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Evaluation of the Relationship of Surface Roughness with Machining Parameters in Milling of AA 7075 Material with Experimental and Deform 3D Simulation

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Abstract

AA 7075 T6 material offers important strength values and is easy to machining. In this respect, it is preferred on a wide scale in the industry. This study aimed to investigate the surface quality that occurs in the end milling of AA 7075 T6 material. For this, three different cutting speeds (40, 80, 120 m/min), three different feed rates (0.04, 0.08, 0.12 mm/rev), two different cutting depths (1 and 2 mm) were selected. The selected cutting parameters are combined with 2 and 4-flute end mills. As a result of the experiments, the average surface roughness (Ra) value was measured. The relations of Ra values with the cut parameters were determined. It was determined that Ra increased with increasing feed rate and decreased with increasing cutting speed. No significant effect of depth of cut was detected. Increasing the number of mouths increased Ra. The milling simulation was performed with the 3D cutting module in the Deform 3D software. 2 and 4 flute end mills are modeled, and the workpiece is defined to the software and the cutting parameters. Temperature, damage, stress, and cutting force outputs were estimated through simulations run at different cutting parameters. The predicted outputs and the experimental Ra outputs were interpreted. Experimental outputs were supported by successfully applying milling simulation in Deform 3D software.

Keywords: AA 7075 T6, milling, surface roughness, flute number, Deform 3D, simulation

1. Introduction

7xxx series aluminum alloys are primarily used in structural applications, aerospace, and aerospace industries due to their resistance to fatigue, high strength, ductility, toughness, and low density [1-2]. In order to increase the hardness, tensile and yield strength of aluminum, alloys made with elements such as Cu, Zn, and Mg are used in carrier profiles and constructions where strength is more prominent than other properties [3].

Milling is one of the most widely used processes among manufacturing processes. The surface form defects and the finishing surface determine the quality of the parts produced by the manufacturing operations. Surface quality plays a role in determining functional properties as well as product quality. Good surface quality effectively increases the tribological properties, wear resistance, fatigue strength, heat conduction, and aesthetic appearance of the materials. However, it can also cause an increase in production costs [4]. It has been reported that the main critical parameters affecting the roughness of the surface in the milling process are cutting speed, feed rate, and depth of cut [5-9]. The effects of feed, cutting speed, and depth of cut on Ra in the end milling of the workpiece were examined in another study. [10].

On the other hand, CNC milling of 6061 Al alloy used genetic programming to estimate Ra in terms of vibrations and machining parameters [11]. Wang and Chang Al investigated the Ra parameter of 2014-T6 end milling [12]. In another study, which presented research on surface roughness estimation in milling, modeling data was collected by a central mixed experiment design. Variable parameters were determined as the depth of cut, cutting speed, and feed. In the modeling process, the authors used regression modeling and Artificial Neural Networks [13,14]. Zaghbani and Songmene developed a mathematical model to predict the cutting force and temperature depending on the material properties and cutting parameters in the milling of Al6061-T6 and Al7075-T6 alloys at high cutting speeds [15]. He investigated the effects of cutting tool type and cutting parameters on burr formation and surface roughness in the milling process using a minimum coolant and conventional cooling technique. Three different cutting tools (HSS, TIN, and Carbide), speed (260, 780, and 1330 rpm), and feed rate (20, 40, and 80 mm/min) were used in the experiments. It was determined that the surface roughness increased with the feed rate, but the surface roughness decreased as the number of revolutions increased. In addition, it was reported that lower surface roughness values were achieved with carbide tools compared to TIN and HSS tools [16]. In another study, Al-5083 alloy was milled. The effects of milling parameters on the surface quality (Surface roughness and burr height) were investigated experimentally. Experiments were carried out using a carbide end mill with a diameter of 10 mm. Three different spindle speeds (3000-4000-5000 rpm), three different feed rates (0.05-0.075-0.1 mm/tooth), and two different cutting depths (1-1.5-2 mm) were selected as cutting parameters. However, the experimental design was determined according to the Taguchi L9 (33) orthogonal experimental setup. Experiments showed that cutting force and surface roughness decreased with increasing cutting speed, and burr height increased. It has been determined that while the cutting forces increase with the increase in feed rate, the surface roughness and burr height also increase. Using analysis of variance (ANOVA), it was found that the feed rate parameter among the control factors was the predominant factor on burr height, cutting force, and surface roughness. It was determined that this situation was followed by the cutting speed and the depth of the cut, respectively. Optimization studies have been proven to be successful with validation experiments [17]. In the study, the comparison of the surface roughness values obtained during the milling process on aluminum material and the simulated values through FEA is discussed. The cutting parameters used are three different cutting speeds, three different cutting depths, and constant feed. The material specified for the cutting tool is carbide (15% cobalt) with a tensile strength of approximately 400 N/mm2. The cutting tool is a solid slab mill. Finite element analysis by using DEFORM 3D software, the milling process was carried out by changing the milling parameters on the workpiece, and roughness values were obtained during each procedure. The error between the experimental study and the simulation made by FEA was found to be in the range of ±50% [19]. The support heads of the fixture system were recommended in a study that suggested using a well-designed fixture with support heads to reduce deformation caused by milling square thin-walled aluminum plates made of high-carbon steel. The milling experiment was performed on a CNC Machining center using the same machining parameters as those used in DEFORM 3D-Simulation. Surface roughness was measured with and without fixtures during the milling process. As a result of using this fixture with a support head to reduce deformation, it was concluded that the surface roughness values were reduced between a minimum of 3% and a maximum of 19% [20]. Another study investigated the effect of cutting parameters and machining conditions on tool wear. Machining experiments were carried out using two different lubricants, and the resulting tool wear was measured and compared. All experiments were carried out with high-speed steel (HSS) cutting tools. The turning process is simulated using DEFORM-3D. The results showed a significant reduction in tool wear when machining with multi-walled carbon nanotubes, with an average decrease of 14.8% compared to mineral oil. On the other hand, it was determined that reducing the depth of the cut was the most effective machining parameter in terms of minimizing tool wear [21].

In the study, milling experiments were carried out under different cutting tool geometries and cutting parameters using AA 7075 T6 material. In addition, a milling simulation was made with the help of Deform 3D software. As a result of the experimental study, the average surface roughness (Ra) parameter was measured. The results obtained from the simulation were used to interpret the surface quality and Ra.

2. Materials and Methods

The AA 7075 T6 material used in the milling experiments is 275x85x30 mm in size, and its chemical composition is shown in Table 1.

Table 1. Chemical composition of AA 7075 material.

Element	*Fe*	*Si*	*Cu*	*Mn*	*Mg*
Rate	0.5	0.5	1.2-2	0.3	2.1-2.9
Element	*Zn*	*Cr*	*Zi+Ti*	*Other*	*Al*
Rate	5.1-6.1	0.18-0.28	0.25	0.15	Rem.

AA 7075 material has been subjected to T6 heat treatment; its yield strength is between 460-505 MPa, its tensile strength is between 530-570 MPa, and its hardness value is between 140-160 Brinell. The cutting tools used for end milling have two different numbers of flutes (2 and 4). Uncoated end mills made of HSS material are 8 mm in diameter. In the study, the comparison of the surface roughness values obtained during the milling process on aluminum material and the

The experiments were carried out using DELTA SEIKI CNC vertical machining center with 11 kW engine power and 10000 rpm spindle speed. AA 7075 plates connected to the bench vise were machined with HSS end mills with 2 and 4 flutes. Figure 1 shows the milled AA 7075 plate.

All experiments were carried out under dry machining conditions. The cutting and tool geometry parameters used are shown in Table 2.

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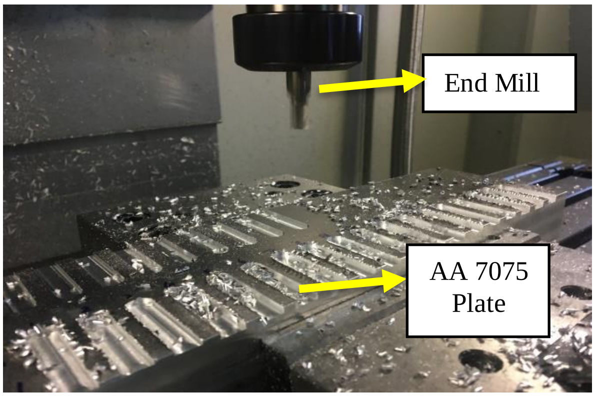

Figure 1. Milling of AA 7075 plate

Table 2. Cutting parameters were used in the experiments

Cutting Tool Material	Flute Number (Z)	Cutting Depth (Ap), mm	Cutting Speed (Vc), m/min	Feed rate (f), mm/rev
HSS	2	1	40	0.04
			80	0.08
	4	2	120	0.12

A total of 36 experiments were carried out with 2 and 4 flute end mills. In addition, milling simulations were made using the cutting parameters that cause the smallest and largest surface roughness to occur with Deform 3D software. Simulation steps with Deform 3D are given in Figure 2.

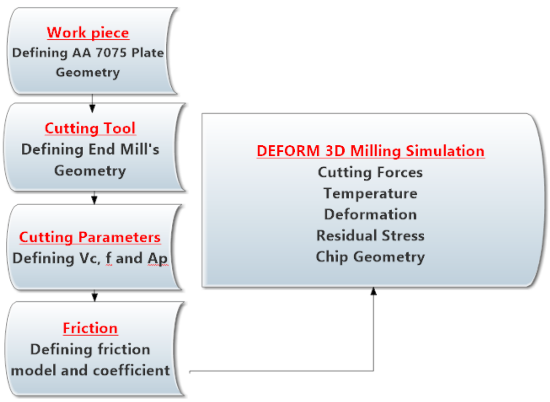

Figure 2. Deform 3D simulation steps.

The workpiece AA 7075 material was selected from the software's library. A triangular mesh is knitted on the selected material. The mesh number is 12000. The cutting tool was also selected from the software library. The number of cutting edges (2 and 4) of the chosen end mill is customized according to the experiment. The mesh of the end mill consists of 12000 triangles. The cutting parameters entered into the software are the parameters that give the largest and smallest average surface roughness values. In the last step before the simulation, the Usui tool wear model shown in Equation 1 is defined.

$$\frac{dW}{dt} = A\,\sigma_n\,V_s\,exp(-B/T) \qquad \textbf{(1)}$$

In Equation 1, T is the shear temperature, σ_n is the normal stress, Vs is the shear rate, and B is the constant. Figure 3 gives a screenshot of the ready-to-run simulation with all definitions.

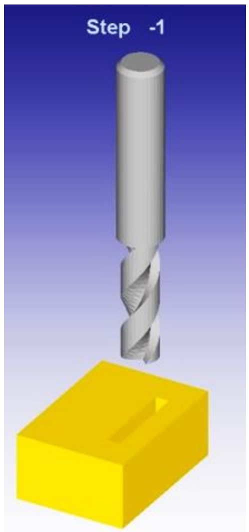

Figure 3. Ready-to-run milling simulation

Actual milling experiments are supported by the results obtained from the milling simulation run. Thus, the behavior of the Ra output made sense.

3. Results and Discussion

As a result of the experiments, the Ra value was measured by a profilometer. The relationship of Ra with the cutting parameters is visualized with the help of 3D graphics. Figure 4 shows the Ra values obtained from the experiments performed with the 2-flute end mill and their relations with the cutting parameters.

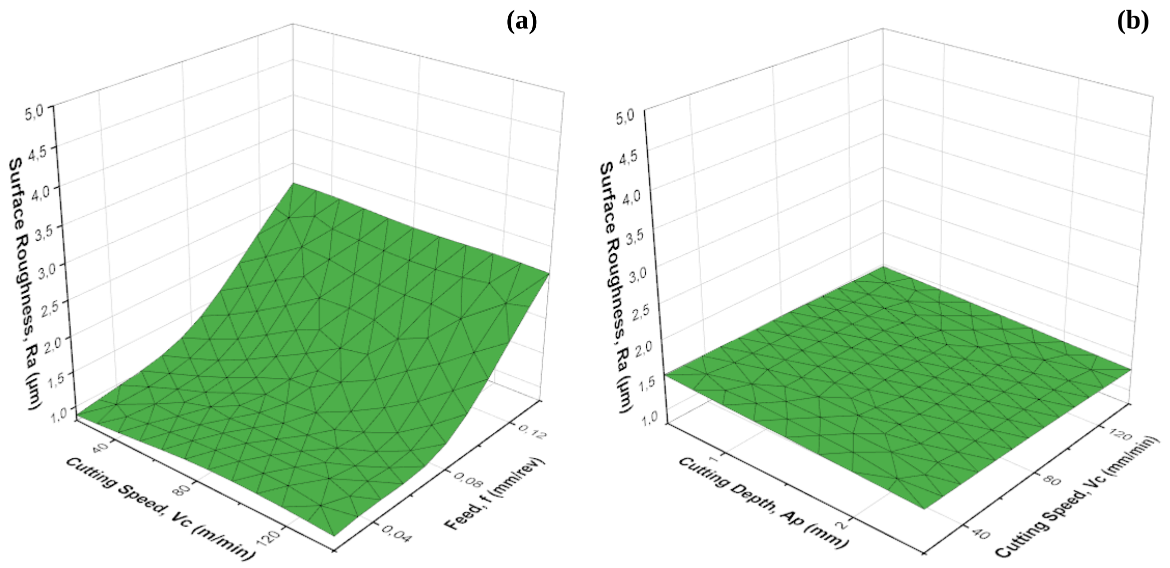

Figure 4. Experiment results with a 2-flute end mill. a) Ap = 1mm, Vc-f relationship b) Ap-Vc relationship

When Figure 4 is examined, it is observed that the surface roughness generally decreases with the increase of Vc in the 2-flute end mill, but this decrease is not very large. It has been determined that the increase of Ap also decreases Ra, but this decrease is not significant. In Figure 5, the Ra values obtained from the experiments performed with the 4-flute end mill and their relations with the cutting parameters are shown.

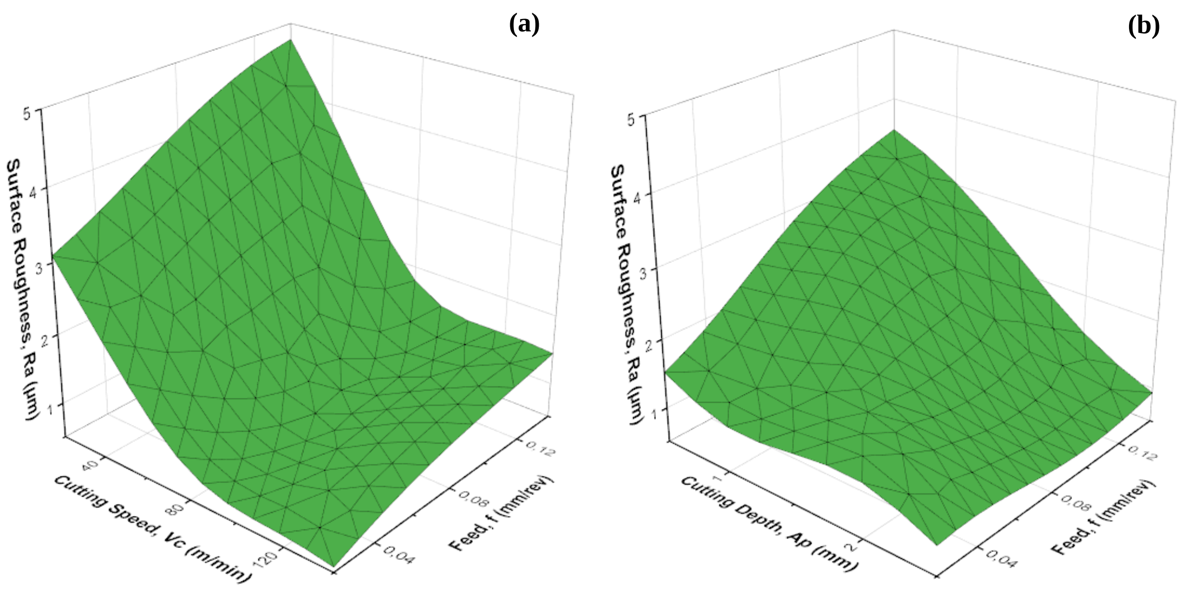

Figure 5. Experiment results with a 4-flute end mill. a) Ap = 1mm, Vc-f relationship b) Ap-Vc relationship

When Figure 5 is examined, the Ra value decreased significantly with the increased cutting speed in the experiments performed using 4-flute end mills. There is a significant increase with the increase in progress. An apparent effect of Ap on Ra was not observed. Figure 6 shows the comparison of 2- and 4-flute end mills. When Figure 6a is examined, it is observed that the 4-flute end mill produces larger Ra results than the 2-flute. Figure 6b shows that the 4-flute end mill produces higher Ra values at low cutting speeds than the 2-flute end mills, while it causes smaller Ra values at high cutting speeds.

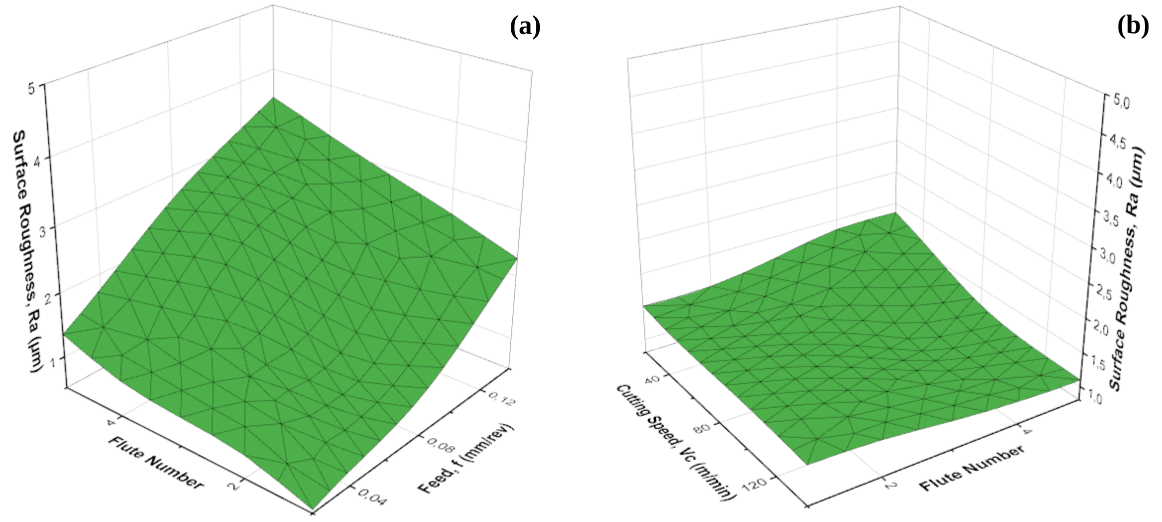

Figure 6. Comparison of test results with 2 and 4 flute end mills. a) Ap= 1mm, b) Ap= 2mm

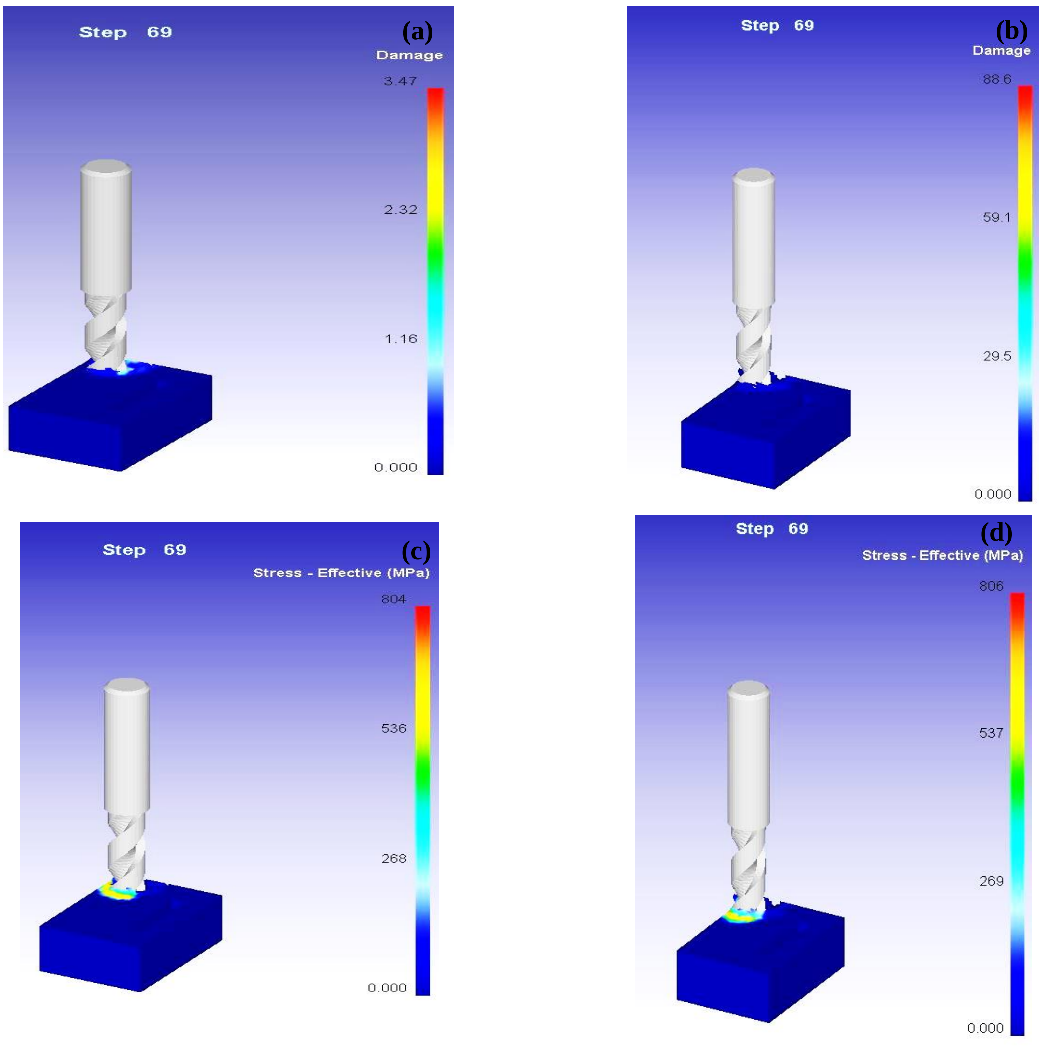

Figure 7. Damage-strain simulation results with a 2-flute end mill. a) f=0.04 mm/rev damage result b) 0.12 mm/rev damage result, c) f=0.04 mm/rev stress result, d) f=0.12 mm/rev stress result

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3.1. Deform 3D Results

Using the 3D cutting module of Deform 3D software, milling simulations of 2-flute and 4-flute end mills were created at different cutting parameters. The results of these simulations, such as damage, temperature, and force, are discussed. Figure 7 shows the damage and stress results of the simulation performed with a 2-flute end mill at a cutting speed of 40 m/min using 0.04 mm/rev and 0.12 mm/rev feed rate.

When Figures 7 c and d are examined, it has been determined that similar stress values occur in both feed rate values.

While the cutting tool contacted the workpiece more slowly at 0.04 mm/rev feed rate, the damage occurred at a maximum rate of 3.47, while at a 0.12 mm/rev feed rate, it occurred at a maximum of 88.6 as a result of a faster contact. This is illustrated in Figures 7 a and b. Feed rate is the cutting parameter that has the greatest influence on surface roughness [18]. Considering this situation, the temperature and force changes occurring at different progressions are presented in the simulation. Figure 8 shows the simulation's temperature and force results performed with a 2-flute end mill at different feed rates.

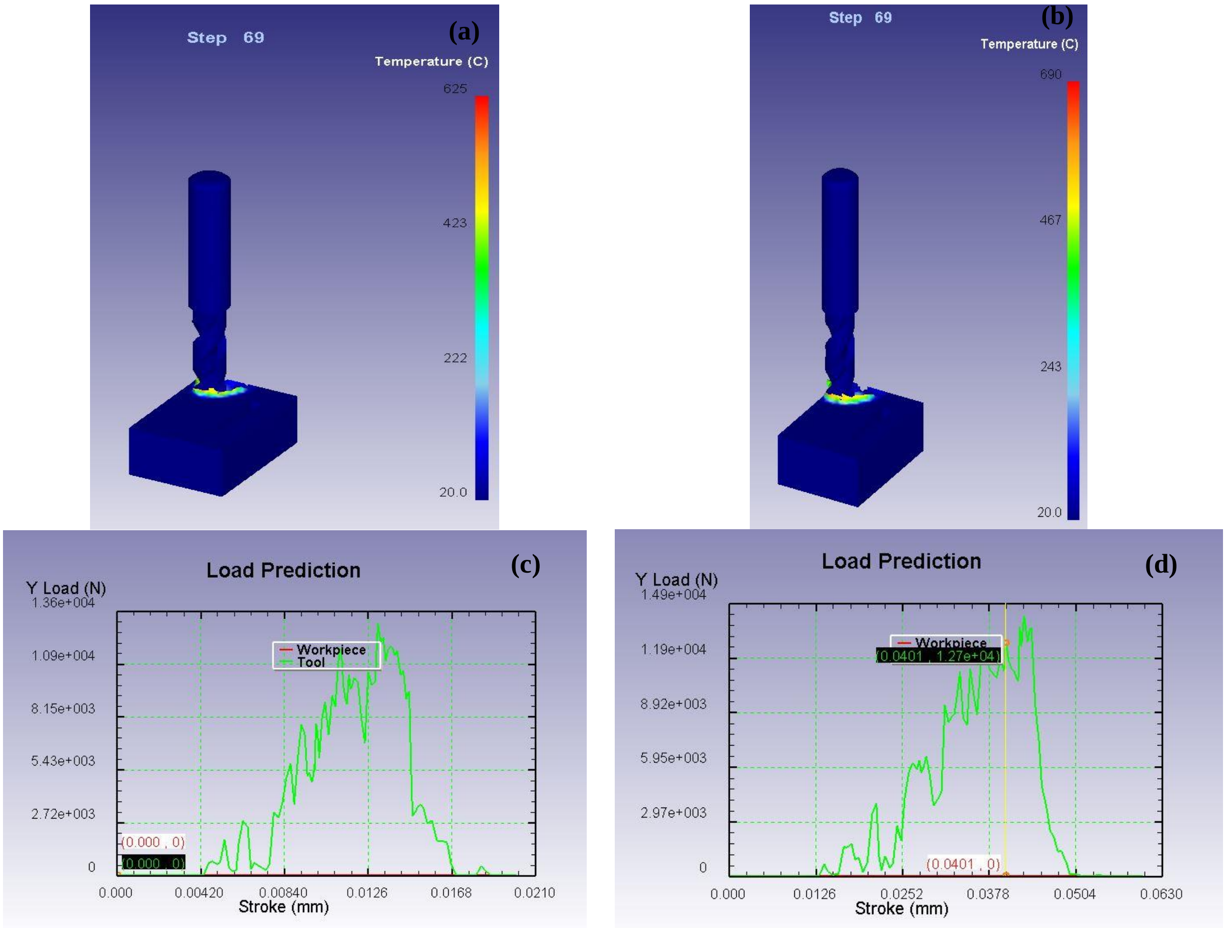

Figure 8. Temperature-force simulation results with a 2-flute end mill. a) f=0.04 mm/rev temperature result b) 0.12 mm/rev temperature result, c) f=0.04 mm/rev force on the Y axis, d) f=0.12 mm/rev result on the Y axis.

Figure 8 shows that the maximum temperature is 625 °C at 0.04 mm/rev feed rate, and it can go up to 690 °C at 0.12 mm/rev feed rate in Figure 8 b. At higher temperatures, due to the ductile nature of AA 7075 material, adhesion to the cutting tool occurs in greater amounts. This is a crucial case that increases it to the Ra parameter. Increasing feed rate increases cutting forces. In Figures 8 c and d, the greatest force in the Y-axis was estimated as 74 N at 0.04 mm/rev feed rate, while this value was estimated to be approximately 81 N at 0.12 mm/rev feed rate. Similar results were obtained in temperature, stress, damage, and force outputs with the change of feed rate in simulations made with a 4-flute end mill. In Figure 9, damage rates of 2 and 4 flute end mills are given.

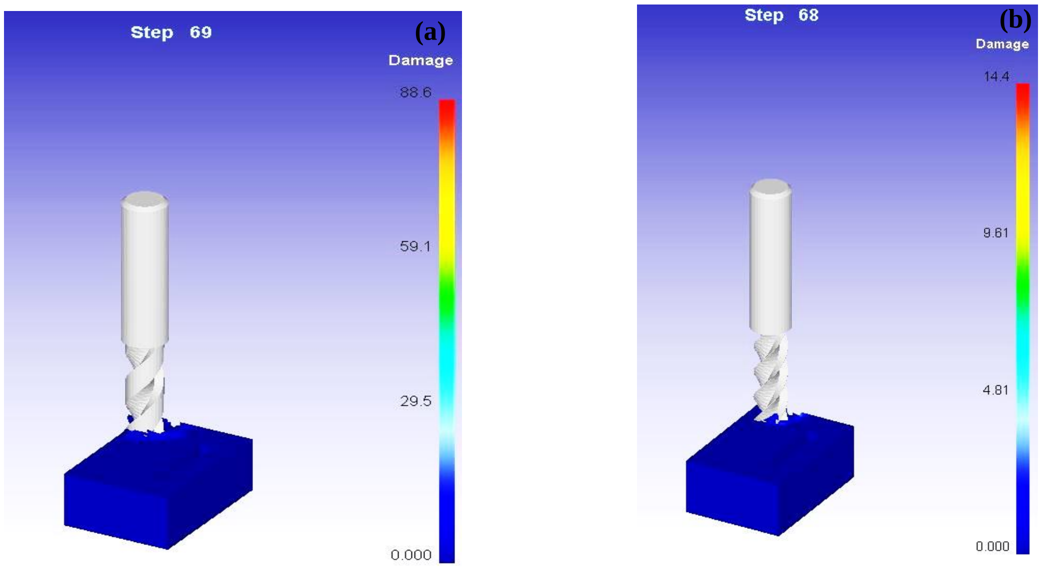

Figure 9. Damage results of 2 and 4 flute end mills at 0.12 mm/rev feed rate. a) 2 flutes b) 4 flutes.

Figure 9 shows that the 2-flute end mill causes greater damage to the AA 7075 material. However, this situation was reflected in contrast to the Ra parameter in actual experiments. The reason for this can be explained as the chips sticking to the cutting tool due to the ductile nature of the AA 7075 material. Since the amount of sticking chips is less in a 2-flute end mill, it causes minor damage to the machined surface, and Ra is lower.

4. Conclusion

AA 7075 material was machined under different cutting parameters with 2 and 4-flute end mills. Ra parameters of the machined surfaces were measured. In addition, milling simulation was made with Deform 3D software for different values of the feed rate parameter, which has the most significant effect on the Ra parameter. The simulation results and predictions supported experimental results. The obtained results can be listed as follows:

- Ra parameter decreased with the increase of cutting speed. Lower Ra values were measured at a 120 m/min cutting speed.
- The Ra parameter increased proportionally with the increase in the feed rate. In experiments with a feed rate of 0.12 mm/rev, Ra is measured larger.
- No significant effect of the depth of cut on Ra was revealed.
- While increasing the number of flutes increased the Ra parameter, it decreased the burrs on the surface.
- As a result of the milling simulation with Deform 3D, it is estimated that the increase in the feed rate will increase the temperature, damage, and cutting force.
- It has been determined that increasing temperature and cutting force have a negative effect on the Ra parameter.
- Milling simulation with Deform 3D has been successfully performed for 2 and 4 flute end mills.

Author's Contributions

The author carried out the experiments and simulations. Wrote and edited the article.

Ethics

There are no ethical issues after the publication of this manuscript.

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