VERIFICATION OF THE NORMAL DISTRIBUTION OF EXPERIMENTAL DATA OBTAINED BY MILLING OF ALUMINUM ALLOYS

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Abstract - In this scientific paper, the research problem addressed is based on the organization of a cylindrical-frontal milling process in well-established conditions, eliminating as much as possible the disturbing external influences. The general objective of the research is to make measurements of the roughness of the surface determined longitudinally and transversely on the machined surface of an aluminum semi-finished product. By measuring this amount of analysis of the quality of the processed surface, a series of links can be deduced between the analyzed factors: cutting speed, cutting depth and feed rate and the laws governing the cutting process. The value of the results obtained from the research, the cost, and the duration of the research program, depend on the choice of methods, means and techniques of investigation, the organization of the stages of experimentation and the way of processing the results. In this sense, the Shapiro-Wilk test was chosen as the statistical method of data analysis to verify the normal distribution of experimental data. The last part of the paper presents the essential conclusions that highlight the importance of adopting this approach to research and the opening of new fields of study.

Keywords: Cutting process, Roughness, Aluminum, Shapiro-Wilk test, Experimental data, Normal distribution.

1. Introduction

The law of normal distribution of random measurement errors (Gauss's law) is most accepted in the practice of processing experimental data resulting from measurements. Each experiment must ensure that the data distribution is consistent with Gauss's law [1-5].

Because for a series of experimental data to be mathematically processed, the experimenter has a certain statistical model, it is possible that it better or less describes the studied model [6-10].

Verification of the concordance between the two experimental data distributions is necessary.

From a statistical-mathematical point of view, the problem of determining a certain statistical model consists in verifying the concordance between the empirical distribution of the experimental data and a theoretical distribution supposed to be adequate for their model [1,11].

Verification of the normal distribution of experimental data can be done by tests [1,4]:

- χ^2 test;
- Massey test;
- Shapiro-Wilk test;
- Kolmogorov test.

The fundamental objective of this research is to study the normal distribution of experimental data obtained by measuring the arithmetic mean deviation of the R_a surface profile, resulting from cylinder-front milling processing of aluminum alloy parts code 7136, depending on the parameters cutting process.

2. Research Design

The design stages of the research are represented by:

- rigorous performance of the bibliographic study, following which the existing information on the studied topic can be inventoried;
- defining the research problem;
- setting input data:
    - choice of semi-finished material;
    - choice of cutting operation;
    - the choice of the factors pursued in the research and their levels of variation;
    - choice of tools;

- choosing the machining center with numerical control;
- choice of measuring instruments and devices;

- setting the output data:
  - the choice of the answers followed in the research and the methods of their determination and their accuracy.
- choosing the experimental method in such a way as to allow the progressive acquisition of information. The experimental method must be efficient, to obtain the maximum information with the help of a minimum number of experiments. It must allow the number of experimental tests required to be kept to a minimum, but this reduction of the number of tests required must not diminish the quality of the results but, on the contrary, allow the highest possible accuracy to be obtained [4,12]. This method will also determine the required number of measured values, samples and tools used;
- effective performance of the experiment;
- the analysis, interpretation and validation of the results must be easy to perform. This is facilitated by the initial choice of the experimental method, which must also allow the proposed objectives to be achieved. At present, the analysis of the results is facilitated by the use of appropriate computer programs [4,13,14];
- The progressive acquisition of information is necessary because if an experimenter studies a phenomenon, he does not know the results, so he must progressively progress and reorient the studies according to the results obtained. A first series of experiments leads to provisional conclusions, depending on these conclusions a new series of experiments is performed. These two series of experiments allow to obtain more complete information about the phenomenon. If necessary, depending on the results obtained in the first two series, a third series of experiments can be performed. In this way the experimenter looks for the answers he needs and stops when he has obtained what he is looking for [4,15];
- knowledge of the studied system (phenomenon).

The actual development of the experiments will take place in the direction of the detailed study of the behavior of the aluminum alloy 7136 according to the proposed objectives, to the variation of the parameters of the cutting regime, within the milling process.

The tool used for machining is SECO type R217.69-1616.0-09-2AN with 2 teeth and a diameter of 16 mm. The corresponding cutting boards are type XOEX090308EN-E05, H15.

The chosen machining center is HAAS VF2.

The analysis of the evolution of the surface roughness in case of different processing conditions was performed using the Mitutoyo SURFTEST SJ-210 roughness meter.

In this way, the main requirements necessary to achieve the established objectives can be met and at the same time to obtain experimental data based on which the influence of the cutting parameters on the surface roughness in the cylinder-front milling process can be analyzed.

Cutting speed (495, 530, 570, 610, 660, 710 [m / min]), cutting depth (2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6 [mm]) and feed rate tooth (0.04, 0.06, 0.08, 0.11, 0.14 [mm / tooth]) exerts its influence on the arithmetic mean deviation of the R_a surface profile.

In mathematical form, the theoretical arithmetic mean deviation of the Rat surface is dependent on the 3 established factors: the cutting speed v [m/min], the cutting depth a_p [mm] and the feed rate per tooth f_z [mm / tooth]:

$$R_a t = f(v, a_p, f_z) \tag{1}$$

A theoretical value of Rat cannot be reached due to experimental errors $\mathcal{E}$, which occur during the tests, but can be estimated by experimentally determined $R_a\, exp$:

$$R_a\, exp = R_a t + \varepsilon = f(v, a_p, f_z) \tag{2}$$

Where ε represents the experimental error.

Given the research strategy proposed for the selection of experimental points (experimental points represent values of the studied cutting parameters) and the way in which the analysis and interpretation of the results is done, our own research will be carried out by adopting a strategy involving the use of experimental plans.

Following the application of this strategy, the research acquires several advantages, such as [16,17]:

- reducing the number of experimental determinations;
- the possibility to study a larger number of variables;
- the possibility of detecting interactions between factors;
- the possibility of determining optimal values;
- achieving better accuracy of results;
- modeling the results and optimizing the model.

The method chosen to determine the arithmetic mean deviation of the R_a surface profile is the experiment.

After performing all the experimental determinations, in this context, the measurements will be performed, and the data will be collected.

The total number of measurements results from the established repetitions of each experiment.

According to Montgomery [3] these repetitions can be between 3 and 7 times for each set of values of the input parameters, to determine the constancy of the measurements. In this case, to obtain the most accurate results, a repetition will be performed 7 times.

Regarding the repeated experiments (each 7 times), only the values of the arithmetic mean deviation of the processed R_a surface profile will be used for data processing and testing, resulting in a total of 2100 measurements (1050 R_a longitudinally measurements, respectively 1050 measurements related to R_a transversely).

In accordance with this decision, the subsequent statistical analysis of the resulting data will be based on an appropriate method in this direction.

The verification of the normality of the experimental data distribution will be performed using the Shapiro-Wilk normality test, which is recommended in the analysis of data sets not exceeding 50 values, to certify that the values obtained are real values of the studied process.

3. Verification of the Normal Distribution of Experimental Data

Verification of the normality of the data distribution can be done with the Kolmogorov, Shapiro-Wilk and Lillefors tests [2].

Own research will be performed using the Shapiro-Wilk normality test, which is recommended in the analysis of data sets that do not exceed 50 values.

Thus, the calculation method has as a starting point the calculation of the value of the number W with the following relation [2]:

$$W = \frac{b^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \tag{3}$$

in which:

- W - is a statistical number to be calculated;
- b – is a linear estimate of the standard deviation and is calculated from the ordered values in the data string;
- $\sum_{i=1}^{n}(x_i-\bar{x})^2$ – is the sum of the squares of the deviations for the n measurements.

The following is a linear estimate of the standard deviation. Therefore, the data set is divided into classes. The maximum number of k_{max} classes is set based on the number of n values in the data string, so:

If n is even then $k_{max} = \frac{n}{2}$, and if n is odd then $k_{max} = \frac{(n-1)}{2}$.

Regarding their own research, for the n = 7 and n = 6 data strings, $k_{max} = 3$, and for the strings of how many n = 5 and n = 4 data, $k_{max} = 2$.

Table 1 chooses the coefficients a, which are related to the Shapiro-Wilk normality test [2,4]. These coefficients are chosen according to the number of values considered and the number of groups k determined. For example, for n = 7, with $k_{max} = 3$, the coefficients of choice are: 0.6233; 0.3031 and 0.1401.

Subsequently, the statistical number W is calculated, which is related to the critical value W_{crt} and is chosen from table 2 [2]. For example, for the string with n=7 values, the calculated statistical number W is related to the critical statistical number W_{crt} = 0.803. We chose this value because the level of confidence chosen in our own research is $\alpha = 0.95$, in other words an error of 0.05% is accepted.

Table 1. Coefficients a for the Shapiro-Wilk normality test

k_n			1	2	3	4	5
	2		0.7071	-	-	-	-
	3		0.7071	0	-	-	-
	4		0.6872	0.1677	-	-	-
	5		0.6646	0.2413	0	-	-
n	6	a	0.6431	0.2806	0.0875	-	-
	7		0.6233	0.3031	0.1401	0	-
	8		0.6052	0.3164	0.1743	0.0561	-
	9		0.6052	0.3244	0.1976	0.0947	0
	10		0.5888	0.3291	0.5141	0.1224	0.0399

Table 2. Critical values for the Shapiro-Wilk normality test

n	Confidence level α		
	0.01	0.02	0.05
3	0.653	0.756	0.767
4	0.686	0.707	0.748
5	0.687	0.715	0.762
6	0.713	0.743	0.788
7	0.730	0.760	0.803
8	0.749	0.778	0.718

If W> W_{crt} then the distribution of the data string can be considered a normal distribution.

In tables 3 and 4 we presented the situation resulting from the calculation steps to determine the normality of the data related to longitudinal R_a and transverse Ra.

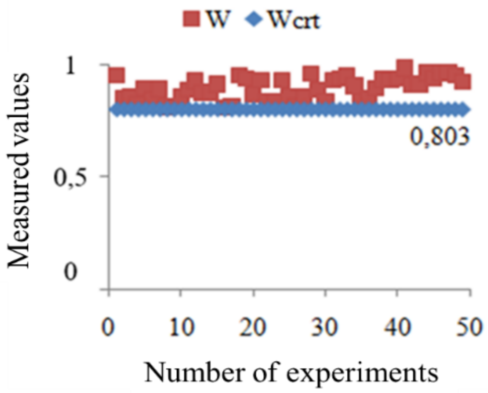
- ***R_a longitudinally***

For the first R_a longitudinally case, we centralized the statistical data through table 3.

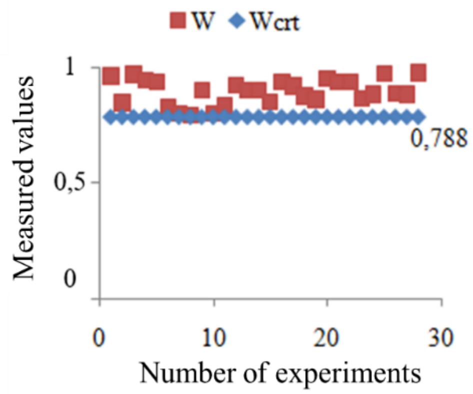
Table 3. Shapiro-Wilk test to verify the normal distribution of R_a longitudinally data

No string data	The given condition	No cutting regimes	Normal distribution
7	$W > W_{crt}$	49	yes
6		28	yes
5		31	yes
4		42	yes

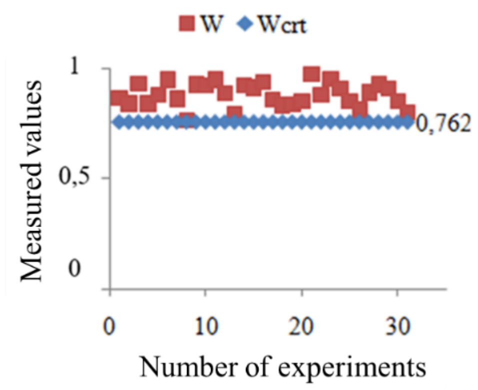
This table shows that all strings of 7, 6, 5, and 4 data, respectively, have a normal distribution of the tested data. In figure 1, we argued this finding, in terms of graphical representations related to the tested statistical data.



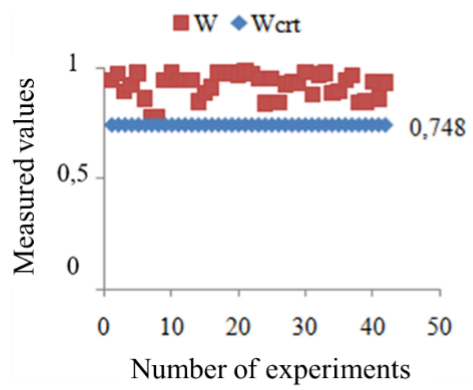
a) 7-data strings



b) 6-data strings



c) 5-data strings



d) 4-data strings

Figure 1: Graphical representations of Shapiro-Wilk test results on longitudinal R_a measurements

In all the cases presented in this figure (a, b, c and d) we represented graphically the results obtained after performing the calculations of the values of the number W, corresponding to each data series.

From the graphs related to these sub-items (a, b, c and d) of Figure 1:

a) corresponding to the strings with 7 values of the 49 experiments each when $W_{crt} = 0.803$;

b) corresponding to the strings with 6 values of the 28 experiments each when $W_{crt} = 0.788$;

c) corresponding to the strings with 5 values of the 31 experiments each when $W_{crt} = 0.762$;

d) corresponding to the strings with 4 values of the 42 experiments each when $W_{crt} = 0.748$,

it turns out that all values calculated for W are greater than its values W_{crt}.

This fulfills the condition of normality regarding the distribution of the tested data, corresponding to the arithmetic mean deviation of the surface profile, measured longitudinally in the direction of the advance movement.

- ***R_a transversely***

Like the previous case, through table 4, we synthesized the statistical data regarding the results of the calculations of the verification of the normality of the distribution of the tested data related to R_a transversely.

Table 4. Shapiro-Wilk test to verify the normal distribution of R_a data transversely

No string data	The given condition	No cutting regimes	Normal distribution
7	$W > W_{crt}$	60	yes
6		26	yes
5		21	yes
4		43	yes

As shown in this table, all strings of 7, 6, 5, and 4 data, respectively, have a normal distribution.

The arguments of this finding were made based on graphical representations related to the statistical data tested for R_a transversely, presented in Figure 2.

In figure 2 (a, b, c, d), we graphically represented the results obtained after performing the calculations of the values of the statistical number W, corresponding to each data string (a - string with 7 data, b - string with 6 data, c - string with 5 data and d - string with 4 data), in the case of measurements obtained in the transverse direction.

From the graphs for these sub-items (a, b, c and d) of Figure 2:

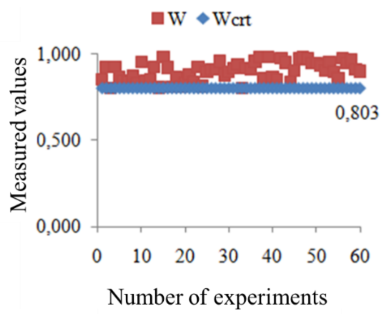
a) corresponding to the strings with 7 values of the 60 experiments when W_{crt} = 0.803;

b) corresponding to the strings with 6 values of the 26 experiments each when W_{crt} = 0,.788:

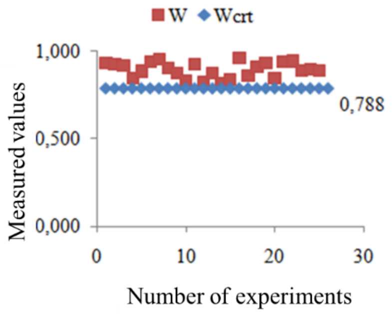
c) corresponding to the strings with 5 values of the 21 experiments each when W_{crt} = 0.762;

d) corresponding to the strings with 4 values of the 43 experiments each when W_{crt} = 0.748,

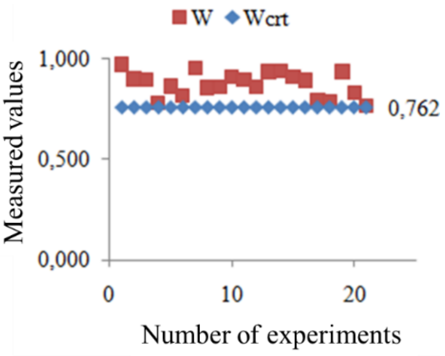
it turns out that all values calculated for W are greater than W_{crt} 's values.



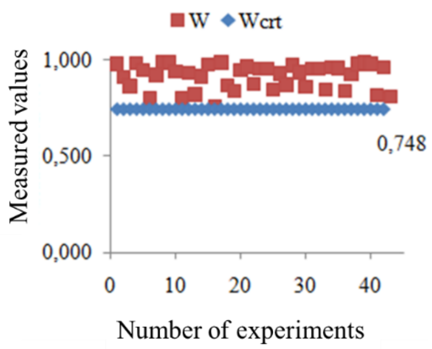
a) 7-data strings



b) 6-data strings



c) 5-data strings



d) 4-data strings

Figure 2: Graphical representations of Shapiro-Wilk test results on R_a measurements in the transverse direction

Thus, the condition of normality regarding the distribution of the tested data is fulfilled, corresponding to the arithmetic mean deviation of the surface profile, measured transversely in the direction of the advance movement.

4. Conclusions

In the case of repeated experiments - each 7 times, a total of 2100 measurements were performed, cumulated from the 1050 measurements related to R_a long, respectively the 1050 measurements related to R_a transversely.

The normal distribution of the experimental data was verified using the Shapiro-Wilk test.

It was found that, after calculating the statistical number W, corresponding to each data series and its relation to the critical reference value, the condition of normality regarding the distribution of the tested data, corresponding to the arithmetic mean deviation of the surface profile, measured both longitudinally and transversely in the direction of the forward movement.

Through the statistical analysis performed on the experimental data, it was found that the values obtained are real values of the studied process. This statement is supported by the previous conclusions.

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