The quality of the machined surface of an aluminum alloy depending on the cutting depth variation

A M Ṭîțu¹,²,* and A B Pop³

¹Lucian Blaga University of Sibiu, 10, Victoriei Street, Sibiu, România
²The Academy of Romanian Scientists, 54, Splaiul Independenţei, Sector 5, Bucharest, Romania
³SC TECHNOCAD SA, 72, Vasile Alecsandri Street, Baia Mare, Romania

Email: mihail.titu@ulbsibiu.ro

Abstract. The surface quality study of the cutting processes is a very current and complex subject, which approached in variously specialized researches. This paper is a continuation of our previous research. The primary objective of this paper is to track the evolution of the surface roughness measured longitudinally on the feed motion direction in the end-milling process of an aluminum alloy used in the aerospace industry. The active experiment is the research method used to achieve the proposed objective. The cutting regime adapted to carrying out the necessary experiments supposes a constant cutting speed, while the cutting depth varies with different values. Obtaining the experimental data did possibly using the roughness tester as a measuring device. The obtained measurements were used to determine the surface quality evolution in the various situations of the cutting regimes resulting from the combination of the process parameters considered in the analysis. The experimental study is very complex and carried in an industrial organization that focuses on the aerospace industry. Through this original research that was carried out in the smallest details, a series of comparative graphs of the surface roughness evolution performed under the cutting depth variation, which led to a package of conclusions to have taken into consideration.

1. Introduction
Since the cutting process has a significant weight in all manufacturing methods, research carried out on the machining processes optimization requires continuous development [1,2,3].

Milling is one of the most common metal cutting processes. This process generally is used in manufacturing, including automotive and aerospace, where quality is an essential factor in production [4,5]. The friction, the heat, and the high energy influence the tool life, and also the surface quality, and tool wear. Surface quality plays a significant role because a good quality surface significantly improves the fatigue resistance, corrosion resistance or the workpiece life [5,6,7]. Therefore, it is essential to optimize the cutting parameters to obtain a good surface finish.

In his research, Erdel found that the main parameters encountered in a machining process are dependent on the cutting speed used, which may lead to an increase or decrease in the life of the cutting tool, the surface quality, the number of removed chips, and cutting forces. Each of these effects ultimately influences the productivity and costs that a process requires [8].

By the most commonly used materials in machining, the steels occupy the majority. In this paper, the attention focus on the aluminum alloys. Specifically, this paper has as its object study the
7136 aluminum alloy. This alloy also was studied in previously own research [9-12], and this paper is a continuation of them.

2. Research method description
A series of experiments were carried out to investigate the effects of one or more factors of the cutting process exerted on the quality of the machined surface. The study, which is hugely complex, was carried out in the enterprise focused on the aerospace industry Universal Alloy Corporation Europe Dumbrăvița, Maramureș County. This company is a world leader in aerospace products, including three fully integrated extruders all over the world. The objective of the paper is to investigate the evolution of the surface roughness in the end-milling process of the 7136 aluminum alloy under the influence of the cutting depth. The adopted cutting regime in carrying out the necessary experiments involves the cutting speed \( v \) [m/min] kept at a constant value, while the cutting depth [mm] and the feed per tooth \( f_z \) [mm/tooth] varies, taking different values.

| Nr. Crt | V [m/min] | \( A_p \) [mm] | \( F_z \) [mm/tooth] |
|---------|-----------|----------------|---------------------|
| 1       | 570       | 2              | 0.04                |
| 2       | 570       | 2.5            | 0.06                |
| 3       | 570       | 3              | 0.08                |
| 4       | 570       | 3.5            | 0.11                |
| 5       | 570       | 4              | 0.14                |

The values of the cutting regime parameters are shown in Table 1. The cutting tool used to perform the machining was the SECO R217.69-1616.0-09-2AN - 2 toothed and 16 mm diameter, with two cutting inserts XOEX090308FR-E05, H15. The CNC machine was HAAS VF2. The dimensions of the two processed aluminum blocks are 500 x 101 x 24.5 mm.

3. Research results
After the machining process, the surface roughness \( R_a \) of each sample was measured using a Mitutoyo SURFTEST SJ-210 over 5 mm.

![Figure 1. Histogram of \( R_a \) measurements.](image)
Figure 1 represents the histogram of surface roughness measurements, from which it follows that, under the conditions set for the experiment, relatively low surface roughness values are obtained in the end-milling process, the recorded data having an approximately normal distribution.

The dispersion diagram of the Ra values according to the cutting depth is presented in figure 2.

By this chart, it follows that the measured values of the roughness have an increasing trend with the increase of the cutting depth.

After a primary analysis of the system behavior (CNC machine - cutting tool-workpiece), we consider that the vibrations are the primary cause of these increases, vibrations produced due to the resonance of the system, tool, the material, cutting parameters and CNC machine and also of the chip breaking phenomenon due to heavy tool loading (high cutting depth and maximum tool width).

4. The quality evolution of the end milled surface of 7136 aluminum alloy under the cutting variation depth

Further, through this research, a comparative graph on the roughness evolution of the milled surface of 7136 aluminum alloy was performed under the cutting depth variation.

The effects of cutting depth variation exerted on the surface roughness when the cutting speed and feed per tooth remain constant can be seen in figure 3.

Figure 3 shows the Ra evolution under the influence of ap variation when fz vary from 0.04 to 0.14 [mm/tooth]. When fz is 0.04 [mm/tooth], the lowest roughness value is 0.442 [μm] when ap is 2 [mm], reaching a maximum of 1.372 [μm] when ap is 3.5 [mm]; when fz = 0.08 [mm/tooth], the lowest roughness value recorded is when ap is 2 [mm], but the maximum value of the roughness is when ap is 4 [mm].

When the feed per tooth is 0.06 [mm / tooth], the maximum roughness is again recorded at a depth of 3.5 [mm]. When fz has the values of 0.11 and 0.14 [mm/tooth], the smallest roughness is when ap reach the minimum values, and the highest Ra values are when the cutting depth reaches the maximum values.
Figure 3. $R_a$ evolution under the influence of $a_p$ variation.

This graph provides an overview of how the recorded surface roughness varies with the cutting depth increase.

Generally, we can see that with a low cutting depth, regardless of the feed per tooth value, the surface roughness is small.

However, with the cutting depth increase, the roughness $R_a$ has an oscillating increase reaching the maximum value when cutting depths is 3.5 and 4 mm.

5. Final Conclusions

The current trends in the analysis and study of the main factors that are influencing the cutting process, are: productivity increasing, the surface quality study, developing and implementing new cutting technology, as well as new materials and tools types with superior cutting properties.

Figure 4. The highest $R_a$ values recorded when $a_p$ and $f_z$ varies, and $v$ remains constant.
After analyzing the quality of the milled surface quality of the 7136 aluminum alloy under the variation of cutting depth and feed per tooth, we can see that the highest $R_a$ values recorded are according to data presented in figure 4.

The best roughness is achieved when: $v = 570$ [m/min]; $a_p = 3$ [mm]; $f_z = 0.14$ [mm/tooth]; $R_a = 0.357$ [$\mu$m] - figure 5 shows the surface microscopically analyzed as well as the profile of the $R_a$ measurement.

![Surface appearance under microscopically analysis and profile related to $R_a$ measurements.](image_url)

**Figure 5.** Surface appearance under the microscopically analysis and profile related to $R_a$ measurements.

This aspect is also confirmed by the spatial graphs shown in figures 6 and 7, regarding the simultaneous influence of the two parameters ($a_p$ and $f_z$), on the $R_a$ values.

These figures show clearly the effects of cutting parameters (feed per tooth and cutting depth) on the surface roughness in the Al7136 end milling case.
Figure 6. Spatial variation of roughness according to feed per tooth and cutting depth.

Figure 7. The contour plot indication of roughness variations according to feed per tooth and cutting depth.

By the results of the experiment and the graphs analysis, we can conclude that the roughness of the end-milled surface (Ra) was mostly affected by the increase of the cutting depth because, with its increase, the chip resistance and the vibration amplitude also increase.

As a result, the chip temperature also rises. Therefore, surface quality is expected to deteriorate.

Experiments and graphs show that as the feed per tooth increases, the surface roughness also increases due to the increased cutting force and vibration.

References
[1] Potdar Y K and Zehnder A T 2003 J of Manuf. Science and Eng. 125, p 645 – 655
[2] Rawangwong S, Chatthong J, Burapa R and Boonchouytan W 2012 An investigation of optimum cutting conditions in face milling aluminum 7075-t6 using the design of the experiment. 4th International Conference on Applied Operational Research, Proceedings 4 125–135
[3] Wince J N 2002 Modeling chip formation in orthogonal metal cutting using finite element analysis. A Thesis Submitted to the Faculty of Mississippi State University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering in the Department of Engineering Mississippi State, Mississippi
[4] Reddy B S, Kumar J S and Reddy K V K 2011 Int J of Eng, Science, and Tech. 3 (8) 102-109
[5] Safari H, Sharif S, Izman S and Jafari H 2012 J of Applied Sciences Research 8 (11) 5280-5284
[6] Ghanem F, Braham C, Fitzpatrick M E and Sidhom H 2002 J of Materials Engineering and Performance 11 (6) 631-639
[7] Lou M S, Chen J C and Li C M 1998 J of Industrial Technology 15 (1)
[8] Erdel B P High 2003 Speed Machining. Society of Manufacturing Engineers, Dearborn, Michigan
[9] Țîțu M A and Pop A B 2017 MATEC Web of Conferences 112, 01009
[10] Țîțu M A and Pop A B 2016 IOP Conference Series: Materials Science and Engineering, 161(1),012014
[11] Pop A B and Țîțu M A 2017 MATEC Web of Conferences 121, 05005
[12] Pop A B and Țîțu A M 2017 MATEC Web of Conferences 137, 03011