SIMULATION OF CUTTING FORCE DURING HIGH SPEED END MILLING OF INCONEL 718

H. N. Ganesan[1], M. S. Kasim[1], R. Izamshah, T.J.S Anand[1], N. H. Harun[1] and S.A. Sundi[2]

[1]Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[2]Faculty of Engineering Technology,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 75450 Ayer Keroh, Melaka, Malaysia.

Corresponding Author's Email: [1]shahir@utem.edu.my

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ABSTRACT: This study aims to investigate the effect of cutting parameters on cutting force by simulation of high speed end milling of Inconel 718. The simulations were carried out using Deform 3D software. TiAlN/AlCrN-coated carbide inserts were employed as the cutting tool for the machining simulation. The milling cutting parameters were cutting speed (100-140 m/min), feed rate (0.1-0.2 mm/tooth) and axial depth of cut (0.5 – 1.0 mm). Response surface methodology (RSM) was used to determine the optimum cutting parameter in order to yield minimum cutting force. The minimum cutting force reported was 38.89 N, under the optimal parameter settings of Vc = 120.58 m/min, fz = 0.13mm/tooth and ap = 0.98mm.

KEYWORDS: *FEM; Inconel 718; Process Optimization; Cutting Force*

1.0 INTRODUCTION

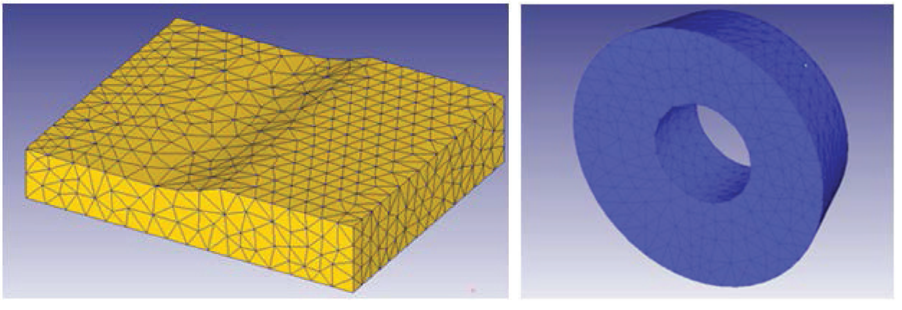
The high speed end milling (HSM) process is used for strong materials such as nickel alloys and titanium alloys. Aerospace and nuclear reactor parts manufacturing industries most widely applied the high speed end ball milling operation [1]. HSM not only save the machining process time, but also saves production costs, and increases the production level without the additional process, which produces a good surface finishing [2]. The advantage inherent in HSM is that it minimizes the cutting force due to small amount chip load during the removing process. In general, when the cutting speed beyond is 5000 RPM, it is considered HSM [3]. But HSM for Inconel is considered when the cutting speed is between 80 – 400 m/min [4]. During machining, the forces component is exerted on the cutting tool, namely, feed force, cutting force and thrust force, exerted in the x-axis, y-axis, and z-axis respectively.

The major difficulty during machining of super alloys is the relatively short in tool life. Inconel 718 is well known as a hard material, so during the machining process, there is a higher cutting force acting on the Inconel 718, as compared to other softer materials [5]. In machining of Inconel 718, the effect of feed rate on the cutting tool affects the cutting tool stress, which is influenced by the cutting force [6]. Flanking is another problem of machining Inconel. This is correlated to cyclic load applied onto rake face of cutting tool [7]. It was reported by Kasim et al. [8] that flaking occurs when the notch wear reaches critical limits. Flank wear, notch wear and crated wear related with cutting force and abrasiveness of Inconel 718 was reported in [9]. The depth of cut, width of cut and feed rate are several factors which are the main effect of the cutting force [10]. Work hardening is a contributing factor in premature tool life [11]. An investigation by Hadi et al. [12] reported that the cutting force increases gradually during up-mill compared to down-mill. Increase momentary cutting force during the tool entry leads to repetitive plucking of the tool to the prone pitting problem on cutting edge.

In 1973, finite element method has been introduced and used to simulate the machining operation [13]. Simulation of machining processes is one of the best ways to study the various cutting forces due to the changes in cutting parameters. In this study, we present a high speed end ball milling of Inconel 718 simulation by using the 3D Deform software. The simulation results were used to determine the most significant parameter to produce lower cutting force. It is difficult to decide the optimization of cutting parameters in real machining process due to the numerous cutting experiments that need to be executed. The simulation was run based on the real experiment methods.

2.0 EXPERIMENTAL

In these machining simulations, Inconel 718 and ball nose, which is PVD, coated TiAlN tungsten carbide (WC-10%), were set as the workpiece and cutting tool respectively. Both cutting tool and workpiece geometries were modeled in STL format as to be compatible with FEA software. The work material was a 10 mm x 8 mm x 2 mm block where the cutting tool insert was a round type with a 10 mm diameter. The workpiece and cutting tool were meshed in Tetrahedron solid element with 100,000 and 20,000 of total elements respectively as shown in Figure 1. This is because of the complexity of the cutting tool shape and to identify the change in structural properties of the Inconel 718 during material removal. The workpiece meshing is more critical than cutting tool, because the workpiece undergo machining process. Therefore, the workpiece needs high resolution mesh. The movement control was assigned for the cutting tool where the cutting speed was controlled by adjusting the rotation speed whereas the feed rate was controlled by adjusting the translation speed. A number of 13 runs were conducted with the combination of three cutting parameters; cutting speed (100-140 m/min), feed rate (0.1-0.2 mm/tooth) and depth of cut (0.5-1 mm).



(a) (b)

Figure 1: Tetrahedral mesh element for (a) workpiece and (b) cutting tool

3.0 RESULTS AND DISCUSSION

Figure 2 shows the simulation results observed for the cutting force exerted onto cutting tool in the Y-axis and the thrust force was the dominating force exerted onto the cutting tool. The rake angle of the cutting tool of -6°, which changes the force magnitude downward.

Increasing the feed rate and depth of cut resulted in increasing the cutting force; this is because of the increase in volume of removing material. The cutting tool generates repetitive maximum and minimum force for every complete revolution. The average entry angle recorded for the maximum and minimum forces was between 130° to 160°, and 30° to 45°, respectively, as shown in Figure 3.

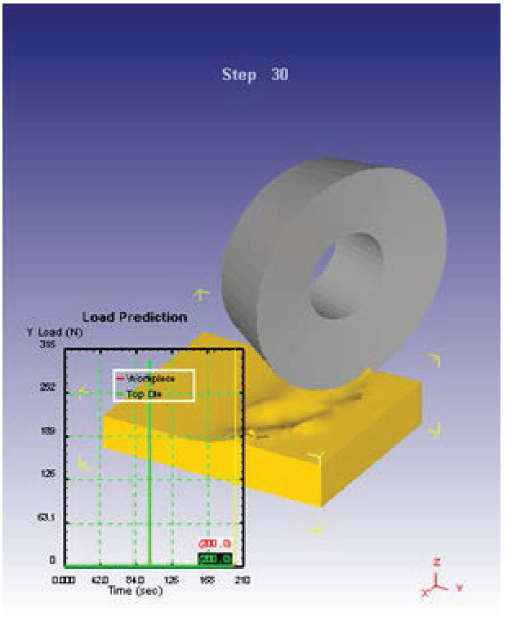


Figure 2: Cutting force exerted on cutting tool in y-axis

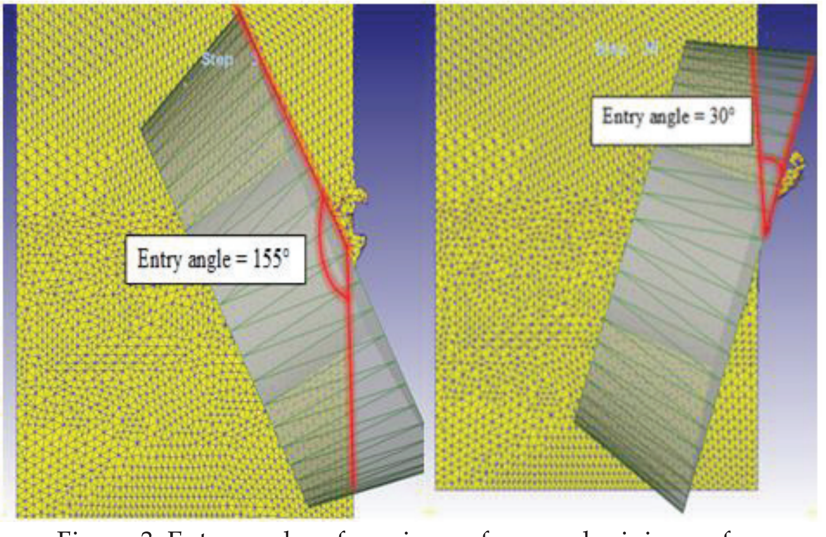


Figure 3: Entry angles of maximum force and minimum force

The average high cutting force was yield during the highest depth of cut, whereas the average lowest force value obtained when the depth of cut was lowest. For every feed value, the greater the depth of cut, the greater the force values produced. Increasing the depth of cut resulted in an increase in the shear plane area and the contact area between rake face and chip. Hence, the increase in the axial depth of cut will increase the Fx, Fy and Fz forces. Based on Figure 4, the forces Fx, Fy and Fz are increased as the depth of the cut increased. The cutting force, feed force and thrust force are increased as the depth of cut increased, due to an increase in the length of contact area between the cutting tool and workpiece [14].

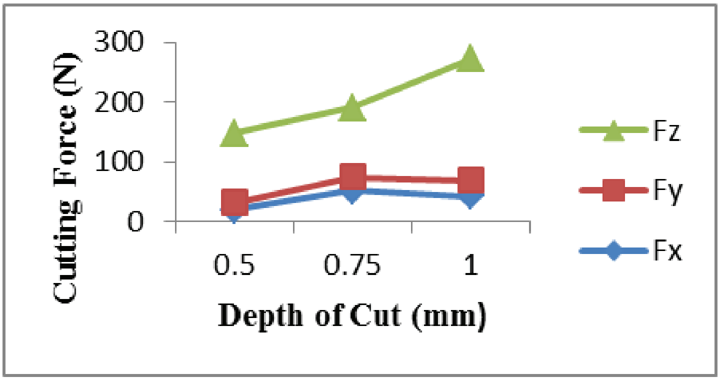


Figure 4: Graph of cutting force against depth of cut

The higher the feed per tooth fz, the higher the average forces generated in the three axis of direction as shown in Figure 5. This is because of the increased in the feed per tooth, which affected the proportion of the shear plane area to be increased as a result from increase in the constant uncut chip width and undeformed chip thickness. As a result, the normal force acting on the rake face augmented. In order to solve the high chip load, the force generation should be higher [8]. The high force can generate through increase in the feed rate. The force that was produced during material removal is greater as a high feed per tooth was used.

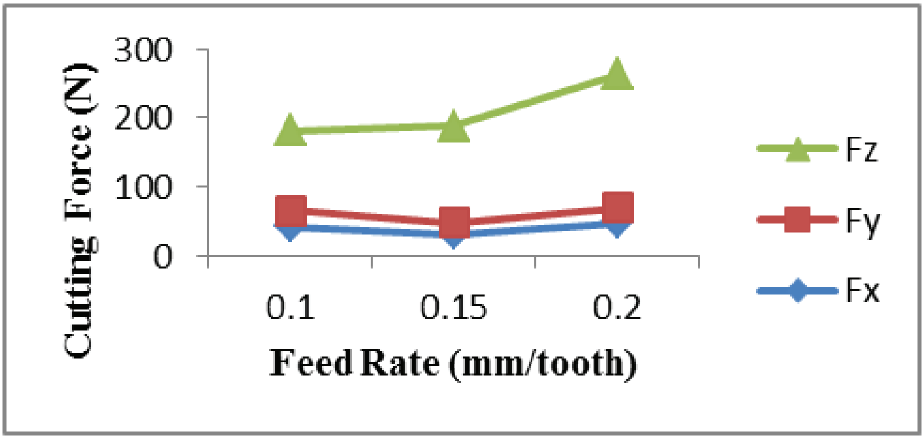


Figure 5: Graph of average force against feed rate

The three forces did not experience many changes with increasing the cutting speed to 140 m/min, which is in line with the experimental observations as reported in the literature. The forces will change under recommended cutting speed range [12]. The average forces created in a range of 30N to 80N with a cutting speed of 120m/min, as shown in Figure 6. The three forces gradually decreasing with a cutting speed of 140m/min, and the cutting speed does not have a significant effect on the three forces, as compared to other parameter feed rate and depth of cut. This insignificant effect is the same as the situations experienced by [15].

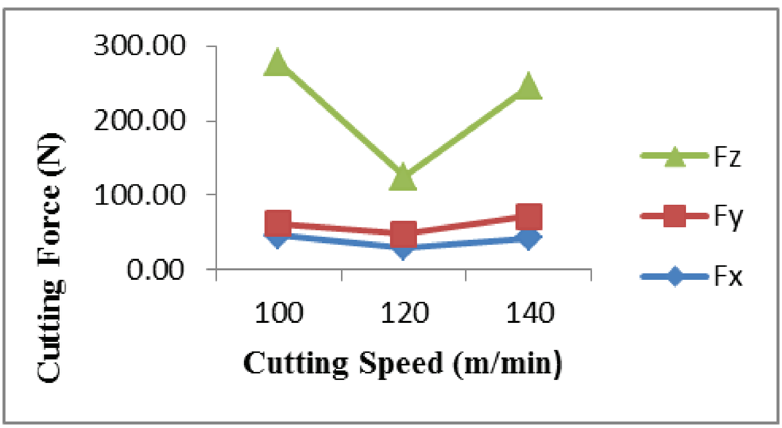


Figure 6: Graph of average force against cutting speed

Design of Experiment, Historical data of Response Surface Methodology (RSM) was used to analyze the best parameter to produce the lowest resultant force. Set no.1 parameter combination generated the least resultant force, as shown in Table 1. The parameter will be used in a real machining process to determine the significant level, which will be done in future work.

Table 1: Suggestion for meeting the full requirement

Solutions Number	Vc (m/min)	*Fz* (mm/tooth)	Ap (mm)	Resultant Force (N)	Desirability	
1	**120.58**	**0.13**	**0.98**	**38.89**	**1**	**Selected**
2	123.03	0.13	0.50	40.09	1	
3	123.78	0.13	0.50	41.61	1	
4	120.72	0.13	0.99	39.66	1	
5	126.16	0.13	0.50	41.30	1	
6	125.70	0.14	0.52	42.53	1	
7	119.38	0.13	0.50	43.53	1	
8	121.54	0.14	0.51	41.65	1	
9	121.65	0.13	0.51	42.85	1	
10	111.57	0.12	0.96	41.30	1	

4.0 CONCLUSION

The finite element model implemented in this study demonstrated a good correlation with the experimental data in terms of cutting force. The results showed that the most dominating factor was the depth of cut, followed by feed rate, while the cutting speed exhibits an insignificant trend in force generation. The optimum set of the parameters was: cutting speed is 120.58m/min, feed rate is 0.13mm/tooth and depth of cut is 0.98mm, in order to generate a low resultant force of about 38.8924 N, which was determined by using the Historical data of Response Surface Methodology (RSM).

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