# SURFACE ROUGHNESS AT MILLING ZINC ALLOYS

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*In lucrare sunt prezentate rezultate ale cercetărilor experimentale şi interpretarea acestora pentru determinarea rugozității suprafețelor prelucrate prin frezare a pieselor din aliaje de zinc. Cu toate că aliajele de zinc sunt folosite în foarte multe domenii pentru producții de serie foarte mare şi de masă, până în prezent aceste materiale nu sunt suficient cunoscute din punctul de vedere al prelucrabilității prin aşchiere. Rugozitatea fiind un criteriu de evaluare a prelucrabilității prin aşchiere, lucrarea îşi propune ca, prin cercetări experimentale, să determine modelele matematice ale rugozității suprafețelor frezate în cazul aliajelor de zinc.*

*The paper presents experimental research and results in case of determining surface roughness when milling workpieces made of zinc alloys. Even if zinc alloys are used in many cases for mass production and large series of products, until present these materials are not known from the cutting ability point of view. Roughness is a criterion of the cutting ability concept and, therefore, this paper intends to present an experimental determination of the mathematical models of the surfaces roughness in case of milling zinc alloys.*

**Keywords**: experimental research, milling, roughness, zinc alloys.

## 1. Introduction

In case of finishing cutting operations, when the quality of the surface is very important, the main criterion to evaluate the cutting ability is roughness [1], [4], [7] and [9]. Other criteria, such as cutting tool durability, cutting efforts, reliability, are not so important in this case [3] and [6].

Roughness is one of the manifestation forms of real surface errors related to the geometrical surface. Roughness can be evaluated in many ways, the most used being as follows:

- average depth of roughness in 10 points, symbolized by $R_z$, is the difference between the arithmetical average of the biggest five heights and the

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lowest five depths of the effective profile, determined inside the basic length, related to a parallel line to the average line, which does not intersect the profile;

- arithmetical average depth of the profile, symbolized $R_a$, is the average value of the coordinates of the effective profile points related to the average line of profile. Coordinates are added without considering their algebraic sign.

In technical literature and in the operative standards are presented values of the surface roughness obtained by different cutting operations. In these norms, the surface roughness is divided in 14 classes, from the highest value $R_a$=100 μm to the lowest value $R_a$=0.012 μm.

For example, in case of end milling rough operation corresponds to the 6-th quality class, with a roughness $R_a$=3.2 μm; semi-finishing operation corresponds to the 7-th quality class, with a roughness $R_a$=1.6 μm; finishing operation corresponds to the 8-th quality class, with a roughness $R_a$=0.8 μm

The purpose of the paper is to determine the relationships between the roughness of the surfaces and the cutting conditions when milling zinc alloys workpiece.

## 2. Set-up the experimental research

The material used in the experiments was zinc alloy ZnAl4Cu1T.

Roughness measurement of the surfaces obtained by cutting operations was made on plates of zinc alloy ZnAl4Cu1T, after their milling with the cutting regime as presented in the following.

Cutting operations were made on a milling machine, using four end milling cutters [2], [5], having the following diameters: $d_A$=16 mm, $d_B$=20 mm, $d_C$=22 mm, $d_E$=25 mm.

Correspondingly, the milling cutters were symbolized *A*, *B*, C, *E*.

## 3. Structure of experiments

When setting the experimental program the variation domain of the cutting conditions parameters and the possibilities of the machine tool must be considered. These parameters set the experimental program [3], [6], [8].

Independent variables of the considered end milling cutting process are the following:

- cutting speed $v_c$ [m/min],
- feed per tooth $f_z$ [mm/tooth],
- cutting depth $a_p$ [mm],
- milling cutter diameter $d$ [mm].

In order to facilitate operations and to reduce apparently the number of experiments, from the four independent variables the milling cutter diameter was considered to be constant. Consequently, for each milling cutter diameter an experimental program was set.

The milling cutters are made of HSS Rp3 and Rp4, having two inclined teeth. The used HSS end milling cutters were selected using the recommendations of the zinc alloy products manufacturers [10].

As well, the cutting depth, $a_p$, had two values in the experimental program.

With these observations, the experimental program for one milling cutter had $2\times3^2=18$ experiments and for all four milling cutters had 4x18=72 experiments.

The remained independent variables are the cutting regime conditions: cutting speed, $v_c$ [m/min]; feed per tooth, $f_z$ [mm/tooth]; cutting depth, $a_p$ [mm].

For each end milling cutter A, B, C and E, the variation levels of the independent variables were set considering their usual values and the possibilities of the machine tool.

After several calculations and trials, the following values were proposed for the three independent variables, as shown in table 1.

Structure of the experimental program, considering three levels and two factors, with another incomplete factor added ($a_p$), has $2x3^2=18$ experiments as it results from table 1.

*Table 1*

**Variation levels of the independent variables**

| **Milling cutter A** $d_A$**=16 mm,** $z$**=2 teeth** | **Code\Level** | **Symbol** | | |
|---|---|---|---|---|
| | | **-1** | **0** | **+1** |
| cutting speed $v_c$ [m/min] | $X_1$ | 40.24 | 50.3 | 62.8 |
| feed per tooth $f_z$ [mm/tooth] | $X_2$ | 0.040 | 0.063 | 0.100 |
| cutting depth $a_p$ [mm] | $X_3$ | 2 | - | 4 |
| **Milling cutter B** $d_B$**=20 mm,** $z$**=2 teeth** | **Code\Level** | **Symbol** | | |
| | | **-1** | **0** | **+1** |
| cutting speed $v_c$ [m/min] | $X_1$ | 50.3 | 63 | 78.6 |
| feed per tooth $f_z$ [mm/tooth] | $X_2$ | 0.040 | 0.063 | 0.100 |
| cutting depth $a_p$ [mm] | $X_3$ | 2 | - | 4 |
| **Milling cutter C** $d_C$**=22 mm,** $z$**=2 teeth** | **Code\Level** | **Symbol** | | |
| | | **-1** | **0** | **+1** |
| cutting speed $v_c$ [m/min] | $X_1$ | 55.3 | 69.2 | 86.4 |
| feed per tooth $f_z$ [mm/tooth] | $X_2$ | 0.040 | 0.063 | 0.100 |
| cutting depth $a_p$ [mm] | $X_3$ | 2 | - | 4 |
| **Milling cutter E** $d_E$**=25 mm,** $z$**=2 teeth** | **Code\Level** | **Symbol** | | |
| | | **-1** | **0** | **+1** |
| cutting speed $v_c$ [m/min] | $X_1$ | 49.5 | 62.8 | 78.5 |
| feed per tooth $f_z$ [mm/tooth] | $X_2$ | 0.040 | 0.063 | 0.100 |
| cutting depth $a_p$ [mm] | $X_3$ | 2 | - | 4 |

## 4. Results of the experimental research and their processing

Using the cutting regime parameters presented in table 1, milling operations were performed on the zinc alloy ZnAl4Cu1T. After each operation, the roughness $R_a$ was measured.

The roughness, together with the independent variables, were organized and presented in four tables, one table for each milling cutter. Just for example, the data corresponding to the milling cutter B, having $d_B$=20 mm, is presented in table 2.

*Table 2*

**Results of experiments using milling cutter B**

| Test No. | Feed $f_z$ [mm/tooth] | Cutting speed $v_c$ [m/min] | Cutting depth $a_p$ [mm] | Roughness $R_a$ [μm] |
|---|---|---|---|---|
| B10 | 0.04 | 50.3 | 2 | 1.6 |
| B11 | 0.04 | 63 | 2 | 1.7 |
| B12 | 0.04 | 78.6 | 2 | 1.5 |
| B13 | 0.063 | 50.3 | 2 | 1.4 |
| B14 | 0.063 | 63 | 2 | 1.8 |
| B15 | 0.063 | 78.6 | 2 | 1.4 |
| B16 | 0.1 | 50.3 | 2 | 2.00 |
| B17 | 0.1 | 63 | 2 | 2.2 |
| B18 | 0.1 | 78.6 | 2 | 2.1 |
| B19 | 0.04 | 50.3 | 4 | 1.8 |
| B20 | 0.04 | 63 | 4 | 2.1 |
| B21 | 0.04 | 78.6 | 4 | 2.00 |
| B22 | 0.063 | 50.3 | 4 | 1.96 |
| B23 | 0.063 | 60 | 4 | 2.3 |
| B24 | 0.063 | 78.6 | 4 | 2.1 |
| B25 | 0.1 | 50.3 | 4 | 2.3 |
| B26 | 0.1 | 60 | 4 | 2.32 |
| B27 | 0.1 | 78.6 | 4 | 2.34 |

For confirmation of obtained data the roughness was measured using two roughness-meters RUGOMAS IMF (ROMÂNIA) and POCKET SURF.

Related to the measurements using two roughness-meters it should be mentioned that the differences were not significant, being tenths of micron.

Using the obtained results the variation diagrams of the roughness were drawn as functions of the mentioned cutting regime parameters.

Totally, there are 16 graphs, each one with three variation diagrams in total, out of which only four are presented in Figs. 1, 2, 3 and 4.

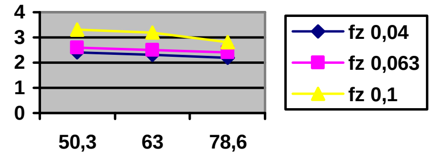


Fig. 1. Roughness vs. cutting speed $a_p$=2 mm, milling cutter *B*

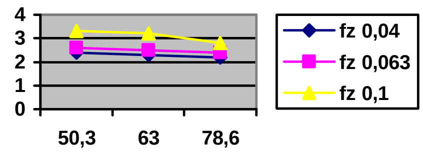


Fig. 2. Roughness vs. cutting speed. $a_p$=4 mm, milling cutter *C*

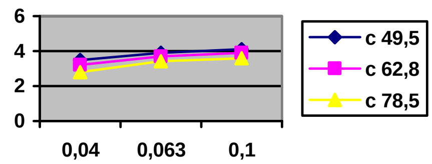


Fig. 3 Roughness vs. feed per tooth $a_p$=4 mm, milling cutter *C*

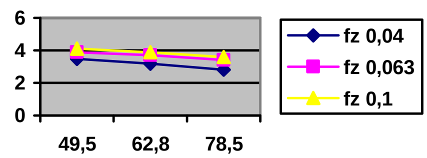


Fig. 4. Roughness vs. cutting speed. $a_p$=4 mm, milling cutter *E*

## 5. Interpretation of results

The problem is to determine the regression functions of exponential type in order to mathematically describe, as accurate as possible, the variation of roughness as a function of the cutting regime parameters. Of course, these regression functions depend on the results of the experimental research.

This means to determine the following complex exponential function:

$$R_a = C_R \cdot a_p^{x_R} \cdot f_z^{y_R} \cdot v_c^{z_R}. \qquad (1)$$

Based on the measured roughness in all experimental cases, using a simple Microsoft Excel file, there the constant $C_R$ and exponents $x_R$, $y_R$ and $z_R$ were calculated.

In order to compare these values, in the following the exponential regression functions are presented, for each end milling cutter:

Milling cutter A

$$R_a = 7.14581 \cdot a_p^{0.340643} \cdot f_z^{0.277531} \cdot v_c^{-0.15825}; \qquad (2)$$

Milling cutter B

$$R_a = 11.13079 \cdot a_p^{0.213168} \cdot f_z^{0.231763} \cdot v_c^{-0.22838}; \qquad (3)$$

Milling cutter C

$$R_a = 21.38962 \cdot a_p^{0.143727} \cdot f_z^{0.265707} \cdot v_c^{-0.32076}; \qquad (4)$$

Milling cutter E

$$R_a = 24.62592 \cdot a_p^{0.163664} \cdot f_z^{0.224224} \cdot v_c^{-0.37945}. \qquad (5)$$

## 6. Conclusions

From the above relations and from the variation diagrams, the following conclusions related to the roughness of the surfaces obtained by milling can be drawn:

*Influence of feed upon the roughness of surfaces obtained by milling*. All the diagrams show the roughness increases with the rise of feed (see figure 3).

The same conclusions are proved by the regression functions in the above relations (2), (3), (4), (5). In all these functions the exponent of the feed is positive, meaning the roughness increases with the rise of feed.

*Influence of cutting speed upon the roughness of surfaces obtained by milling*. All the diagrams show that roughness decreases with the increase of cutting speed (see figure 1, 2 and 4). For one cutting speed value, the roughness increases with the feed.

The same descendent trend is proved by the regression functions, shown by the exponent of the cutting speed, which is negative.

It should be mentioned in the diagrams showing variation of roughness versus feed the graphs are positioned decreasingly with the increase of the cutting speed, the lowest graph belonging to the highest cutting speed.

This decreasing trend must be related to the increase of temperature together with the cutting speed, thus the mechanical resistance of the workpiece material diminishes. Furthermore, the plastic deformation capacity of the workpiece material increases and the cutting process conditions improve.

*Influence of cutting depth upon the roughness of surfaces obtained by milling*. At the same feed and cutting speed, the roughness increases proportionally with the cutting depth. For the same cutting conditions, but different cutting depths, the roughness increases with the cutting depth. This is also shown by the regression functions, the exponent of the cutting depth being positive. This means the roughness increases with the cutting depth.

From the regression functions, the *influence of the milling cutter diameter* is obtained. The constant $C_R$ of the regression functions is continuously increasing with the milling cutter diameter, showing the increase of the roughness with the diameter.

$R_a$ roughness values of the surfaces obtained by milling operations upon zinc alloys workpieces correspond to roughing and semi-finishing operations.

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