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INFLUENCE OF CUTTING PARAMETERS ON THE ROUGHNESS OF MACHINED SURFACES

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ABSTRACT

Aluminum-based alloys are increasingly used in the aeronautical, automotive, defense, etc. industries. This has led to the development of research on the machinability of these materials. Although aluminum is not considered to be a material characterized by good machinability, there are, among its alloys, some that stand out for this quality. This is the case of duralumin 2024 T351, which is an alloy characterized by good mechanical strength, relatively high hardness, and corrosion resistance. These characteristics, combined with the low density of the alloy, make the material widely used in the aeronautical, automotive and defense industries. Among the methods of processing parts made from 2024 T351, machining is also employed. One of the indicators of the quality of this type of processing is the roughness of the chipped surface. In this paper, we aim to identify which of the parameters of the machining process have a more important influence on the resulting roughness.

KEYWORDS: cutting, surface roughness, ANOVA

1. INTRODUCTION

Aluminum alloys are increasingly used in various industries due to their unique combination of mechanical and chemical properties. Among them, aluminum-based alloys play an essential role in the aeronautical, automotive and defense industries due to their favorable strength-to-weight ratio, corrosion resistance, and ability to be processed by various methods.

One of the most widely used aluminum alloys is duralumin 2024 T351, known for its outstanding properties:

- High mechanical resistance: It is ideal for applications where structures resistant to mechanical stress are required.

- Relatively high hardness: This ensures resistance in difficult environments and extends the life of the components.

- Corrosion resistance: Although not the best of aluminum alloys, this characteristic makes it suitable for use in environments where exposure to moisture or chemicals is moderate.

- Low density: This attribute makes it preferred in the aeronautical industry, where every gram counts for performance and energy efficiency.

These properties make duralumin 2024 T351 widely used in the manufacture of aeronautical structures, automotive components, and also military applications where high performance is essential.

Among the manufacturing processes used for this alloy, machining occupies a central place due to its ability to produce parts with dimensional accuracy and high-quality finish. The quality of the machined surface is an important indicator of the success of this process. In this context, surface roughness plays an essential role, influencing part performance in applications such as fatigue resistance, coating adhesion, and corrosion resistance, [1].

The roughness of the machined surface is determined by several parameters of the machining process [2], including:

1. Depth of cut (ae): It is directly related to the volume of material removed and can influence both machining forces and surface quality.

2. Feed (fz): It has a major impact on the microgeometry of the surface and can influence the formation of burrs or plastic deformations.

3. Cutting speed (vc): Too low or too high a speed can led to vibrations and increased roughness. In addition, at low cutting speeds, the possibility of build-up edge increases. This build-up edge has a

major influence on the cutting force and the quality of the machined surface.

4. Tool material and its coating: Tools made from metal carbides or coated with materials such as TiAlN can influence the durability and quality of the surface obtained.

This paper aims to identify and analyze the influence of each machining parameter on the surface roughness obtained for duralumin 2024 T351. Understanding these relationships can lead to optimization of the machining process, ensuring both efficiency and a high level of quality in the finished parts.

2. THE ROUGHNESS OF THE MACHINED SURFACE

As is well known, the concept of machined surface quality is closely related to the notion of machining precision.

The quality of the machined surface includes its physical as well as its geometric appearance. This latter aspect includes macro irregularities, undulations and roughness, [3-6].

The SR EN ISO 21920-2:2022 standard defines a series of criteria for the quantitative assessment of roughness. Among them, the Ra, Rq and Rz criteria are more frequently used [3].

The Ra criterion represents the arithmetic average deviation of the evaluated profile, i.e. the arithmetic average of the absolute values of the profile ordinates within the limits of a basic length.

The Rq criterion is the root mean square deviation of the evaluated profile and represents the standard deviation of the distribution of the profile heights.

The Rz criterion is the height in 10 points of the profile, i.e. the average of the absolute values of the heights of the top 5 projections and the deepest 5 valleys within the reference length.

Surface roughness is influenced by the parameters of the machining process, but the influence of these parameters varies and depends on the material being processed.

3. MATERIALS AND METHODS

3.1. Materials used

To determine the effect of the machining parameters on the roughness of the surface, the processing of 2024 T351 duralumin samples was considered.

The chemical composition of the alloy is shown in table 1, [7].

Table 1. *The chemical composition of the alloy 2024 T351*

Si ≤ [%]	**Fe ≤ [%]**	**Cu [%]**	**Mn [%]**	**Mg [%]**	**Cr [%]**	**Zn ≤ [%]**	**Ti [%]**	**Others elem. ≤**	**Al**
0.50	0.50	3.8÷4.9	0.3÷0.9	1.2÷1.8	0.1	0.25	0.15	0.05	Remainder

A 4-tooth, Ø10 mm diameter, AlTiCrN carbide end mill was used for cutting.

Processing was carried out on a HAAS V1 vertical milling machine.

The main parameters of the machining process were varied as follows:

- Cutting speed: 180; 215; 280 m/min.
- Feed per tooth: 0.05; 0.075; 0.1 mm.
- Cutting width: 1; 2; 3 mm.

By varying these parameters, 27 sets of values were obtained, with which 27 channels were processed by milling. For each of these channels, the roughness were measured, taking into account the Ra, Rq and Rz parameters.

For each channel, 3 measurements were taken: one in the area corresponding to the middle of the channel width and two near the two edges.

The average of the three values obtained for each channel was considered as the roughness value.

Figure 1 shows the specimen fixed on the dynamometer plate, and Figure 2 shows a dimensioned sketch of the specimen.

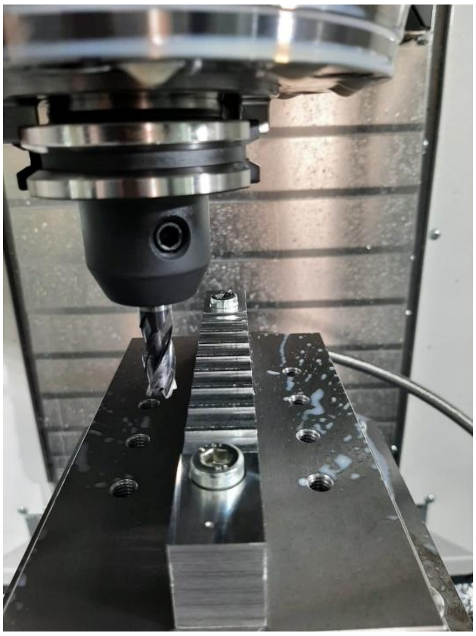

Fig. 1. *The processed sample*

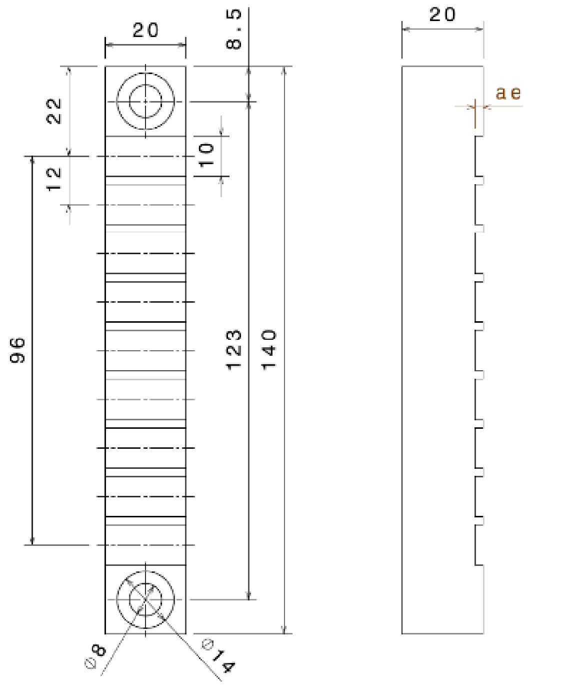

Fig. 2. *The dimensions and location of the processed channels*

3.1. ANOVA method

The analysis of variance (ANOVA) method was used for the statistical analysis of the obtained data.

As is well known [8], ANOVA is a statistical method used to compare the means of several groups and determine if there are significant differences between them. It is an extension of the two- sample t-test and is applied when three or more groups are involved.

There are three main types of ANOVA:

1. One-Way ANOVA: It compares the means of three or more groups based on a single factor or independent variable.

2. Two-way ANOVA: In this case, means are compared based on two independent variables and an analysis is made whether there are interactions between these variables.

3. Multivariate ANOVA (MANOVA - Multivariate Analysis of Variance): This method extends ANOVA to analyze multiple dependent variables simultaneously.

In the ANOVA analysis, one of the following assumptions is applied:

1. Null hypothesis (H_0). According to this hypothesis, there are no significant differences between the means of the groups.

2. Alternative hypothesis (H_1). According to this hypothesis, there is at least one significant difference between the means of the groups.

For the analysis performed, the multifactorial method was applied, and the actual calculations were carried out using the MatLab program.

4. STATISTICAL DATA ANALYSIS

The results of the performed measurements are presented in Table 2.

Table 2. *The obtained roughnesses*

Crt. no.	*v*	*fz*	*ae*	*Ra*	*Rq*	*Rz*
1	180	0.05	1	0.835	0.979	3.834
2	180	0.075	1	0.963	1.160	4.858
3	180	0.1	1	1.005	1.204	5.030
4	215	0.05	1	0.772	0.927	3.680
5	215	0.075	1	0.914	1.093	4.093
6	215	0.1	1	0.981	1.177	4.920
7	250	0.05	1	0.829	0.986	3.714
8	250	0.075	1	0.967	1.139	4.184
9	250	0.1	1	1.102	1.319	5.250
10	180	0.05	2	0.881	1.087	4.808
11	180	0.075	2	1.141	1.304	4.791
12	180	0.1	2	1.081	1.286	5.296
13	215	0.05	2	1.015	1.217	5.089
14	215	0.075	2	1.061	1.269	4.875
15	215	0.1	2	1.122	1.388	5.880
16	250	0.05	2	1.031	1.279	5.561
17	250	0.075	2	1.208	1.472	6.128
18	250	0.1	2	1.383	1.666	6.758
19	180	0.05	3	0.990	1.173	4.869
20	180	0.075	3	1.200	1.378	5.180
21	180	0.1	3	1.117	1.303	5.176
22	215	0.05	3	1.168	1.428	5.922
23	215	0.075	3	1.173	1.414	5.744
24	215	0.1	3	1.282	1.566	6.670
25	250	0.05	3	1.120	1.354	5.801
26	250	0.075	3	1.315	1.578	6.290
27	250	0.1	3	1.554	1.865	7.325

Figure 3 shows the results obtained after measuring the roughness of one of the processed channels (set no. 1).

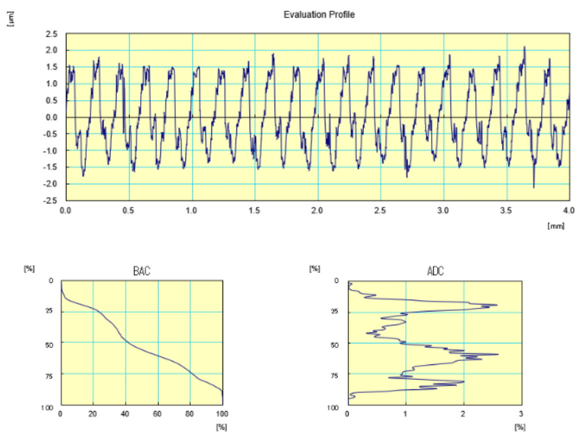

Fig. 3. *Profile evaluation, bearing curve and frequency distribution*

4.1. Analysis of data variance

For the obtained data, multifactorial analysis of variance was applied [9], based on the parameters of the machining process.

The results for the three roughness criteria are shown in Tables 3, 4 and 5.

Table 3. *The results of the ANOVA analysis - the criterion Ra*

Source	Sum Sq.	d.f.	Mean sq.	F	p
ae	0.367	2	0.184	79.64	0
fz	0.226	2	0.113	49.025	0
v	0.103	2	0.052	22.456	0.0005
Error	0.113	8	0.002		
Total	0.809	26			

Table 4. *The results of the ANOVA analysis - the criterion Rq*

Source	Sum Sq.	d.f.	Mean sq.	F	p
ae	0.534	2	0.27	32.000	0
fz	0.309	2	0.154	18.297	0
v	0.183	2	0.091	10.835	0.0006
Error	0.169	20	0.008		
Total	1.195	26	0		

Table 5. *The results of the ANOVA analysis - the criterion Rz*

Source	Sum Sq.	d.f.	Mean sq.	F	p
ae	10.626	2	5.313	26.200	0
fz	4.726	2	2.363	11.650	0.0004
v	2.877	2	1.438	7.090	0.0047
Error	4.056	20	0.203		
Total	22.285	26			

The meaning of the columns of tables 3-5 is as follows:

Source – represents the analyzed factor.

Sum Sq. – (SS sum of squares) is the variation explained by each factor. For example, for Table 2, *ae* explains a variation of 0.367, *fz* explains a variation of 0.226, and *v*- a variation of 0.103. Residual error (Error) is the variation in the data that cannot be explained by the analyzed factors. The total value (Total) is the sum of the previous variations, including the residual error.

d.f. – the degree of freedom associated with each source of variation. It represents the number of independent elements used in the statistical calculation and is one unit less than the number of values that each of the analyzed factors takes.

Mean sq – (MS mean square) for each source of variation. It is calculated using the following formula:

$$MS = \frac{SS}{df}. \quad (1)$$

F – the ratio between the variation explained by each factor and the residual variation.

p – the probability that the observed effect is due to chance. If this probability is less than 0.05, the effect of the factor is considered statistically significant.

5. CONCLUSIONS

The aim of this paper was to determine if the parameters of the machining process have influence on the roughness obtained.

Understanding the relationships between these parameters can lead to the optimization of the machining process, ensuring both efficiency and a high level of quality in the machined parts.

As it can be seen, the probability is less than 0.05 for all three independent variables in each of the three tables.

It can be concluded that each of the cutting parameters has a significant influence on any of the three roughness criteria analyzed.

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