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# Modeling the machined surface quality of an aluminum alloy using the active experiment type

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**Abstract.** The surface roughness obtained by the cutting processes has always been a subject of great interest when it is intended to improve the quality of the final product requested by the customer. The objective of this scientific paper involves a comparative study on the tracking of the surface roughness measured both longitudinally and transversely in the direction of the cutting feed movement, following the end-milling process of an aluminum alloy used in the aerospace industry worldwide. Practical experiments have conducted in a prestigious company in the aerospace industry of Romania. Regarding the cutting regime, in terms of milling, a cutting speed was adopted to maintain its constant value at 570 m/min, and the cutting depth and feed per tooth are within the range recommended by the cutting tool manufacturer in aluminum machining. The measuring and control devices used to obtain the experimental data were chosen after careful analysis, such as the surface tester and the electronic microscope. With the help of the obtained data, it was possible to interpret the surface roughness results measured longitudinally in the direction of the feed motion, compared to the roughness measured transversally in the same direction of the cutting tool. Different variations of the surface roughness have highlighted with the help of profiles and microscopic analyses of the machined surfaces. This study is in the category of scientific papers with an extremely high level of applied scientific research using experimental statistical modeling of active type.

## 1. Introduction

In the cutting process, a particularly important aspect is the workpiece that has to be accurate, both in terms of surface quality and dimensional precision. These conditions must be achieved as soon as possible and at the lowest possible energy consumption. In order to meet these requirements, irrespective of the machining operation chosen, it is essential to choose the machining parameters.

Among the representative studies carried out in this direction are the research carried out by Warhade [1], which analyzed the optimal combination of cutting parameters: the speed, feed and cutting depth in the machining of aluminum, in order to get the shortest processing time, with the power consumed by the numerically controlled machine and the material removal rate as high as possible. It is also remembered by Jomaa [2], which in his research shows that in addition to the feed per tooth, the surface quality is also influenced by the sharpness of the cutting edge of the tool. Mizugaki [3]

performs a comparative study of Al1050, Al2017, Al2024, Al5025 and Al7075 alloys processed by end-milling. In his paper, he tracked the processing errors that occurred during the cutting process and the influence of the cutting speed on the forces and surface quality. Processing errors for the Al1050 alloy are less than 15 [μm] in the cutting state at speeds ranging from 62.7 [m/min] to 251.2 [m/min], and with the other alloys, they are much higher. The resulting cutting forces are mainly constant throughout the Al1050 and Al5052 alloy cutting field, and in the case of the other alloys, they are directly proportional to the hardness of the material. The surface roughness of Al7075 shows the smallest $R_a$ values remaining below 0.2 [μm] and $R_z$ below 1 [μm]. The most significant variations in roughness are for the Al2017 alloy, and the increases in the roughness values of the Al2017 and Al2024 alloys are due to deposits on the cutting edge.

About this research, the primary object of study is the Al 7136 material. This is an aluminum alloy used in the aerospace industry. This alloy was also studied in the researches of [4-11] and by this study the authors want to continue the previous research.

## 2. Research method

The objective of the paper involves a comparative study on the tracking of surface roughness measured both longitudinally and transversely in the direction of the feed motion, following the end-milling of the aluminum alloy 7136. Aluminum blocks measuring 500 x 110 x 24.50 [mm] were processed. The chemical composition of the aluminum alloy 7136 is shown in Table 1.

**Table 1.** Al7136 - chemical composition.

| Element | Min | Max | Element | Min | Max |
|---|---|---|---|---|---|
| Silicon | - | 0,120 | Zinc | 8,400 | 9,400 |
| Iron | - | 0,150 | Titanium | - | 0,100 |
| Copper | 1,900 | 2,500 | Zirconium | 0,100 | 0,200 |
| Manganese | - | 0,050 | Other Elements, each | - | 0,050 |
| Magnesium | 1,800 | 2,500 | Other Elements, total | - | 0,150 |
| Chromium | - | 0,050 | Aluminum | remainder | |

The experiment is the research strategy used in the study. This work is a purely technical research done in a renowned aerospace company. Regarding the cutting regime adopted in the experiments, the cutting speed retains its constant value at 570 [m/min], and the cutting depth and the feed per tooth vary in the range recommended by the tool manufacturer for the aluminum machining. The full data of the adopted cutting regime is given in Table 2.

**Table 2.** Cutting regime parameters.

| No. | v [m/min] | $a_p$ [mm] | $f_z$ [mm/tooth] |
|---|---|---|---|
| 1 | 570 | 2.00 | 0.040 |
| 2 | 570 | 2.50 | 0.060 |
| 3 | 570 | 3.00 | 0.080 |
| 4 | 570 | 3.50 | 0.110 |
| 5 | 570 | 4.00 | 0.140 |

The experiments were carried out with a standard end-milling cutter in aluminum machining - SECO R217.69-1616.0-09-2AN with two teeth (Figure 1), 16 [mm] diameter, having a 100% tool engagement, and the encoding of the related cutting inserts is XOEX090308FR-E05, H15.

**Figure 1.** SECO cutting tool type R217.69-1616.0-09-2AN used to conduct experiments.

The CNC machine used to carry out the experiments was the HAAS VF-YT2.

The cutting fluid used during the experiment was Blasocut BC 35 Kombi SW mineral oil. The cooling fluid pressure of the machine pump was 8 [bar], three Ø6 flow direction hoses were used.

The measurement tools used to obtain experimental data were the Mitutoyo SURFTEST SJ-210 portable surface tester and the Micro-Vu VERTEX 310 optical microscope.

## 3. Research results

As a result of the machining, the surface roughness $R_a$, measured both longitudinally and transversely in the direction of the feed motion, of each sample was determined using a Mitutoyo SURFTEST SJ-210 surface tester at a distance of 5 mm according to Figure 2.



**Figure 2.** Making roughness measurements using the Mitutoyo SURFTEST SJ-210.

The actual values of the surface roughness measurements $R_a$ [μm] determined longitudinally and transversely in the direction of the feed motion are presented in Table 3. 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.

With the help of the obtained data, it was possible to perform comparative graphs between the evolutions of the roughness of the surfaces measured longitudinally and transversally in the direction of the feed motion of the cutting tool. Different variations in surface roughness have been highlighted with the help of profiles and microscopic analyses of the processed surfaces.

**Table 3.** $R_a$ longitudinal values.

| No. | v [m/min] | $a_p$ [mm] | $f_z$ [mm/tooth] | $R_a$ long [µm] | $R_a$ transv [µm] |
|-----|-----------|------------|------------------|-----------------|-------------------|
| 1 | 570 | 2 | 0.04 | 0.442 | 0.282 |
| 2 | 570 | 2.5 | 0.04 | 0.473 | 0.349 |
| 3 | 570 | 3 | 0.04 | 0.880 | 0.323 |
| 4 | 570 | 3.5 | 0.04 | 1.372 | 0.318 |
| 5 | 570 | 4 | 0.04 | 1.120 | 0.245 |
| 6 | 570 | 2 | 0.06 | 0.465 | 0.363 |
| 7 | 570 | 2.5 | 0.06 | 0.509 | 0.310 |
| 8 | 570 | 3 | 0.06 | 0.478 | 0.274 |
| 9 | 570 | 3.5 | 0.06 | 0.493 | 0.280 |
| 10 | 570 | 4 | 0.06 | 0.533 | 0.300 |
| 11 | 570 | 2 | 0.08 | 0.470 | 0.689 |
| 12 | 570 | 2.5 | 0.08 | 0.488 | 1.162 |
| 13 | 570 | 3 | 0.08 | 0.493 | 0.295 |
| 14 | 570 | 3.5 | 0.08 | 0.644 | 0.335 |
| 15 | 570 | 4 | 0.08 | 0.606 | 0.367 |
| 16 | 570 | 2 | 0.11 | 0.429 | 1.559 |
| 17 | 570 | 2.5 | 0.11 | 0.427 | 1.563 |
| 18 | 570 | 3 | 0.11 | 0.412 | 1.724 |
| 19 | 570 | 3.5 | 0.11 | 0.396 | 1.295 |
| 20 | 570 | 4 | 0.11 | 0.568 | 1.113 |
| 21 | 570 | 2 | 0.14 | 0.369 | 1.223 |
| 22 | 570 | 2.5 | 0.14 | 0.393 | 2.386 |
| 23 | 570 | 3 | 0.14 | 0.357 | 1.872 |
| 24 | 570 | 3.5 | 0.14 | 0.407 | 2.768 |
| 25 | 570 | 4 | 0.14 | 0.622 | 2.115 |

## 4. Comparison between $R_a$ long vs. $R_a$ transv under the feed per tooth variation

Figure 3 presents the comparison between the surface roughness evolution $R_a$ long vs. $R_a$ transv when the cutting depth and cutting speed remain constant at 570 [m/min], and 2 [mm] and the feed per tooth varies. As can be seen in these cutting conditions, $R_a$ long exhibits an insignificant variation in the range of 0.369 and 0.470 [µm] and $R_a$ transv in the range of 0.245 and 0.349 [µm].
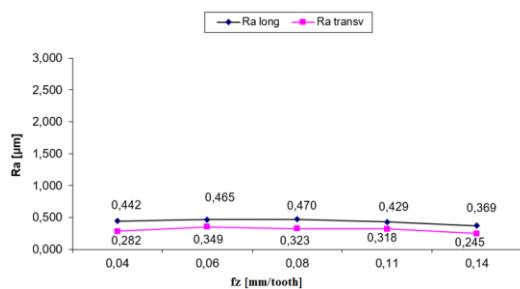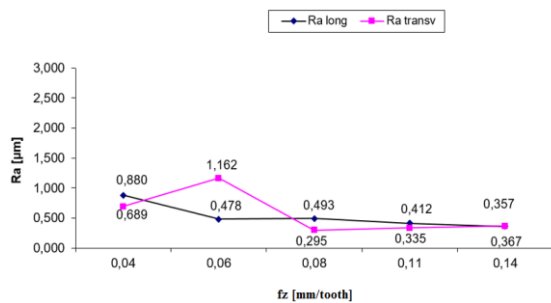


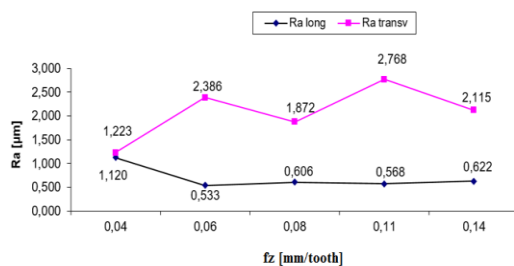**Figure 3.** Evolution of $R_a$ long vs. $R_a$ transv under the influence of $f_z$ variation when $a_p = 2$ mm.
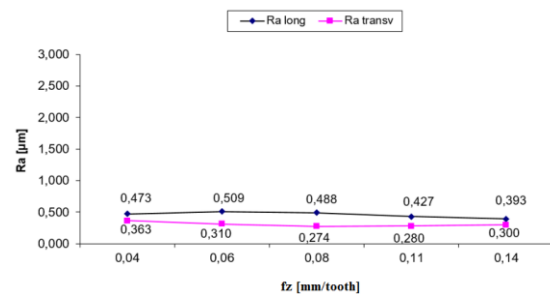
**Figure 4.** Evolution of $R_a$ long vs. $R_a$ transv under the influence of $f_z$ variation when $a_p = 2.5$ mm.

In the graph of Figure 4, the evolution of $R_a$ long vs. $R_a$ transv, when v = 570 [m/min] and $a_p$ = 2.5 [mm] and $f_z$ varies, the situation is similar to the previous one.

As can be seen in the case where v = 570 [m/min] and $a_p$ = 3 [mm], both $R_a$ long and Ra trans show slight variations.

At the feed per tooth of 0.06 [mm/tooth] $R_a$ long has a sudden decrease in the measured value from 0.880 [μm] to 0.478 [μm], in contrast $R_a$ transv increases sharply to 1.162 [μm] followed by a further decrease at 0.295 [μm] (Figure 5).



**Figure 5.** Evolution of $R_a$ long vs. $R_a$ transv under the influence of $f_z$ variation when $a_p$ = 3 mm.
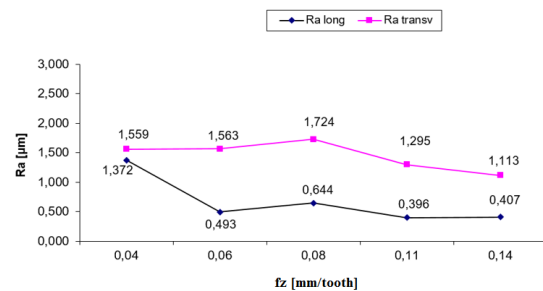
**Figure 6.** Evolution of $R_a$ long vs. $R_a$ transv under the influence of $f_z$ variation when $a_p$ = 3.5 mm.

In Figure 6 is presented the comparative evolution Ra long vs. Ra transv when the cutting speed is 570 [m/ min], the cutting depth of 3.5 [mm] and the feed per tooth varies. The values recorded in the range of 1.113 and 1.724 [μm] of $R_a$ transv show a slight increase at a feed rate of 0.08 [mm/tooth] while the $R_a$ long values show in the first phase a decrease in the feed of 0.06 [mm/tooth] followed by a further increase at a feed of 0.08 [mm/tooth].

Figure 7 shows the evolution of $R_a$ under the influence of the feed per tooth at the cutting speeds of 570 [m/min] and the 4 [mm] cutting depth.

The situation presented at $a_p$ = 4 [mm] shows an oscillating increase of $R_a$ transv while $R_a$ long shows an initial decrease of the measured value at a 0.06 [mm/tooth] feed per tooth, then keeping the values recorded at an approximately constant level.

As a general finding on the five graphs, it can be mentioned that the highest value of the $R_a$ long of 1.372 [μm] is recorded at a feed per tooth of 0.04 [mm/tooth] and in the case of $R_a$ transv – 2.768 [μm] at an feed per tooth of 0.11 [mm/tooth]. In other words, the values of the roughness value are highest at high $a_p$ and low $f_z$.



**Figure 7.** Evolution of $R_a$ long vs. $R_a$ transv under the influence of $f_z$ variation when $a_p$ = 4 mm.
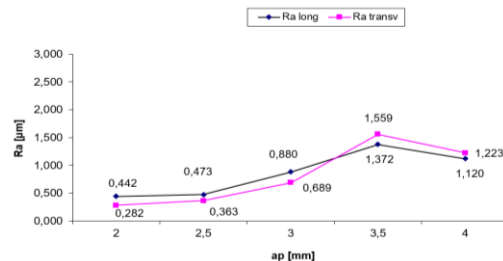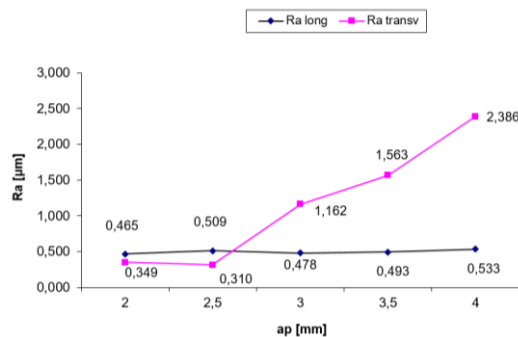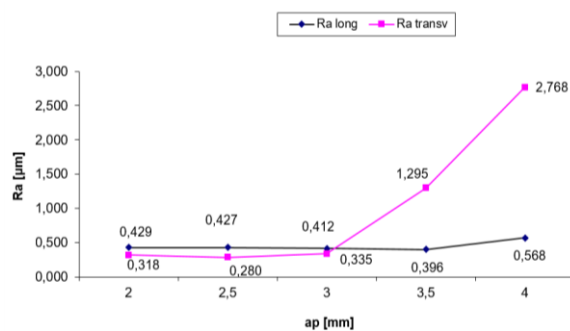
**Figure 8.** Evolution of $R_a$ long vs. $R_a$ transv under the influence of $a_p$ variation when $f_z$ = 0.04 [mm/tooth].

However, with the feed per tooth increase and the cutting depth has a high value, the $R_a$ roughness decreases.

### 5. Comparison between $R_a$ long vs. $R_a$ transv under the cutting depth variation

Below is the comparative evolution of Al7136 milling surface quality when the cutting depth varies, and the cutting speed and feed per tooth remains constant.

Therefore, Figure 8 shows the evolution of $R_a$ long vs. $R_a$ transv under the influence of $a_p$ variation when $f_z = 0.04$ [mm/tooth]. Both $R_a$ long and $R_a$ transv values grow with the increase of the cutting depth. The maximum values are $R_a$ long of 1.559 [μm] and $R_a$ transv of 1.372 [μm] at the 3.5 [mm] depth.

Figure 9 shows the evolution of $R_a$ long vs. $R_a$ transv under the influence of $a_p$ when $f_z = 0.08$ [mm/tooth].

In this case, $R_a$ transv shows a sharp and steady increase of recorded values starting with a 2.5 [mm] cutting depth, while $R_a$ long has insignificant increases, remaining almost constant, regardless of variation in the cutting depth.



**Figure 9**. Evolution of $R_a$ long vs. $R_a$ transv under the influence of $a_p$ variation when $f_z = 0.06$ [mm/tooth].
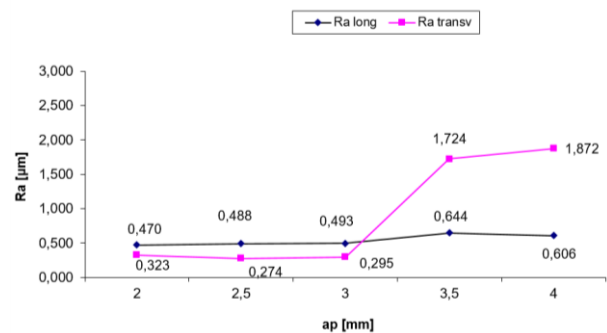


**Figure 10.** Evolution of $R_a$ long vs. $R_a$ transv under the influence of $a_p$ variation when $f_z = 0.08$ [mm/tooth].

Figure 10 shows the evolution of $R_a$ long vs. $R_a$ transv under the influence of the cutting depth at 570 [m/min] cutting speed and 0.06 [mm/tooth] of the feed per tooth.

Figure 11 shows the surface quality evolution $R_a$ long vs. $R_a$ transv in the situation where $f_z$ is 0.11 [mm/tooth].



**Figure 11.** Evolution of $R_a$ long vs. $R_a$ transv under the influence of $a_p$ variation when $f_z = 0.11$ [mm/tooth].
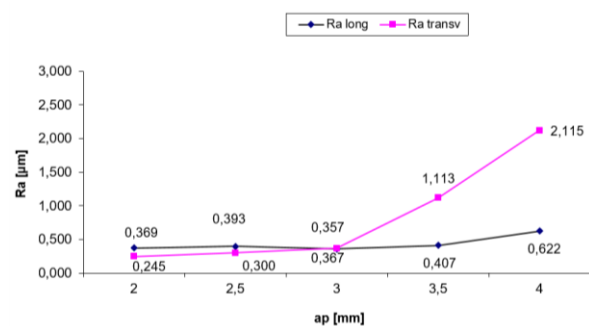


**Figure 12.** Evolution of Ra long vs. Ra transv under the influence of ap variation when fz = 0.14 [mm/tooth].

As can be seen from the graphs where $f_z$ is 0.08 [mm/tooth], 0.11 [mm/tooth] and even 0.14 [mm/tooth], the situation is similar to the case where $f_z$ was 0.06 [mm/tooth].

Figure 12 shows the situation where $f_z$ is 0.140 [mm/tooth], and the cutting speed is 570 [m/min], and the cutting depth varies.

Analyzing the last five graphs, it can generally be concluded that at a low cutting depth, regardless of the amount of feed per tooth, the surface roughness $R_a$ is small.

However, with the increase of the cutting depth, the roughness $R_a$ long and $R_a$ transv show an increase in reaching the maximum value at depths of 3.5 and 4 [mm].

After the comparative analysis of the surface quality evolution $R_a$ long vs. $R_a$ transv, obtained by end milling process of Al7136 at the variation of the cutting depth and the feed per tooth, it is found that the highest values of $R_a$ long and $R_a$ transv are recorded according to the data presented in Figures 13 and 14 and the Tables 4 and 5.



| No. | $a_p$ [mm] | $f_z$ [mm/tooth] |
|-----|-----------|------------------|
| 1 | 3.5 | 0.04 |
| 2 | 4 | 0.04 |
| 3 | 3 | 0.04 |
| 4 | 3.5 | 0.08 |
| 5 | 4 | 0.14 |
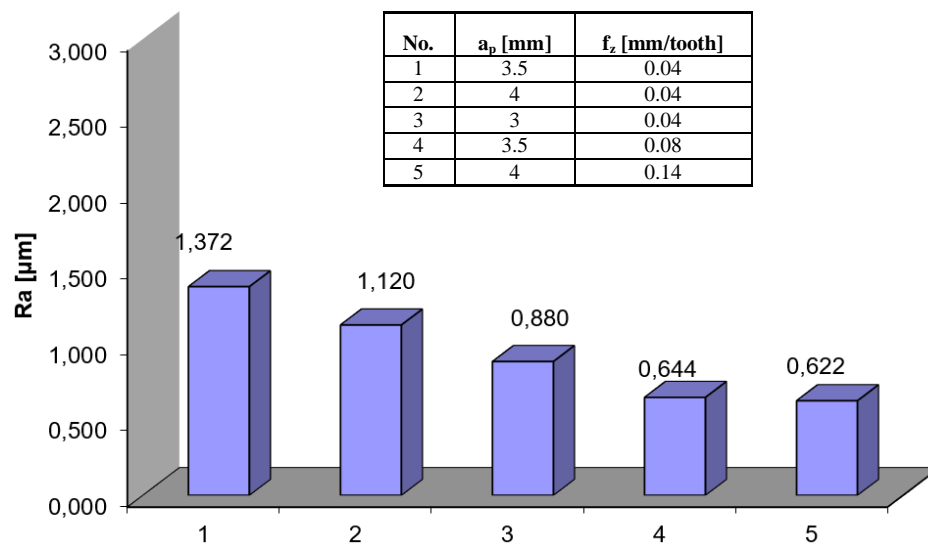
**Figure 13.** The highest $R_a$ long values recorded at $a_p$ and $f_z$ variations when v remains constant.



| No. | $a_p$ [mm] | $f_z$ [mm/tooth] |
|-----|-----------|------------------|
| 1 | 4 | 0.11 |
| 2 | 4 | 0.06 |
| 3 | 4 | 0.14 |
| 4 | 4 | 0.08 |
| 5 | 3.5 | 0.08 |
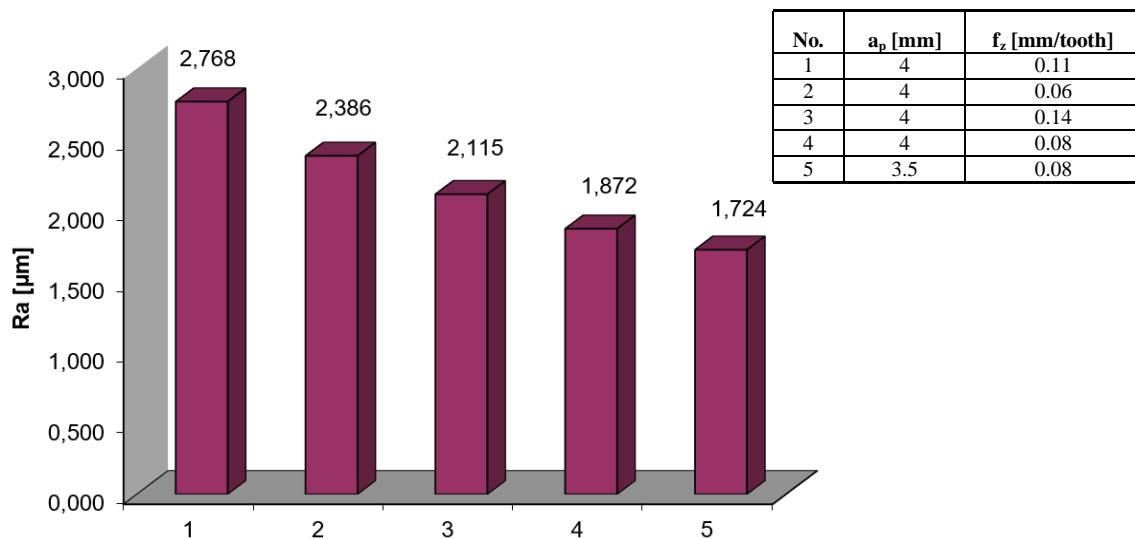
**Figure 14.** The highest $R_a$ transv values recorded at $a_p$ and $f_z$ variations when v remains constant.

**Table 4.** Hierarchy of $R_a$ long values under the influence of variation of cutting parameters.
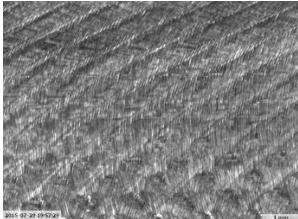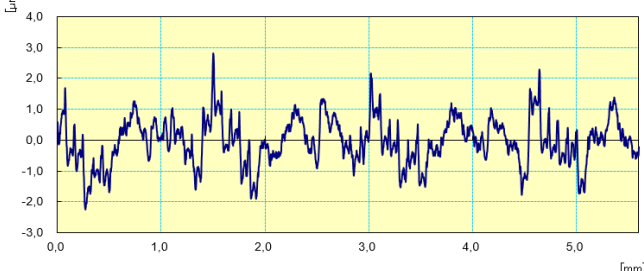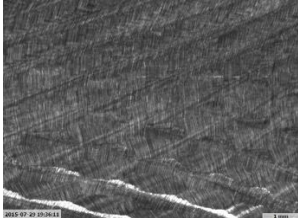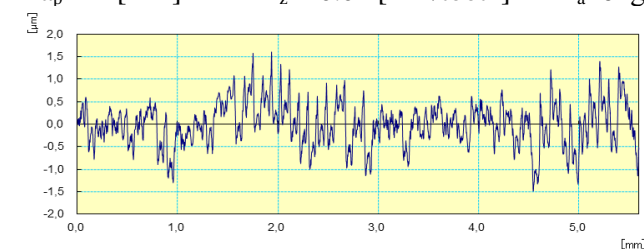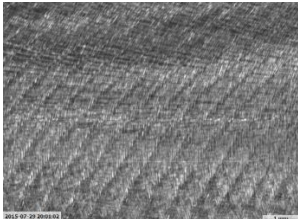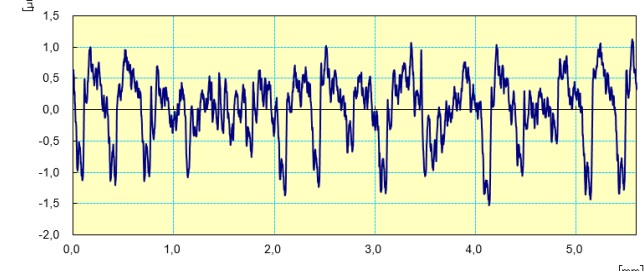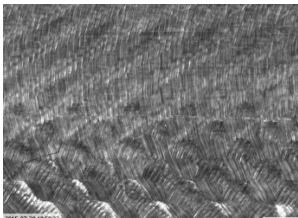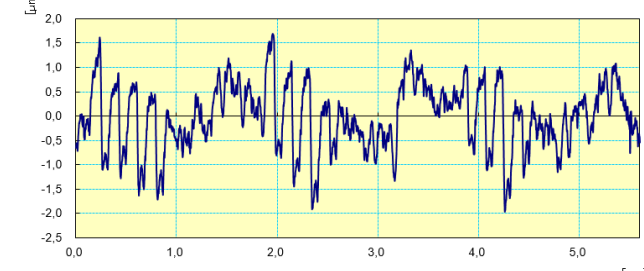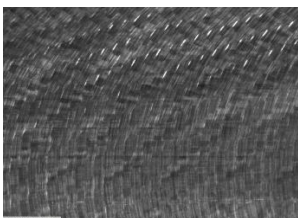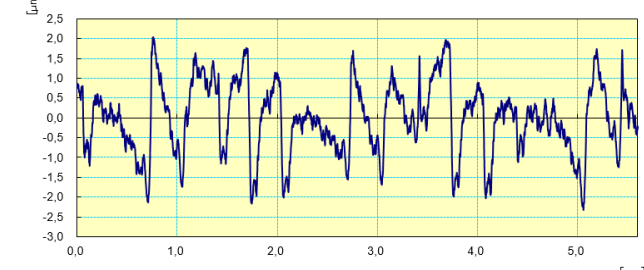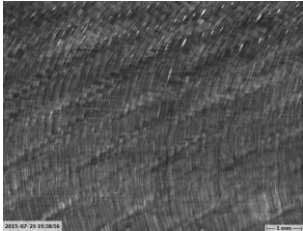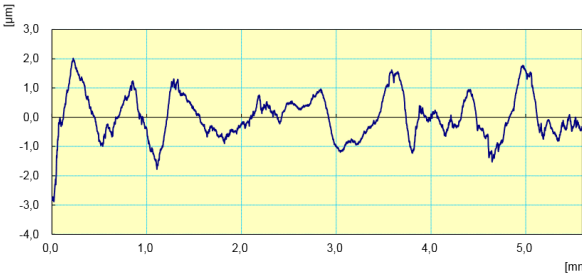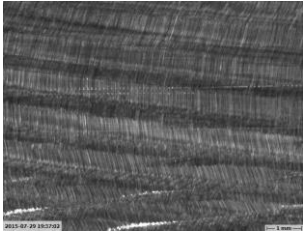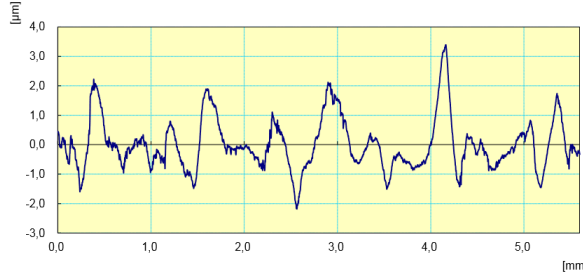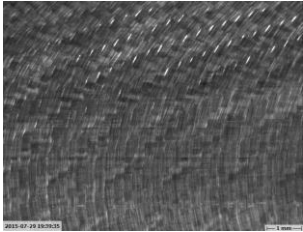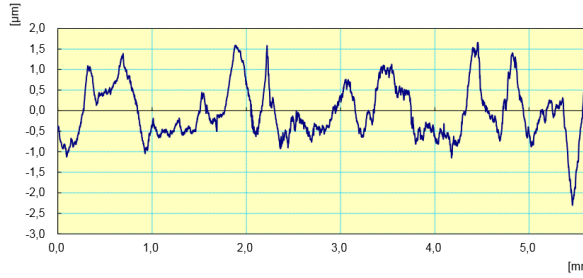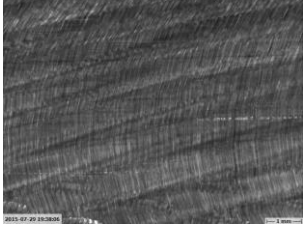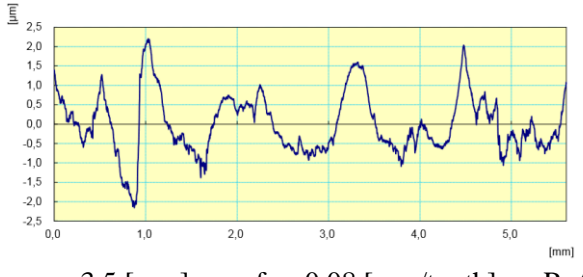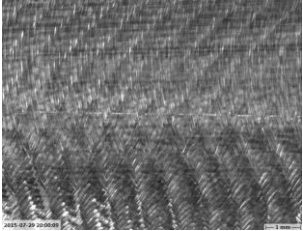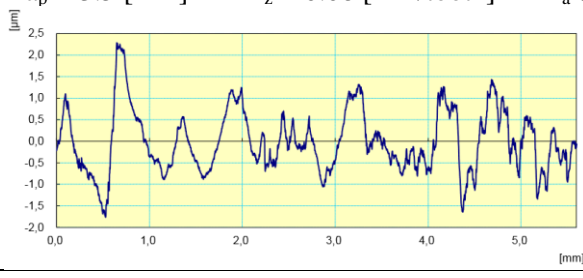
| The highest $R_a$ long values |
|---|

| v = 570 [m/min] | $a_p$ = 3.5 [mm] | $f_z$ = 0.04 [mm/tooth] | $R_a$ long = 1.372 [μm] |
|---|---|---|---|



| v = 570 [m/min] | $a_p$ = 4 [mm] | $f_z$ = 0.04 [mm/tooth] | $R_a$ long = 1.120 [μm] |
|---|---|---|---|



| v = 570 [m/min] | $a_p$ = 3 [mm] | $f_z$ = 0.04 [mm/tooth] | $R_a$ long = 0.880 [μm] |
|---|---|---|---|



| v = 570 [m/min] | $a_p$ = 3.5 [mm] | $f_z$ = 0.08 [mm/tooth] | $R_a$ long = 0.644 [μm] |
|---|---|---|---|



| v = 570 [m/min] | $a_p$ = 4 [mm] | $f_z$ = 0.14 [mm/tooth] | $R_a$ long = 0.622 [μm] |
|---|---|---|---|

**Table 5**. Hierarchy of $R_a$ transv values under the influence of variation of cutting parameters.

| The highest $R_a$ transv values | | | |
|---|---|---|---|
| $v = 570$ [m/min] | $a_p = 4$ [mm] | $f_z = 0.11$ [mm/tooth] | $R_a$ transv = 2.768 [µm] |



| $v = 570$ [m/min] | $a_p = 4$ [mm] | $f_z = 0.06$ [mm/tooth] | $R_a$ transv = 2.386 [µm] |
|---|---|---|---|



| $v = 570$ [m/min] | $a_p = 4$ [mm] | $f_z = 0.14$ [mm/tooth] | $R_a$ transv = 2.115 [µm] |
|---|---|---|---|



| $v = 570$ [m/min] | $a_p = 4$ [mm] | $f_z = 0.08$ [mm/tooth] | $R_a$ transv = 1.872 [µm] |
|---|---|---|---|



| $v = 570$ [m/min] | $a_p = 3.5$ [mm] | $f_z = 0.08$ [mm/tooth] | $R_a$ transv = 1.724 [µm] |
|---|---|---|---|

## 6. Conclusions

The objective of this research was to conduct a comparative study to track the surface roughness measured longitudinally and then transversely on the direction of the cutting feed movement, following the end-milling process of the Al7136 which is an aluminum alloy used in the aerospace industry worldwide.

After this comparative analysis of the Ra long vs. Ra transv evolution, under the variation of the cutting depth and the feed per tooth, it is found that the highest values of Ra long of 1.372 [μm] is recorded when the ap is 3.5 [mm] and fz is 0.04 [mm/tooth], and in the Ra transv case, the highest roughness value of 2.768 [μm] is recorded when the ap is 4 [mm] and fz is 0.11 [mm/tooth].

Confirmation of the obtained results was performed using profilograms and images of the microscopic analysis of the machined surface.

## 7. References

[1]    Warhade K P, Bhilare S K, Gaikwad S R and Phate M R 2013 *Int. J. of Emerging Trends in Eng. and Dev*. **2** 3
[2]    Jomaa W, Songmene V and Bocher P 2014 *Materials*, **7** (3) 1603-1624
[3]    Mizugaki Y, Takafuji K and Kikkawa K 2009 *Key Engineering Materials* **714** 407-408
[4]    Țîțu M A, and Pop A B 2017 *MATEC Web of Conferences* **112**, 01009
[5]    Țîțu M A, and Pop A B 2016 *IOP Conference Series: Materials Science and Engineering*, **161** (1) 012014
[6]    Pop A B, and Țîțu M A 2017 *MATEC Web of Conferences* **121** 05005
[7]    Țîțu M A, Pop A B 2017 *MATEC Web of Conferences* **112** 01010
[8]    Dobrotă D, Țîțu M, Dobrița F and Petrescu V 2016 *Revista de Chimie* **67** (3) 520-523
[9]    Achitei D, Vizureanu P, Dana D, and Cimpoesu N 2013 *Metalurgia International* **18** 104-109
[10]   Tóth L and Fábián R E 2019 *International Journal of Engineering and Management Science* **4** 286-294
[11]   Borlea Tiuc A, Rusu T, Ionescu S and Nemes O 2012 *Romanian Journal of Materials* **42** 405