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SIMULATION AND STATISTIC METHODS – IMPORTANT TOOLS IN STUDYING MILLING PROCESS OF A COMPOSITE MATERIAL

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Abstract: *Simulation and statistics represent important tools to be used in research and study of any machining process. Polymeric composite materials are widely used and subject to continuous improvement due to their special characteristics. The milling of parts made of these materials represents a widely used machining procedure. The research on the reciprocal influence of the involved process parameters can be efficiently done if modern simulation and statistic methods are involved.*

Key words: *simulation, statistics, regression, milling, surface roughness.*

1. INTRODUCTION

The term "composite material" refers to artificial materials made of two or more different materials that do not mix together. Additional elements can be added to obtain special characteristics.

So, composite material involves macroscopically combined materials that usually have the best characteristics of the component elements, even characteristics that none of the elements has [6].

The basic one is called "matrix" and can be of metallic, polymeric or ceramics type, while the other(s) is (are) called "reinforcing element(s)" and can be ceramics, glass, carbides, wood, paper etc. That is why, when the matrix is represented by a polymer, the new material obtained is referred to as "polymeric matrix composite".

The most important aspect to be considered, when choosing composite elements, has to be the type and the strength of the bond between matrix and reinforcing element, when regarding their interface [1].

Some special characteristics of composite materials are stated to be: high resistance/weight ratio values; high environment and/or chemical agents corrosion resistance; high vibration softening ability; low thermal expansion coefficient values; good machinability at low temperature below 200 °C, etc.

Obtaining parts made of polymeric composites can be achieved by many procedures, such as manually, spraying, resin transfer molding, injection molding, extrusion, etc. As consequence, parts geometric precision (shape, dimensions, position and roughness) can be different from the prescribed one so, further machining could be required.

The studies on polymeric composite material machinability have been carried out, even from their very early appearance [4]. Many factors (nature and structure of component elements, reinforcing elements disposal into the matrix, obtaining procedure of the rough/final composites part, cutting tool characteristics, machining procedure parameter values, etc.) resulted in having influence on it and therefore their dependence relations would be very important to be known.

Polymeric composites materials machinability is classified into four groups: good, medium, difficult, very difficult [5] but, this is only a qualitative approach, without the specification of the considered parameter, meaning surface roughness, machining force values, cutting zone temperature, cutting tool durability, machining parameter values, etc. [3].

Widely used machining procedures can be classified in conventional (milling, drilling, turning) and non-conventional (electroerosion, laser, ultrasounds, etc.).

The machining process simulation is essential to be done. It allows us avoiding possible errors in the shape, dimensions and/or position of machined surfaces.

Many computer programs can be used for simulation, but the best has proved to be is one specific to the CNC machine tool on which machining is performed.

The statistic methods represent efficient means when the process analysis and/or optimization have to be done. Due to many aspects involved, it should be mentioned that this paper presents applied statistics in manufacturing process study that refers to experiment design and regression models.

An important factor for evaluating one material machinability is its resulting surface roughness.

The regression model has to be determined because it represents an accurate way of estimating roughness values, when some important machining parameters are set to their optimum values [2]. Reversing, when a certain surface roughness has to be obtained, the model enables determination of any machining parameter value, among the considered ones, for getting the required roughness value.

Based on all the above mentioned, this paper presents an experimental and theoretical research on glass fiber reinforced polymeric composite machinability in milling. The studied aspect is that of resulting surface roughness, evaluated by R_a parameter (average value, DIN 4768). The machining procedure is cylindrical milling while the studied material is random glass fiber reinforced polymeric composite.

Similar studies were not found in the specific literature studied.

2. MILLING PROCESS SIMULATION

CNC machine tools are often used when machining is necessary. Accurate, complex, various shapes and dimensions of parts can be obtained on them.

Cylindrical milling simulation of experimental samples was carried out on Isel-automation manufacturing system. Mainly, it consists of three parts, namely [7]:

- Isy CAM software – operating under Windows, enabling Isy-CAM CAD part (for designing and modeling parts 2D or, 3D) and Isy-CAM CAM part (for machining on CNC machine-tools with 3, 3.5 or 5 axes);
- ProNC software – modern interface for operating and programming machine-tools, according to Isel PAL or, DIN 66025 specifications,
- CNC EUROMOD basic units, used for part machining and/or control, with rigid and low vibration structure

Most of the time, the cutting tool trajectory has to be correct, with no error, as it determines machined surfaces shape. This is one of the reasons why process simulation has to be done.

This paper is intended to point out the application of both simulation and statistic methods, the goal being that of obtaining the surface roughness regression model. The cutting tool machining trajectory has been considered as simple as possible.

The experiments involved a lot of machined material and real samples availability was limited, therefore the milling process was carried out on all their side faces.

Considering all the above presented facts, a cylindrical milling process has been simulated for a rectangular shape sample, similar with the real ones.

An image of the CNC EUROMOD basic unit – the one used with experiments, can be seen in Fig. 1 [7], while the cutting tool trajectory simulation, required by experiments, is shown in Fig. 2.

Fig. 1. CNC EuroMod-P basic unit [7].

The phases of cylindrical milling simulation process, performed with Isy-CAM CAM software, are presented in Fig. 3,a., b, and c, while the part at the end of simulation process can be seen in Fig. 4.

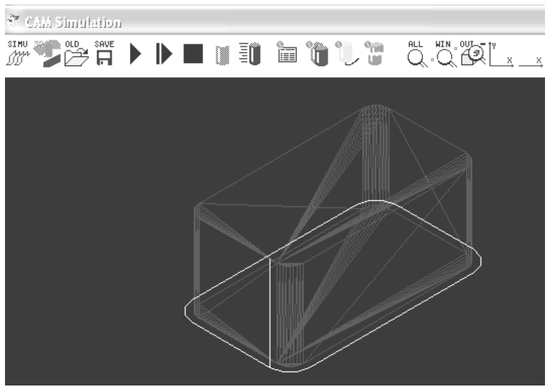
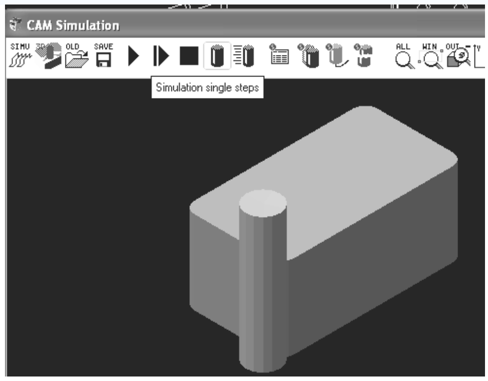


Fig. 2. Cutting tool trajectory simulation.



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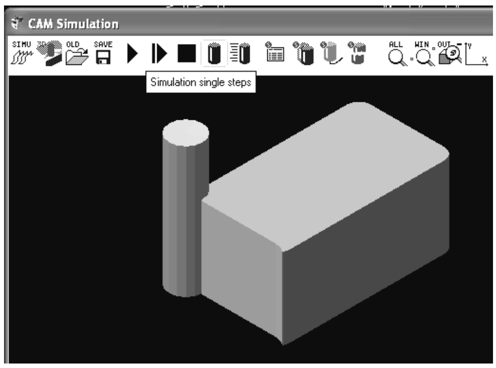

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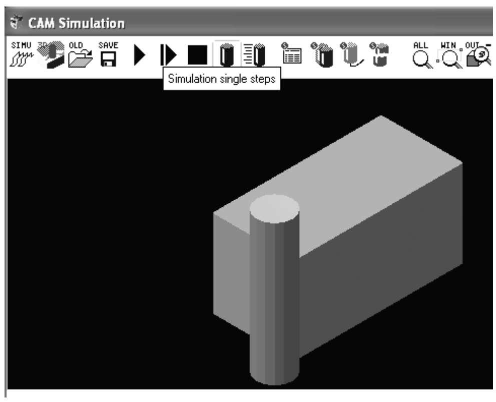

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Fig. 3. Isy-CAM software simulation process (phases).

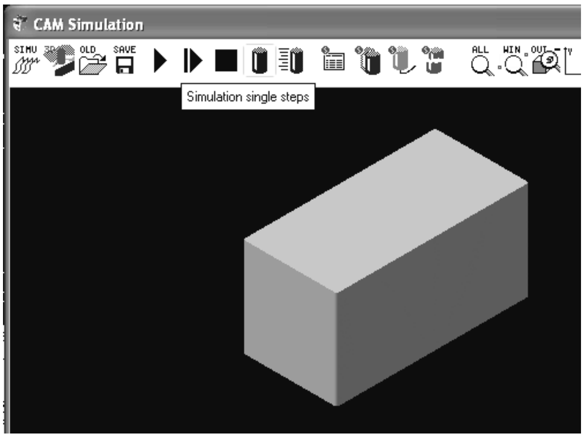


Fig. 4. Part at the end of simulation process.

3. STATISTICAL RESEARCH METHODOLOGY

The processe involving inputs and outputs as quantitative data can be described [3] by multivariable process function as:

$$Y = \Gamma\left(z_1, z_2, ..., z_j, ..., z_k\right), \quad (1)$$

where:

z_j , j = 1, 2, …., k represents the process independent variables (controllable inputs);

Y – process dependent variable (output);

Γ – type of dependence relation.

The optimum Γ type can be determined by statistic analysis of existing (experimental) data by means of regression models.

So, one must establish the values and variation field of each input − both real (z_j) and coded (x_j) together with the experiment design type that fits best [2].

The researches, authors of this paper, deal with three independent variables and one dependent variable. The relationship of real and coded is as follows: when z_j has a minimum or a maximum real value, the x_j coded value is −1 (low level) or +1 (high level) respectively.

Each considered variable has three values (minimum, maximum and medium) within the experimental considered region, the medium one of z_j representing the geometrical mean of its minimum and maximum values. Consequently, the x_y medium level is considered to be the value 0.

The dependence relation considered is the regression model is:

$$Y = A_0 \cdot x_1^{a_1} \cdot x_2^{a_2} \cdot x_3^{a_3} \cdot x_4^{a_4}, \quad (2)$$

which leads to a linear one, by a logarithmic way.

Correlated to the above mentioned aspects, the design of experiments "pointed" toward a fractional factorial one, of P2.1 experiment design type, its structure being presented in the specific references [3, 8].

The regression analysis was performed with the REGS software designed for determining coefficients of linear regression models [8].

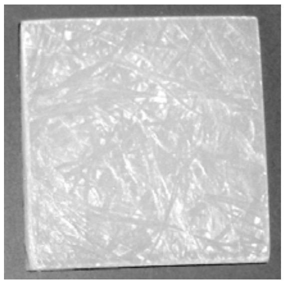


Fig. 5. Samples before experimenting.

Fig. 6. Glass fibers polymeric composites milling tool.

4. EXPERIMENTS AND RESULTS

The experiments were carried out on rectangular shape samples, made of AROPOL S 599 polyester resin random reinforced with EC 12–2400 short glass fibers. Their dimensions were 200×200×10 (mm) – see Fig. 5.

The cutting tool was a special one, FGR-7M EDP No. 83038, as presented in Fig. 6.

The independent variables studied were (Table 1):

- cutting speed, v_c [m/min];
- cutting feed speed, v_f [mm/min];
- axial cutting depth, a_a [mm];
- radial cutting depth, a_r [mm].

The surface roughness, evaluated by its R_a parameter (average value [μm]) represents the dependent studied variable.

The measurements were done on the digital Pocket Surf (NAMICOM) apparatus. Each measurement consisted of five measurements on a 50 mm long surface region, the final value considered representing the average of each five measurement set.

The image of the samples "ready" to be measured, after cylindrical milling is shown in Fig. 7.

Table 1

Real and coded values of input variables

Variable	Values		
v_c [m/min]	18.84	37.69	75.39
	−1	0	+1
v_f [mm/min]	100	160	250
	−1	0	+1
a_a [mm]	1	2	4
	−1	0	+1
a_r [mm]	3	6	12
	-1	0	+1

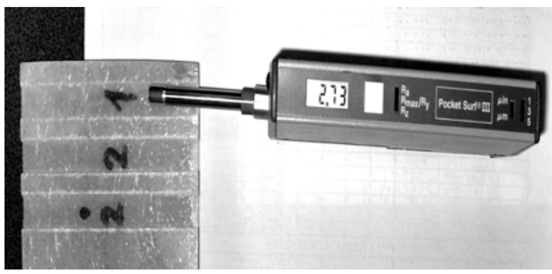
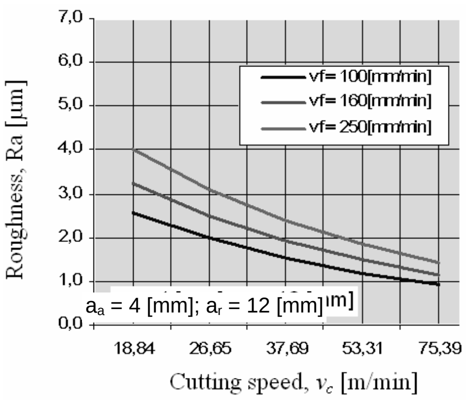


Fig. 7. Measuring surface roughness.

Table 2

Experiments results

Exp. No.	Ra [μm]	Exp. No.	Ra [μm]
1	2.45	7	3.97
2	0.87	8	1.43
3	3.86	9	1.87
4	1.34	10	1.91
5	2.50	11	1.88
6	0.91	12	1.94



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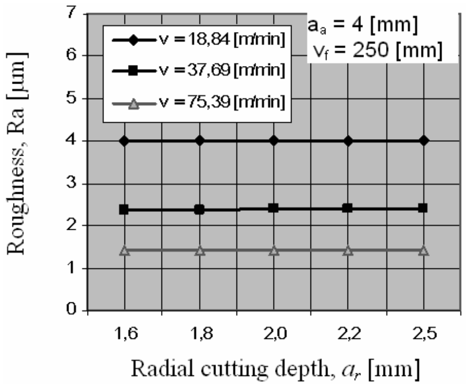

b

Fig. 8. Surface roughness variation graphs.

The experimental values obtained are presented in Table 2. We should mention that both cutting and feed speeds have the same orientation.

5. STATISTIC ANALYSIS

The statistic analysis, for this presented research, involves regression. It was performed with REGS, a software designed for determining coefficients of linear regression models [8].

The result of regression analysis and, consequently, mathematical regression model obtained is:

$$R_a = 2_{.188} \cdot v_c^{-0.744} \cdot v_f^{0.491} \cdot a_a^{0.029} \cdot a_r^{0.0075} \quad (3)$$

The equation (3) relieves the fact that the strongest influence on the surface roughness R_a parameter values is that of the cutting speed v_c, while the weakest influence is that of the radial cutting depth a_r.

More suggestive evidence of the dependent variable variation, on all of the studied independent variables, can be performed by plotting graphs – see Fig. 8a, b.

6. CONCLUSIONS

The high and special characteristics of polymeric composite materials point out their importance to nowadays industry. Reinforcing elements have the target of increasing mechanical properties, very good results being obtained when the reinforcing element is represented by random oriented short glass fibers.

Milling is often used when obtaining the final shape and dimensions of polymeric composite parts and that is why some important parameters, as well as their relationship characterizing the process, are important to be known.

The surface roughness of the resulting machined surface has been studied, so that the determined regression model estimates the values of R_a roughness parameter, related to cylindrical-face milling process parameters.

The simulation of the cylindrical milling process, with specialized CNC machine software, Isy-CAM, has been done.

Applied statistics, meaning experiments design and regression analysis with a special software, REGS, pointed out the fact that all considered process variables – cutting speed v_c, cutting feed speed v_f, axial cutting depth a_a, and radial cutting depth a_r – did significantly influence the R_a parameter values.

Further research should be developed, for obtaining other regression models of the surface roughness and/or milling force, cutting zone temperature, and cutting tool wear. All of them represent important and efficient tools in studying polymeric composite materials machinability, meaning knowing optimum process parameters values, both as inputs and outputs.

REFERENCES

[1] Holcman, V., Liedermann, K. (2007). *New Mixing Rule of Polymer Composite* Systems, WSEAS Trans. on Electronics, Issue 9, Vol. 4, ISSN: 1109–9445.

[2] Iliescu, M., Spânu, P., Costoiu, M. (2007). *Glass Fibres Reinforced Polymeric Composites–Statistic Models of Surface Roughness,* Plastics, No. 4, ISSN: 0025–5289.

[3] Iliescu, M. (2000). *Research on Quality and Machinability of Thermal Sparayed Coatings*, PhD Thesis, Bucharest.

[4] Puw, H.Y., Hocheng, H.(1992). *Milling force prediction for fiber reinforced thermoplastics*, Processing and Manufacturing Composite Materials, ASME.

[5] Vlase, A., et. al. (2005). *Mechanic Products' Manufacturing Technology*, Edit. Matrix Rom, Vol. II, Bucharest.

[6] Zgură, G., Moga, V. (1999). *Bases of Composite Materials' Design*; Edit. Bren, Bucharest.

[7] *** ProNC Instruction + Isel-automation Catalogue, 2007.

[8] *** REGS – Regression Program, improved by Stăncescu B., 1999.

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