Glass Fibres Reinforced Polymeric Composites - Statistic Models of Surface Roughness

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Due to their important and special characteristics composites have known a continuous development lately. Consequently there has been given great attention to improve, both, their manufacturing and machining technologies. In machining, milling represents an important procedure and, as there are not many data concerning process parameters dependence, some statistic models were considered worth to be determined. So, there has been studied Romanian glass fiber reinforced polymeric composites and have been obtained two mathematical relations of surface roughness dependence - R_a parameter- on some milling process variables.

Keywords: composites, glass fibers, milling, surface roughness

Composites, specially glass fibers reinforced polymeric matrix ones, are widely used because of their very good characteristics. There can be mentioned [6] aerospace, marine and automotive applications, as well as sports or consumer goods fields.

A composite represents the "combination" of fibers and matrix whose special characteristics refer to: high strength and light weight; low coefficient of thermal expansion; resistance to fatigue, impact and extreme temperatures, as well as to corrosion and wear. Glass fibers reinforced composites represent the most common form of composite, which is inexpensive and offers high strength, excellent electrical insulation and tensile strength halved at 500 °C.

Once composite products manufactured, there is often the need of machining some of their surfaces and the most common used procedures [1] are represented by milling and drilling. The References [7] does not present – for milling - any specific values of machining parameters, or dependence mathematical relations of process characteristics (surface roughness, machining forces and torques, cutting tool wear, temperature into the cutting zone, etc.) on machining parameters.

So a study on surface roughness in milling Romanian made glass fiber reinforced composites has been considered useful,. Statistic models have been obtained and, thus, the machining process variables could be set, as to obtain optimum value of R_a (surface roughness) parameter.

Experimental part

In machining glass fibers reinforced polymeric composites, optimum results can be obtained if there are quantitative data, which should be expressed [4] as multivariable function. So, the variables of a technological process, should be "connected" by relation, as:

$$Y = \Gamma(z_1, z_2, ..., z_j, ..., z_n) \qquad (1)$$

called process function, where:

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

Y – the process dependent variable (output);

Γ - the type of dependence relation.

In order to determine optimum Γ type, there must be established the values - both real (z_j) and coded (x_j) - and variation field of each input, as well as the experiment design that fits best.

There have been considered [5] two types of experiment designs, as follows:

- Full Factorial Design, FFD – a two level design for three independent variables, 8 runs and 3 replicates;
- Box-Wilson (Central Composite) Design, CCD – a three level design for two independent variables, 10 runs and 5 replicates.

The appropriate software, for statistical modeling, was *DOE KISS* (Student Version), that computes regression coefficients and all the other values required by a multiple regression analysis [2, 3]. The *DOE KISS* also provides the Pareto Chart of Coefficients - a graph that points out how much the influence of each input (as well as its interactions) on the output is and an *Expert Optimizer* - which sets the inputs values, so as to optimize the output.

The structure of experimental programs is presented in table 1.

The regression functions determined are polynomial type, as:

- for full factorial design

$$Y = a_0 + a_1 z_1 + a_2 z_2 + a_3 z_3 + a_{12} z_1 z_2 + a_{13} z_1 z_3 + a_{23} z_2 z_3 + a_{123} z_1 z_2 z_3 \qquad (2)$$

- for central composite design

$$Y = a_0 + a_1 z_1 + a_2 z_2 + a_{12} z_1 z_2 + a_{11} z_1^2 + a_{22} z_2^2 \qquad (3)$$

The relation between real (z_j) and coded (x_j) values of the independent variable is:

$$x_j = \frac{z_j - \bar{z}}{\frac{z_{max} - z_{min}}{2}} \qquad (4)$$

where:

$\bar{z}$ - represents the mean for z_j, over the experimental region

z_{min} - minimum value of z_j, over the experimental region

z_{max} - maximum value of z_j, over the experimental region

The experiments were carried out on composite samples made of AROPOL S 599 polyester resin and EC

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Table 1
EXPERIMENTAL PROGRAMS

Full Factorial Design, FFD	Run	x_1	x_2	x_3	Central Composite Design, CCD	Run	x_1	x_2
	1.	-1	-1	-1		1.	-1	-1
	2.	-1	-1	+1		2.	-1	+1
	3.	-1	+1	-1		3.	+1	-1
	4.	-1	+1	+1		4.	+1	+1
	5.	+1	-1	-1		5.	0	0
	6.	+1	-1	+1		6.	0	0
	7.	+1	+1	-1		7.	-1	0
	8.	+1	+1	+1		8.	+1	0
						9.	0	-1
						10.	0	+1

Table 2
POLYMERIC COMPOSITES CHARACTERISTICS

Characteristics	Measuring Units	Values
Mechanical properties		
- density	g/cm^3	1.35 ÷ 2.30
- compressive strength	MPa	103 ÷ 206
- elongation	%	0.5 ÷ 5
- tensile strength	MPa	103 ÷ 206
- shock strength	J/m	107 ÷ 1070
Electrical properties		
- volume resistivity	Ωcm	1014
- dielectric constant		
60 Hz		3.8 ÷ 6
103 Hz		4 ÷ 6
106 Hz		3.5 ÷ 5.5
Resistance characteristics		
- thermal resistance	^{0}C	149
- water absorption (in 24h) for a thickness of 3,1 mm	%	0.1 ÷ 1

Table 3
CODED (xj) AND REAL VALUES (zj) OF THE CONTROLLABLE INPUTS

v [m/min]			v_f [mm/min]			a_a [mm]			G_f [%]		
(-1)	(0)	(1)	(-1)	(0)	(1)	(-1)	(0)	(1)	(-1)	(0)	(1)
25,12	31,42	50,27	63	100	160	2	2,8	4	20	30	40

12-2400 glass fibers. The fibers' content varies between 20% and 40% (there were studied three types of samples, whose fibers content was: 20%, 30 % and 40%).

The samples were made at S.C. TURINGIA S.R.L., a certified company in composites manufacturing, and they were plates of 200 . 200 . 10 (mm) with Conformity Certificate. Their characteristics are shown in table 2.

Controllable inputs (z_j) considered were: cutting speed (v [m/min]), feed speed (v_f [mm/min]), axial cutting depth (a_a [mm]) and glass fibers content (G_f [%]). The real and coded values are presented in table 3.

Constant inputs were considered to be environment parameters (temperature, humidity) and cutting tool characteristics.

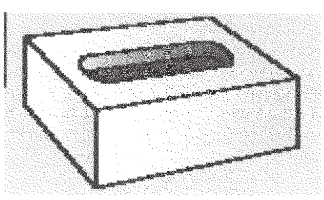
The cutting tools were made by SGS Company and their characteristics are according to the requirements of machining fibers reinforced composites, as mentioned by the Conformity Certificate.

Figure 1 schematically shows the machining type studied – cylindrical face milling of a slot – and the appropriate cutting tool used – FGR-7M EDP no. 83038.

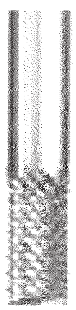
Uncontrollable (noise) inputs were the technological system's vibrations - at constant speed milling, on FUS 22 milling machine.

Dependent process variable (output) measured was the R_a [μm] surface roughness parameter .

The measurements were made with Pocket Surf, a pocket-sized economical instrument which performs



cylindrical face milling of a slot



milling tool –
FGR-7M EDP 83038

Fig. 1. Machining type and cutting tool

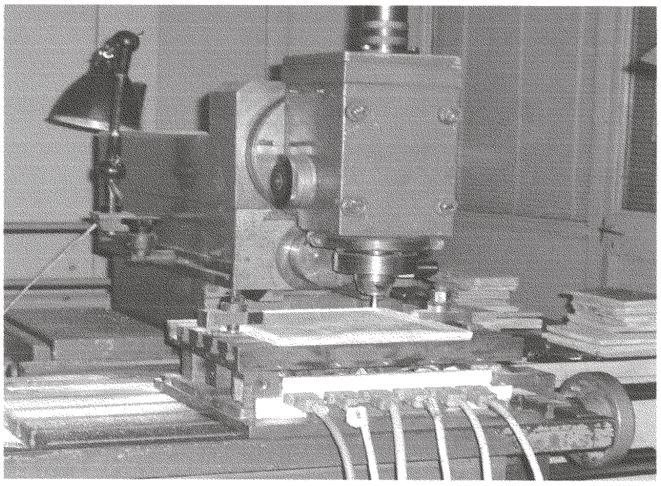


Fig. 2. Technological system while milling

traceable R_a, R_{max}, R_z and R_y surface roughness values on a wide variety of surfaces including small inside diameters.

An image of the technological system, while machining, is presented by figure 2.

Results and discussions

It was assumed that the greatest influence on surface roughness' is that of: cutting speed (v [m/min]), feed speed (v_f [mm/min]) and axial cutting depth (a_a [mm]).

So, the other input variables: radial cutting depth (a_r [mm]), cutting tool wear (U [mm]) and cutting tool diameter (D [mm]) were set to constant values. Composite glass fibers content (G_f [%]) was, also, set to constant value at medium level (coded 0). Experiments were carried out.

The medium values of surface roughness, R_a [µm], obtained are presented in table 4, by mentioning that the experiment design used for study was the Full Factorial Design.

The regression analysis results, using DOE KISS software, are presented in figure 3.

The statistic model obtained by regression analysis is:

$$R_a = 1.8977 - 0.534 \cdot v + 0.131 \cdot v_f + 0.184 \cdot a_a - \\ - 0.079 \cdot vv_f - 0.066 \cdot va_a - 0.076 \cdot vv_f a_a \quad (5)$$

Obs.:

A factor is considered to have significant influence on the output as long as the P (2 Tail) value is less or equal, to 0.05.

The DOE KISS also provides the *Pareto Chart of Coefficients* – that points out how much the influence of each input (as well as its interactions) on the output is, (fig. 4), and the *Expert Optimizer* – that sets the inputs values as to minimize R_a values, as shown in figure 5.

As there were three sample types, depending on the glass fibers content, it was considered to be useful a study on the influence of composite's glass fibers content on surface roughness.

The statistic model, previously determined, pointed out the fact that the greatest influence on R_a parameter is that of the cutting speed, v.

So, the controllable inputs considered this time were: cutting speed (v [m/min]) and glass fibers content (G_f [%]), as long as the other inputs (see the above paragraphs) were considered to be constant and set to their medium values (coded as "0").

The medium values of surface roughness, R_a [µm], obtained are presented in table 5, by mentioning that the experiment design used for study was the Central

Table 4

EXPERIMENTAL RESULTS - MEDIUM VALUES (Y-HAT) OF SURFACE ROUGHNESS, R_a [µm]

Experiment Design	Experimental results								
FFD	Run	1	2	3	4	5	6	7	8
	R_a [µm]	2.10	2.34	2.26	3.02	1.17	1.45	1.32	1.51

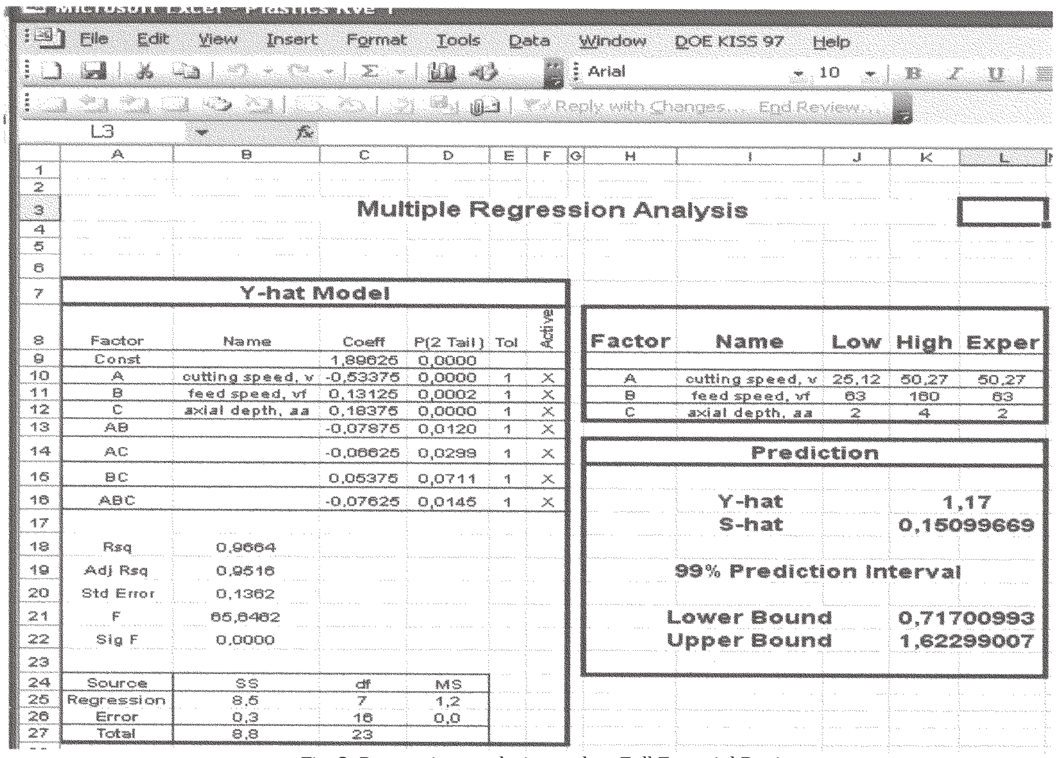


Fig. 3. Regression analysis results - Full Factorial Design

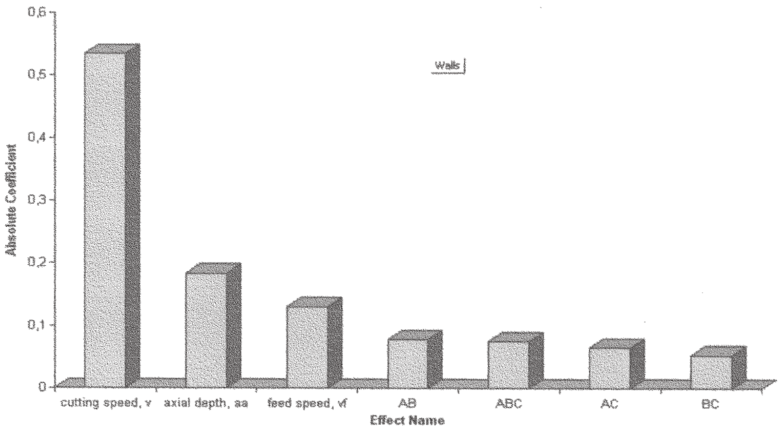


Fig. 4. Pareto chart of coefficients

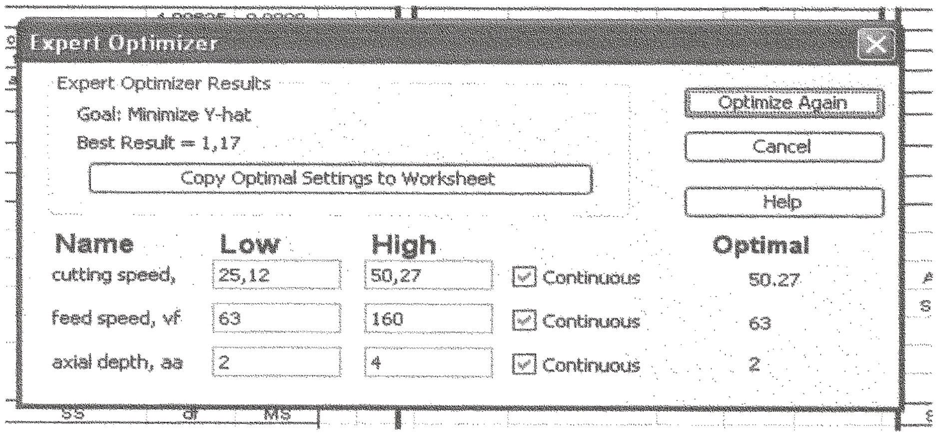


Fig. 5. Expert optimizer

Table 5

EXPERIMENTAL RESULTS - MEDIUM VALUES (Y-HAT) OF SURFACE ROUGHNESS, R_a [μm]

Experiment Design	Experimental results										
CCD	Run	1	2	3	4	5	6	7	8	9	10
	R_a [μm]	2.22	2.32	1.17	1.21	1.88	1.93	2.02	1.73	2.04	2.17

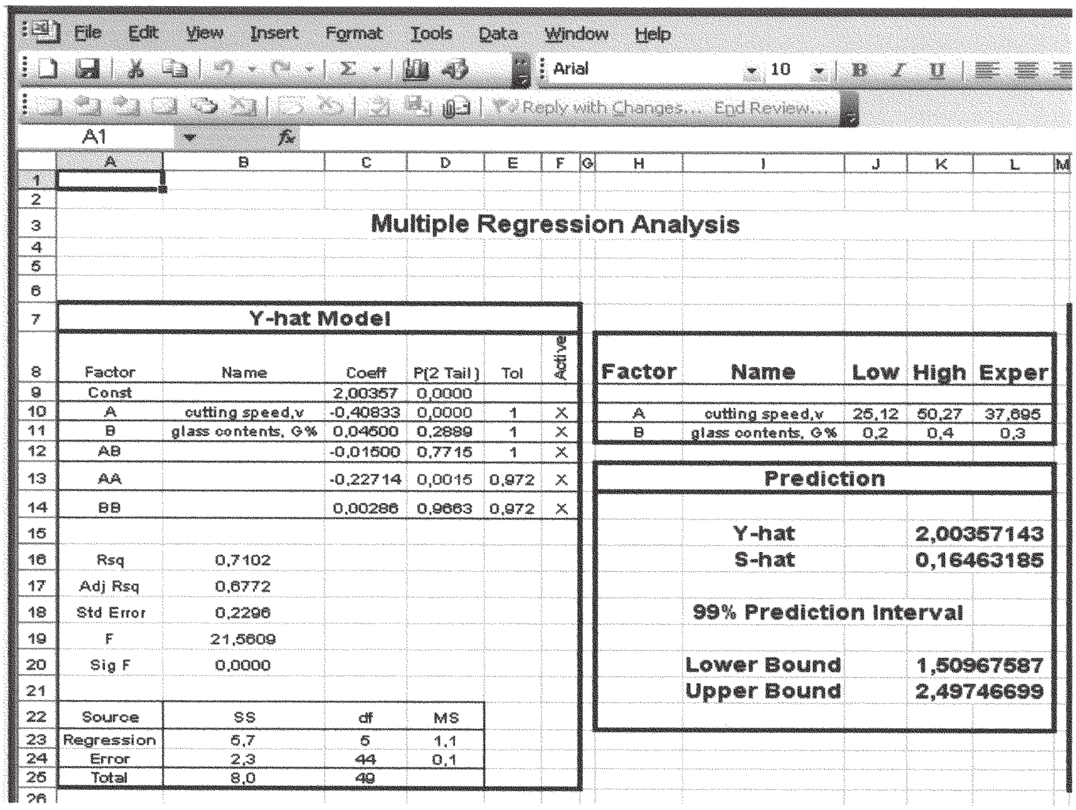


Fig. 6. Regression analysis results - central composites design

Composite Design.

The statistical model, obtained by regression analysis is:

$$R_a = 2.004 - 0.408 \cdot v - 0.227 \cdot v^2 \qquad (6)$$

Obs.:

One can notice that the only factor that significantly influences the surface roughness is cutting speed, both first order, v, and second order, v^2, terms.

Conclusions

Fibers reinforced composites are extremely important, because of their mechanical characteristics which are superior to the ones of other composite types – higher tensile strength, higher hardness, reduced thermal expansion coefficient, improved resistance to chemical environment, etc.

As the use of glass fibers reinforced composites has been knowing a great extent in our country, it has been considered useful the study of one very important machining parameter – surface roughness.

There haven't been found, all over the studied references, any mathematical relations of surface roughness dependence on any machining process variables.

The experiments were carried out on three types of Romanian manufactured glass fibers reinforced polymeric composites and the machining procedure was that of cylindrical face milling. Cutting tools used were the ones recommended for these material types.

So, the paper presents two statistic models of R_a surface roughness parameter (commonly used in real machining situations), meaning its dependence on some machining parameters, the goal being that of enabling to set their value as to obtain the desired machined surface roughness.

First model shows the dependence of R_a on some milling parameters - cutting speed (v [m/min]), feed speed (v_f [mm/min]) and axial cutting depth (a_a [mm]) – and their interactions. The interesting aspect is that only the $v_f a_a$ factor does not significantly influence surface roughness.

The second model points out the dependence of R_a on the most important milling parameter - cutting speed (v [m/min]) and the fibers content (G_f [%]). One can notice that the glass fibers content does not have significant influence on surface roughness, as well as neither of its interactions (second order terms).

Further researches could be developed so as to determine surface roughness dependence on other machining process parameters, in order to get the optimized values.

Maybe other polymeric composite type materials should, also, be considered.

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