INPUT PARAMETERS

Parameters	***Levels***		
Feed (mm)	0.051	0.071	0.102
Cutting Speed (rpm)	140	224	315
Depth of Cut (mm	0.5	0.75	1
Tool Nose Radius (mm)	0.4	0.8	1.2

$$Fv = 24.6 + 29.8\, Nr - 0.1022\, Cs - 44\, f - 49.3\, d - 30.21\, Nr*Nr + 0.000148\, Cs*Cs - 848\, f*f + 15.1\, d*d + 0.0006\, Nr*Cs + 26.6\, Nr*f + 28.33\, Nr*d + 0.198\, Cs*f + 0.0196\, Cs*d + 513.1\, f*d \quad (1)$$

III. RESULTS AND DISCUSSION

ANOVA test for cutting force was carried out to analyze the effect and significance of individual parameters on the response. The result of ANOVA is tabulated in Table 2. It can be said from Table 2 that P-value for Nose radius, feed, and depth of cut is less than 0.005, which shows that the parameters are significantly affecting cutting force. The interaction of nose radius and depth of cut is also significant.
The R-square value for the developed model is 92.81%, which shows that model is accurate enough for the prediction.

TABLE 2 ANOVA TEST FOR CUTTING FORCE FV

Source	***DF***	***Adj SS***	***Adj MS***	***F-Value***	***P-Value***
Model	14	9155.85	653.99	60.88	**<0.005**
Linear	4	8201.1	2050.28	190.85	**<0.005**
Nr	1	206.71	206.71	19.24	**<0.005**
Cs	1	9.13	9.13	0.85	0.36
f	1	2706.09	2706.09	251.89	**<0.005**
d	1	5278.73	5278.73	491.37	**<0.005**
Nr*Cs	1	0.01	0.01	0	0.971
Nr*f	1	2.69	2.69	0.25	0.618
Nr*d	1	289	289	26.9	**<0.005**
Cs*f	1	7.14	7.14	0.66	0.418
Cs*d	1	6.6	6.6	0.61	0.436
f*d	1	391.15	391.15	36.41	0
Error	66	709.03	10.74		
Total	80	9864.89			
R-sq	**92.81%**				
R-sq (Adj)	**91.29%**				

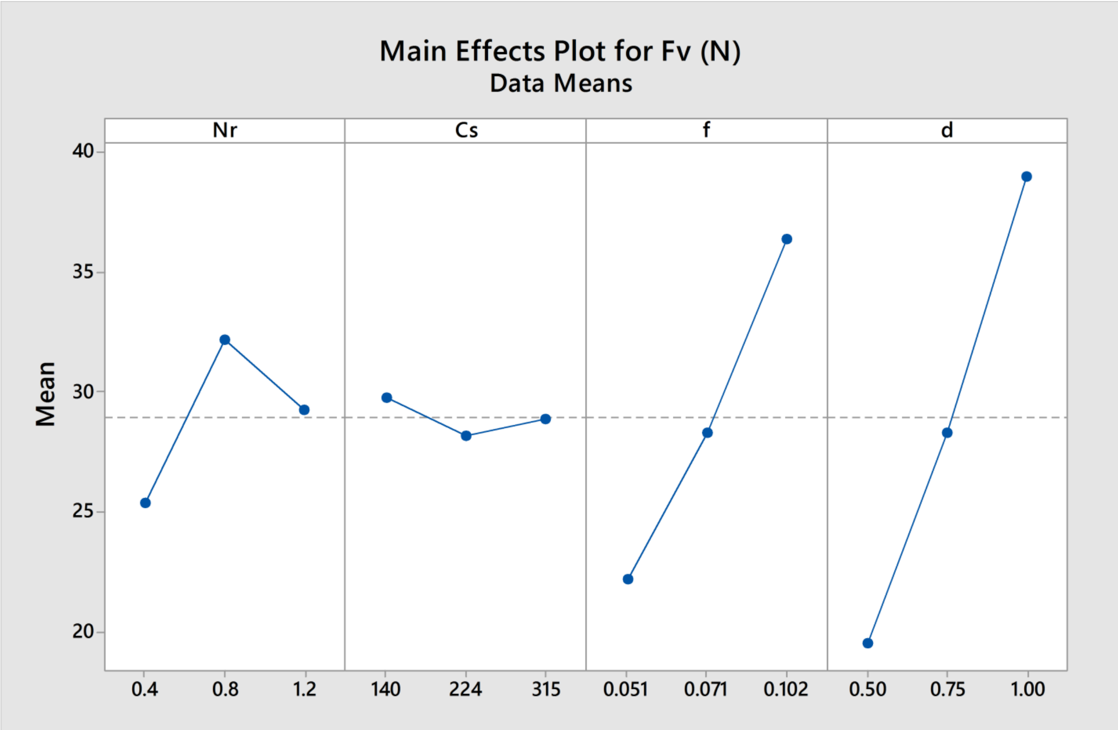

Figure 1 Main effect plots for Cutting Force Fv

The effect of individual parameters on cutting force is shown in Figure 1. It can be said that feed rate and depth of cut are having more effect on cutting force. Nose radius is also affecting the cutting force. The effect of cutting speed on cutting force is less compared to other parameters.

The increase in nose radius increase the cutting force at the roundness of cutting edge is increased and more force is required for cutting. Feed rate and depth of cut are highly affecting cutting force as little increase in their values increase the cutting force significantly.

The prediction of cutting force using equation 1 was compared with the actual experimental values. The comparison is shown in Figure 2. The error between the predicted and experimental values is less than 10%.

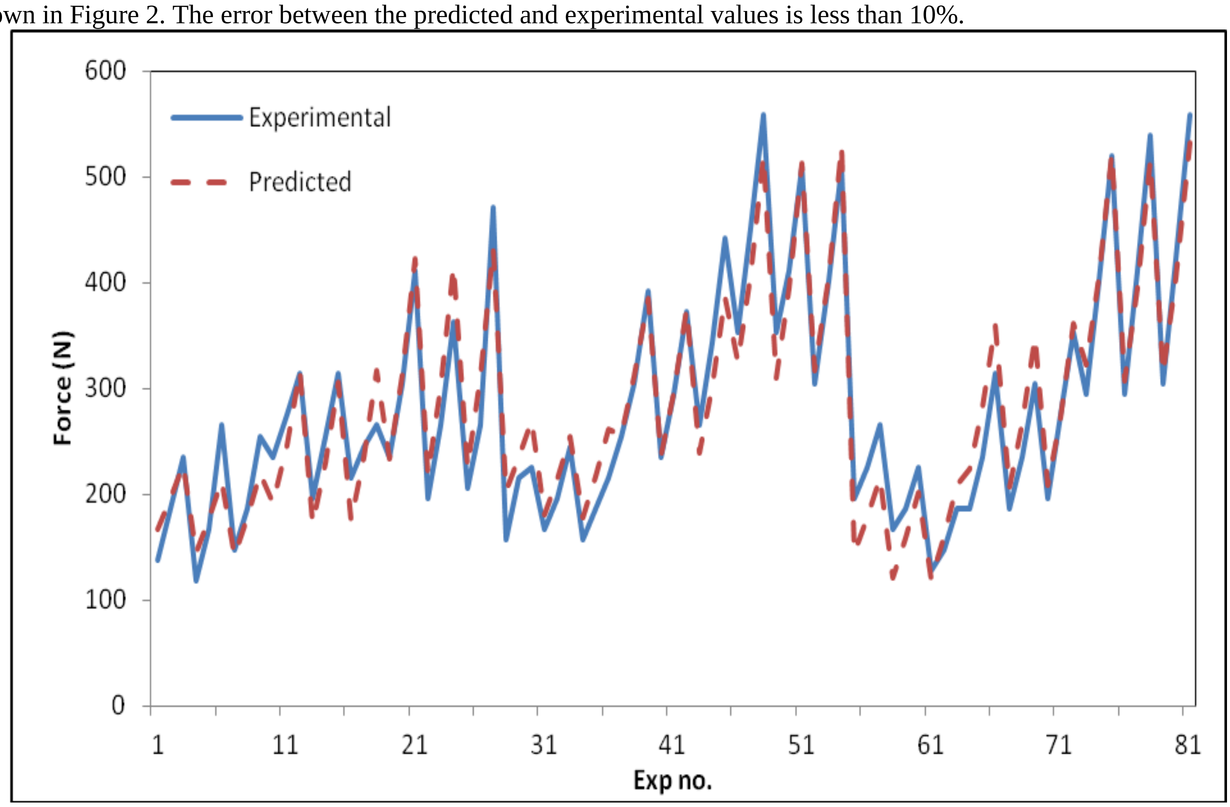

Figure 2 Comparison of predicted and experimental values of cutting force

IV. CONCLUSIONS

Following points can be concluded from this study.

- Depth of cut and feed rate is having more effect on cutting force followed by nose radius and cutting speed.
- The developed mathematical model for cutting force is having R-sq value as 92.81% which means the model is fit for prediction
- The actual and predicted values of cutting force are compared and are in close relation.

REFERENCES

[1] N. Narutaki, A. Murakoshi, S. Motonishi, H. Takeyama, Study on Machining of Titanium Alloys, CIRP Ann. - Manuf. Technol. 32 (1983) 65–69. doi:10.1016/S0007-8506(07)63362-9.

[2] M. Niinomi, Mechanical properties of biomedical titanium alloys, Mater. Sci. Eng. A. 243 (1998) 231–236. doi:10.1016/S0921-5093(97)00806-X.

[3] H.S. Lee, J.H. Yoon, C.H. Park, Y.G. Ko, D.H. Shin, C.S. Lee, A study on diffusion bonding of superplastic Ti-6Al-4V ELI grade, J. Mater. Process. Technol. 187–188 (2007) 526–529. doi:10.1016/j.jmatprotec.2006.11.215.

[4] C.H. Che-Haron, A. Jawaid, The effect of machining on surface integrity of titanium alloy Ti-6% Al-4% v, J. Mater. Process. Technol. 166 (2005) 188–192. doi:10.1016/j.jmatprotec.2004.08.012.

[5] T. Akahori, M. Niinomi, Fracture characteristics of fatigued Ti–6Al–4V ELI as an implant material, Mater. Sci. Eng. A. 243 (1998) 237–243. doi:10.1016/S0921-5093(97)00807-1.

[6] Y.V.R.K. Prasad, T. Seshacharyulu, S.C. Medeiros, W.G. Frazier, Influence of oxygen content on the forging response of equiaxed (α+β) preform of Ti-6Al-4V: Commercial vs. ELI grade, J. Mater. Process. Technol. 108 (2001) 320–327. doi:10.1016/S0924-0136(00)00832-3.

[7] S. Tamilselvi, V. Raman, N. Rajendran, Corrosion behaviour of Ti-6Al-7Nb and Ti-6Al-4V ELI alloys in the simulated body fluid solution by electrochemical impedance spectroscopy, Electrochim. Acta. 52 (2006) 839–846. doi:10.1016/j.electacta.2006.06.018.

[8] H.Y. Valera, S.N. Bhavsar, Experimental Investigation of Surface Roughness and Power Consumption in Turning Operation of EN 31 Alloy Steel, Procedia Technol. 14 (2014) 528–534. doi:10.1016/j.protcy.2014.08.067.

[9] M.S. Sulaiman, M.A. , Che Haron, C.H. , Ghani, J.A. and Kasim, Optimization of Turning Parameters for Titanium Alloy Ti-6Al-4V ELI Using the Response Surface Method (RSM), J. Adv. Manuf. Technol. 7 (2013) 11–28.

[10] T. Yildiz, A.B. Irez, G. Sur, Effect of Cementite Carbide Tool Coating Type and Tool Radius on Cutting Performance, (2016) 78–82.

