Influence of the feed per tooth variation on the surface roughness at end milling of an aluminum alloy

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Abstract. As a part of the cutting process, a researched aspect continuously is surface quality. Based on and using the results of previous research, the present scientific paper addresses the problem of the machined surfaces roughness. The cutting process approached in this study is the end-milling one, and the workpiece material used to carry out the study is the aluminum alloy used in the aerospace industry. The adopted cutting regime imply to keep the cutting speed at a constant value while the cutting parameters: cutting depth and feed per tooth vary with different values. The experimental research carried out by the authors in a prestigious industrial company is complicated and complies with the specific methodology. The conclusions stand based on the interpretation of the results obtained from the experiments which were carried out based on the active experimental type. The confirmation of the obtained results was performed using the profiles and images of the microscopic analysis of the machined surface.

1. Introduction

The end-milling process is one of the most commonly used metal cutting operations of the machining parts due to its ability to remove materials in large and fast quantities with relatively good surface quality.

Surface roughness plays an essential role in determining the product quality because it strongly influences the performance of the manufactured parts as well as production costs. The optimal values of the cutting process parameters must be obtained concerning the imposed technical and economic conditions.

Knowing these values is a prerequisite for the cutting process to take place under conditions of stability and productivity, the precision of machining, tool, and energy consumption, and so forth to finally get to prescribed values. There is a need to develop a methodology for optimizing the cutting process parameters.

Steels are the most commonly used materials in the machining process, but aluminum alloys are widely used in engineering, especially in the automotive, aerospace, aeronautics and medicine industries [1,2].

Regarding the aluminum alloys, the most frequently studied were Al6061, Al7075, and Al2024, due to their superior mechanical characteristics compared to other alloys. Various surface roughness
studies have been carried out using circular-frontal milling using different materials, cutting tools, experimental methods, and optimization.

As Klocke [3] mentions, uncoated cemented carbide cutting tools are most commonly used to machine the aluminum alloys.

The research of Rao and Shin [4] concerned the analytical and experimental study on high-speed end-milling of Al7075-T6. They analyzed the results in terms of cutting forces, chip morphology, and integrity of the workpiece surface, using carbide and diamond tool inserts.

The effect of the cutting speed, cutting depth and feed rate on the surface roughness in the end-milling of aluminum alloys, was studied by Yang and Chen [5].

Benardos and Vosniakos [5] used Taguchi's method to consider Ra's prediction in aluminum alloy milling.

The cutting depth, cutting speed, feed per tooth, wear of the cutting tool, and the use of the cutting fluid were the factors considered in the experiment.

Among the reference in which is Al6061 studied, can be mentioned: [7] which tracked the temperature and the deformations occurred in the workpiece and the chip during the machining process, [8,9,10] which studied the chip formation in the case of orthogonal cutting using the finite element analysis method.

Regarding the aluminum Al7075 [11] studied the surface quality under the influence of process parameters. It has found that the most significant influence on the surface quality has the cutting speed and the feed per tooth.

In [12,13] it was studied the influence of the feed rate on the cutting forces in the end-milling process of Al 2024-T6 alloy and at the same time the chip formation when the feed rate value decrease, also simulated by the finite element analysis.

Chip formation under the influence of cutting speed and feed rate was also analyzed by [14]. In this paper Al7136, will be analyzed which was studied in the own previously research papers [15-18].

2. The research method description
To evaluate the feed per tooth influence on the surface roughness by the end-milling process of the aluminum alloy, a series of 25 experiments were performed.

This research was carried out using 7136 Aluminum Alloy, which has superior properties to other alloys.

This alloy used in the aeronautical industry due to its main properties, which are: hardness, high strength relative to low weight, low thermal expansion, better mechanical and thermal properties than other alloys, chemical resistance, resistance to corrosive atmospheres, non-magnetic, good electrical and thermal conductor.

The two samples were cut to 500 x 101 x 24.5 mm. Each workpiece was fixed on the machine table.

The cutting regime adopted in the experiments is: cutting speed: 570 [m/min]; cutting depth: 2; 2.5; 3; 3.5; 4 [mm]; feed per tooth: 0.04; 0.06; 0.08; 0.11; 0.14.

Experiments were performed using the HAAS VF2 CNC machining center. The research was carried out using a standard end-milling cutter recommended to aluminum machining, type SECO R217.69-1616.0-09-2AN of 16 mm diameter with two cutting inserts, type XOEX090308FR-E05, H15.

The measurement devices were the Micro Vu VERTEX 310 an optical microscope to analyze the surface aspect, and the Mitutoyo SURFTEST SJ-210 to evaluate the surface roughness under different cutting conditions.

3. Research results
After the machining, the surface roughness $R_a$ was measured on 5 mm distance with the surface tester.

The valid values of the surface roughness measurements $R_a$ [μm] determined longitudinally in the feed motion direction are present in Table 1.
The obtained measurements were used to determine the surface quality evolution in the different situations related to the cutting regimes resulting from the combination of the process parameters.

Table 1. $R_a$ longitudinal values.

| $v=570$ [m/min]; $a_p=2$ [mm] | $v=570$ [m/min]; $a_p=2.5$ [mm] | $v=570$ [m/min]; $a_p=3$ [mm] |
|---------------------------------|---------------------------------|---------------------------------|
| $f_z$ [mm/tooth] | $R_a$ [μm] | $f_z$ [mm/tooth] | $R_a$ [μm] | $f_z$ [mm/tooth] | $R_a$ [μm] |
| 0.04 | 0.442 | 0.473 | 0.04 | 0.488 | 0.08 | 0.427 | 0.493 | 0.11 | 0.393 | 0.509 | 0.14 | 0.369 | 0.478 |
| 0.06 | 0.465 | 0.06 | 0.427 | 0.06 | 0.493 | 0.08 | 0.427 | 0.08 | 0.493 | 0.11 | 0.393 | 0.427 | 0.14 | 0.369 | 0.478 |
| 0.08 | 0.470 | 0.08 | 0.427 | 0.08 | 0.493 | 0.08 | 0.427 | 0.08 | 0.493 | 0.11 | 0.393 | 0.427 | 0.14 | 0.369 | 0.478 |
| 0.11 | 0.429 | 0.11 | 0.427 | 0.11 | 0.393 | 0.11 | 0.427 | 0.11 | 0.393 | 0.14 | 0.369 | 0.427 | 0.14 | 0.369 | 0.427 |
| 0.14 | 0.369 | 0.14 | 0.393 | 0.14 | 0.369 | 0.14 | 0.393 | 0.14 | 0.369 | 0.14 | 0.369 | 0.393 | 0.14 | 0.369 | 0.393 |

4. The quality evolution of the machined surface under the feed per tooth variation

Figure 1 shows the surface roughness evolution in the situation where the cutting speed remain constant at 570 [m/min] and the feed per tooth varies.

[Graph showing $R_a$ evolution when $v=570$[m/min] and $ap$ varies]

As it can be seen here, on a feed rate of 0.04 [mm/tooth] the $R_a$ value is 0.442 [μm], followed by an increase of the surface roughness with the increase of the feed rate but up to 0.08 [mm/tooth], then there is a decrease of the roughness value with the feed per tooth increasing.
Figure 2. Hierarchy of Ra values under the $a_p$ and $f_z$ variations, the highest $R_a$ values.
Thus, the maximum roughness value in this situation is 0.470 [μm]. The situation when \( v = 570 \) [m/min] and \( a_p = 2.5 \) [mm] and \( f_z \) varies, is similar to the previously with the difference that the maximum value of \( R_a = 0.509 \) [μm] is recorded on \( f_z = 0.06 \) [mm/tooth]. As it can be seen in the case where \( v = 570 \) [m/min] and \( a_p = 3 \) [mm], \( R_a \) shows the maximum values at the lowest \( f_z \) of 0.04 [mm/tooth]. When \( a_p = 3.5 \) [mm] with the increase of the feed rate, the \( R_a \) value decreases. When \( a_p = 3.5 \) [mm] and 4 [mm] the situations are similar to \( a_p = 3 \) [mm]. As a general finding, on this comparative graph, it can be mentioned that the roughness value is highest when the \( a_p \) is high, and \( f_z \) is low. However, with the increase of the feed per with a high cutting depth, the roughness \( R_a \) decreases. Therefore, the cutting process parameters must be chosen appropriately to achieve the desired quality of the machined surface at a minimum cost.

5. Conclusions

In this scientific paper, the influence of the selected cutting parameters exerted on the surface roughness obtained by end-milling of the 7136 aluminum alloy, was analyzed. Based on the experimental investigations, the conclusions below can be formulated.

When the cutting depth and the feed per tooth vary, the highest surface roughness value is 1.372 [μm] and is recorded when the \( a_p = 3.5 \) [mm], and \( f_z \) is 0.04 [mm/tooth].

The confirmation of the obtained results was performed using profileograms and images of the microscopic analysis of the machined surface according to figure 2.

As a result of the experimental results analysis, the optimal cutting parameters have the values: cutting speed - 570 [m/min], cutting depth - 4 [mm] and feed per tooth - 0.14 [mm/tooth].

![Figure 3](image1.png)  ![Figure 4](image2.png)

**Figure 3.** 3D surface plot of the surface roughness according to the feed per tooth and cutting depth.  **Figure 4.** 3D contour plot of surface roughness variation according to the feed per tooth and cutting depth.

In figures 3 and 4 the spatial graphs of the simultaneous influence of the two parameters and their effects exerted on the surface roughness are shown.

Vibrations that occurred during the end-milling process have a significant influence on surface quality.

These vibrations come directly from the rigidity and damping capability of the environment-CNC machine-cutting tool-clamping system.
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