U.P.B. Sci. Bull., Series B, Vol. 70, No. 1, 2008 ISSN 1454-2331

MATHEMATICAL MODEL OF TEMPERATURE IN MILLING GLASS FIBER REINFORCED POLYMERIC COMPOSITES

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Materialele cu matrice polimerică, ranforsate cu fibră de sticlă, reprezintă grupa materialelor compozite cu cea mai largă utilizare in practică, datorită proprietăților mecanice superioare, pe care le oferă .În vederea obținerii caracterisiticlor dimensionale, de formă sau de rugozitate impuse pieselor realizate din acest tip de materiale, uneori, este necesară prelucrarea – prin frezare, a anumitor suprafețe ale acestora.

Datorită rolului important, pe care îl are în cadrul procesului de aşchiere, căldura care se degajă şi, în conseciință, temperatura din zona de aşchiere, lucrarea prezintă etapele parcurse în vederea determinării unui model matematic care să permită calculul valorii temperaturii.

Glass fiber reinforced polymeric matrix materials represent the most widely used composite materials group, because of their superior mechanical properties. In order to have the dimensional, shape or, roughness characteristics prescribed for parts made of this material type, sometimes, machining – by milling, of some of their surface is necessary s.

Because the generated heat has an important role into the cutting process and, consequently in the cutting zone temperature, the paper presents the steps carried out in order to determine a mathematical model that allows the temperature's value calculus.

Keywords: glass fiber, polymeric composite, milling, temperature, mathematical model, regression

1. Introduction

Glass fiber reinforced polymeric matrix composite materials represent [1] the most widely used group of composites, due to their improved mechanical characteristics. Their versatile applications can be explained by the ease of obtaining the rough materials implied, as well as the various glass fiber types. It is estimated that glass fiber reinforced composites represent over 90% of the world used polymeric composites.

Several fields where polymeric composites are widely used can be stated to be: navy, automotive and aircrafts industries; medical equipments, etc.

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A glass fiber reinforced polymeric composite is made of two basic components: the reinforcing element and the matrix.

The reinforcing element is represented by glass fiber and, for ordinary manufactured reinforced polymeric composites, the maximum glass fiber content [2,3] can be about 40% - if discontinuous fibers are used but, can be extended up to 60% - if long fibers are used.

The matrix represents the most important component, because it determines the temperature range (for part's exploitation) and the fibers load transfer. The matrix material, usually, is a polyester resin that has good mechanical properties, can be obtained with big enough thickness – in one layer, and, not the least, has a low price.

Some glass fiber reinforced polymeric composites parts need machining and, one of the most common used procedure is represented by milling. So, milling can be used in order to: get high dimensional and shape precision, eliminate some manufacturing defects – such as spews, get samples used various testing procedures.

While machining polymeric materials, a special attention must be gives to the temperature within the cutting zone. This temperature should not exceed [4] the vitrifying value, T_v, that represents the temperature up to which, the polymeric composites maintain their glassy state – with very low elastic deformations. If the temperature is higher than T_v, the material gets into the high elastic state, characterized by high, reversible deformations.

Experimental researches [4,5] have proven that, because of polymeric composites' low thermal conductibility (500 times lower than metals), while cutting process there is a high increase of temperature within machined part. The heat, so generated, is distributed so: (55% .. 60%) into the chip, (15% .. 20%) into the machined part and (20 … 25%) into the cutting tool.

An efficient mean for temperature study while machining is the thermograph method – infrared thermograph.

This method deals with capturing the infrared radiation emitted by the studied object and converting it into an electrical signal. The infrared radiation [3] is captured from the distance and by scanning (point by point), the obtained information is converted into a visual image of point's temperature.

It is important to mention that the specific literature studied, **does not present** any relations (both experimentally or analytically determined) enabling the evaluation of cutting process temperature, for glass fiber polymeric composite materials.

It is assumed that cutting parameters, such as cutting speed, cutting feed and cutting depth, do have important influence on cutting temperature but, there are no specific interdependences presented.

So, based on the above mentioned, the *objective* of this paper is *to present the required steps carried on in order to obtain a mathematical model of the cutting zone, temperature, while milling*. This model is important as it enables the calculus of temperature's value, as function of cutting parameters' values.

2.Experimetal Program

The technological system, considered in machining glass fiber reinforced polymeric composite, is characterized [6,7] by variables connected through relations as:

$$Y = \Gamma\left(z_1, z_2, \ldots, z_j, \ldots, z_n\right) \tag{1}$$

called process function, where:

z_j , j = 1, 2, …., k represents the process independent variables (inputs);
Y – the process dependent variable (output);
Γ - the type of dependence relation.

In order to determine optimum Γ type, there must be established variation fields and values of each input, as well as the experiment design that fits best.

The z_j represent the real value of input, j, while the coded value (used in statistical modeling, for getting the mathematical model needed), x_j, is obtained with the following relationship:

$$x_j = \frac{z_j - \bar{z}}{\frac{z_{\max} - z_{\min}}{2}} \tag{2}$$

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

In order to do the researches, there were used plate samples, with dimensions of $200 \times 200 \times 10$ (mm), manufactured at S.C. TURINGIA S.R.L., a certificated company in composites manufacturing.

The glass fibers used were EC12-2400-P1800 type (made by another company. S.C. FIROS S.R.L.) and its content, into the studied samples varied from 20%, to 30% and up to 40%.

The composite's matrix was a polyester resin, AROPOLL S 599.

Both glass fibers, and the resin, as well as the glass fibers reinforced polymeric composite, were delivered with Conformity Certificates – as proof of their characteristics (physical, mechanical, electrical, etc.).

So, the variables considered in experiments were, as follows,

- z_j inputs (independent variables), meaning: cutting speed (v [m/min]), feed speed (v_f [mm/min]) and radial cutting depth (a_r [mm]);

- Y output (dependent variable), meaning temperature into the cutting zone (T [°C]).

The real and coded values of the inputs are presented in Table 1.

Table 1

Coded and real values of the controllable inputs, x_i

v [m/min] (x_1/A)			v_f [mm/min] (x_2/B)			a_r [mm] (x_3/C)		
(-1)	(0)	(1)	(-1)	(0)	(1)	(-1)	(0)	(1)
25.12	31.40	50.24	100	160	250	1	2	3

It is mentioned that the cutting tool is one, specially designed for machining fiber glass reinforce polymeric composites, whose diameter is 8 mm.

The experimental program considered was Full Factorial three level design (8 runs and 5 replicates) [8], whose structure is shown in Table 2.

Table 2

Experimental Program – Full Factorial Design

Run	x_1	x_2	x_3
1.	-1	-1	-1
2.	-1	-1	+1
3.	-1	+1	-1
4.	-1	+1	+1
5.	+1	-1	-1
6.	+1	-1	+1
7.	+1	+1	-1
8.	+1	+1	+1

The regression function determined with DOE KISS is of the polynomial type:

$$Y = a_0 + a_1 z_1 + a_2 z_2 + a_3 z_3 + a_{12} z_1 z_2 + a_{13} z_1 z_3 + a_{23} z_2 z_3 + a_{123} z_1 z_2 z_3 \qquad (3)$$

Obs.:

It is mentioned that if the value of a certain parameter in the regression analysis [P (2 Tail)] is higher than 0.05, than the corresponding variable is not considered to have significant influence on the output variable.

3. Experiments and Statistical Modeling

In order to carry out experiments, under the above mentioned conditions the machining procedure studied was the cylindrical milling one.

An image of the technological system, while experimenting, is presented in Fig. 1 (a. and b.).

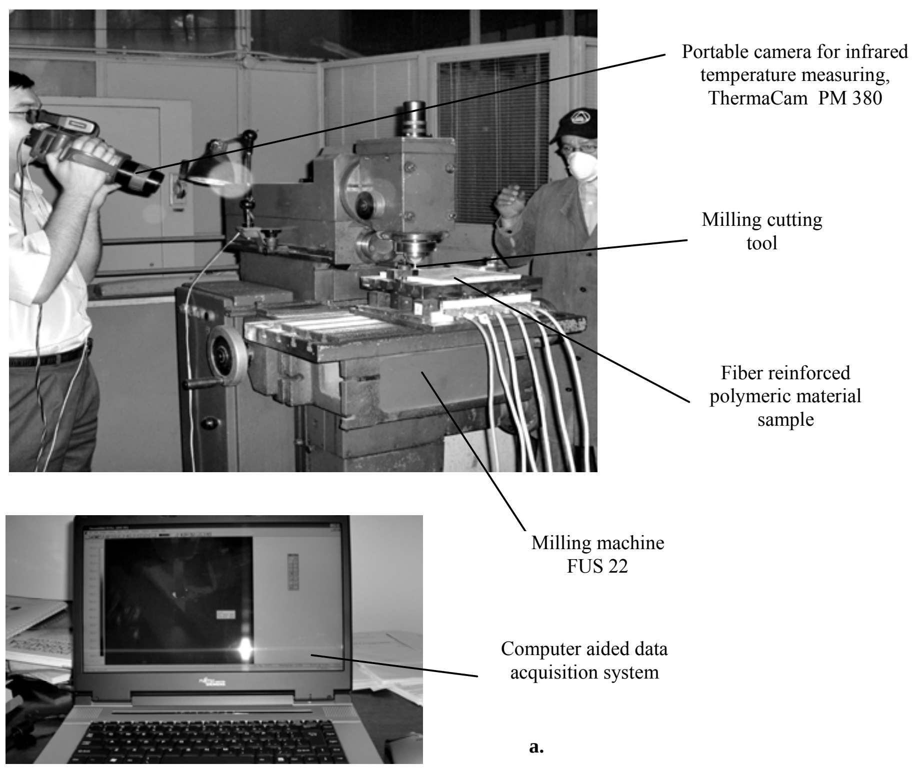


Fig. 1. Technological system in cylindrical milling

b.

Fig. 1. Technological system in cylindrical milling

According to the experiment design considered, the milling process was monitored and images of the temperature into the cutting zone, were captured. An example is shown by Fig. 2, where one can notice the significant temperature variance along the milling cutting tool.

Fig. 2. Temperature variance into the cutting zone

An example of the temperature curve, as well as its maximum value, while the cutting process, is presented in Fig. 3.

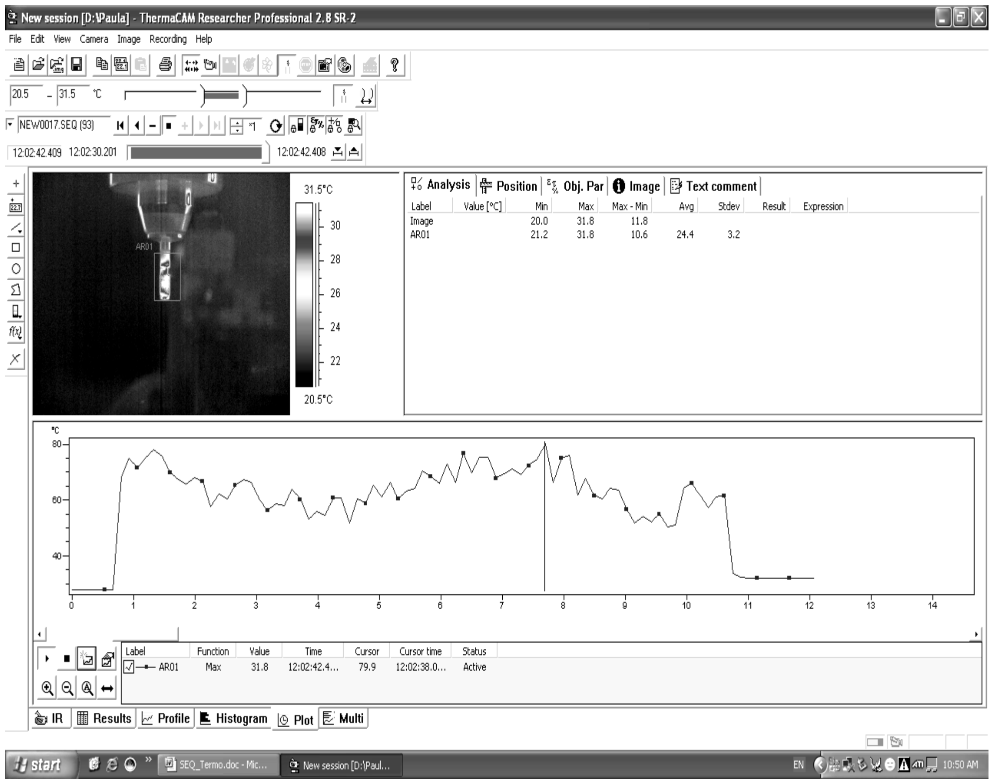


Fig. 3. Temperature curve for the cutting zone

As mentioned above, each of the eight runs consists in five replicates, whose arithmetic average represents the medium value.

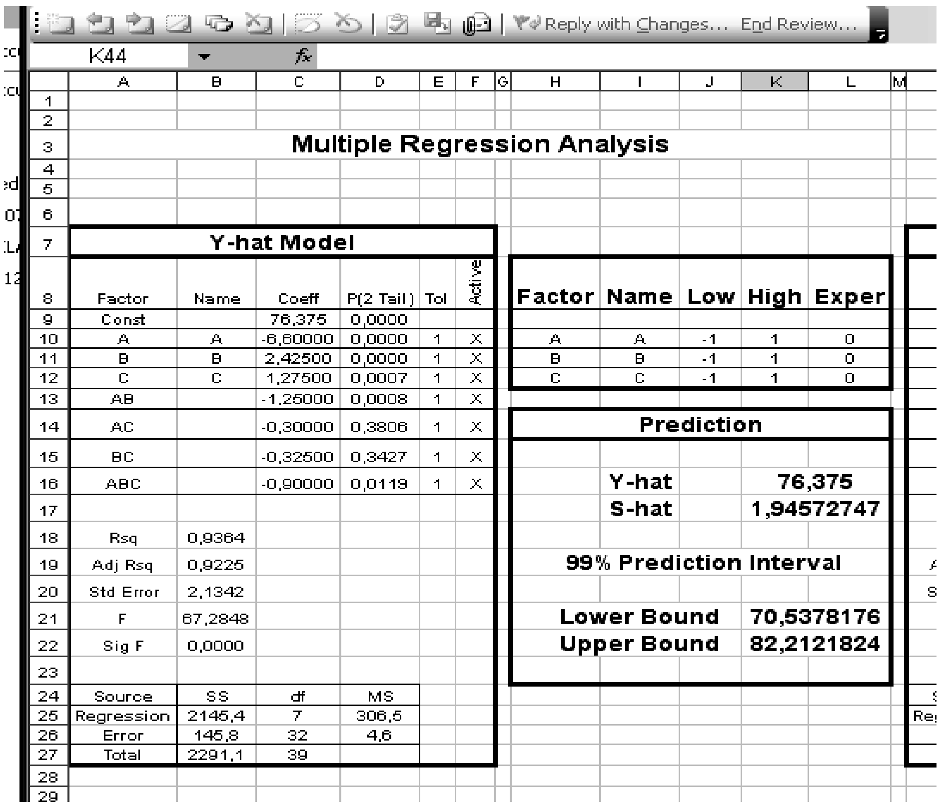
The medium values (y-hat) of the cutting zone temperature, T [°C], experimentally measured are presented in Table 3.

Table 3

Experimental data – cutting tool temperature, T [°C]

Designed experiment	Run							
Full Factorial Design	1	2	3	4	5	6	7	8
	78.30	80.30	81.50	88.80	66.40	70.80	70.70	70.70

The analysis' results, using *DOE KISS software*, are presented in Fig. 4.



Y-hat Model

Factor	Name	Coeff	P(2 Tail)	Tol	Active
Const		76,375	0,0000		
A	A	-6,60000	0,0000	1	X
B	B	2,42500	0,0000	1	X
C	C	1,27500	0,0007	1	X
AB		-1,25000	0,0008	1	X
AC		-0,30000	0,3806	1	X
BC		-0,32500	0,3427	1	X
ABC		-0,90000	0,0119	1	X

Rsq	0,9364
Adj Rsq	0,9225
Std Error	2,1342
F	67,2848
Sig F	0,0000

Source	SS	df	MS
Regression	2145,4	7	306,5
Error	145,8	32	4,6
Total	2291,1	39	

Factor	Name	Low	High	Exper
A	A	-1	1	0
B	B	-1	1	0
C	C	-1	1	0

Prediction

Y-hat	76,375
S-hat	1,94572747
99% Prediction Interval	
Lower Bound	70,5378176
Upper Bound	82,2121824

Fig. 4. DOE KISS software – regression results

Thus, the mathematical model for cutting zone temperature is:

$$T = 76.375 - 6.600 \cdot v + 2.425 \cdot v_f + 1.275 \cdot a_r - 1.250 \cdot vv_f - 0.900 \cdot vv_f a_r \quad (4)$$

The DOE KISS also provides the *Pareto Chart of Coefficients* – see Fig. 5. This chart points out how much the influence of each input (as well as its interactions) on the output is.

Also, the DOE KISS has an *Expert Optimizer*, which enables to set the input variables' values as to get optimum output variable's value. The results, thus obtained, are shown in Fig. 6.

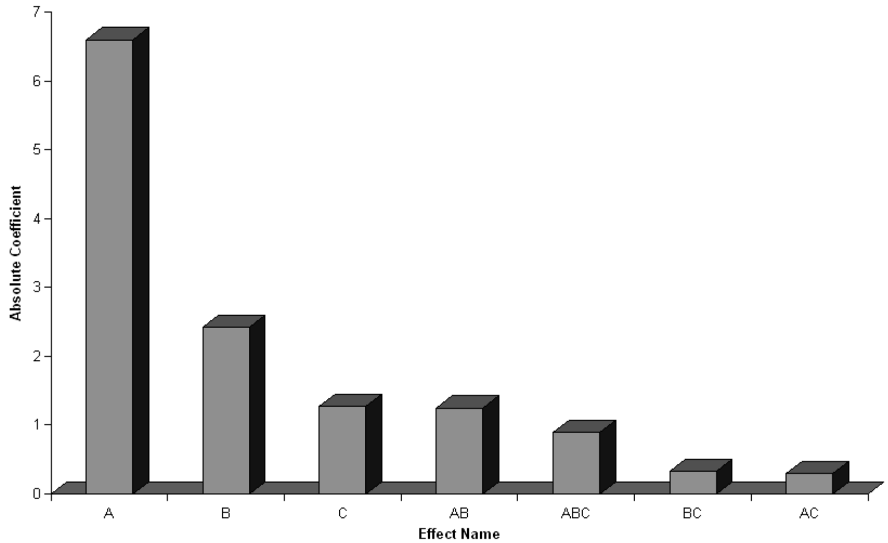


Fig. 5. Pareto Chart of Coefficients

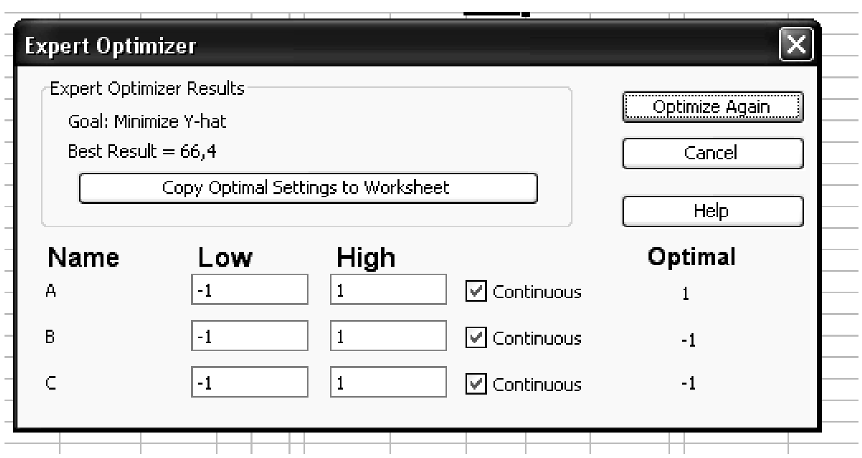


Fig. 6. Expert Optimizer

4. Discussion of Obtained Results

All the obtained results proved good concordance with the theoretical aspects presented by specific literature.

So, it has been shown, by Fig. 2 and Fig. 3 that the heat generated in the cutting process is dissipated through the parts of the technological system involved, meaning: chips, cutting tool and machined part.

The infrared thermograph method used for measuring the temperature of the cutting zone was adequate and useful as, it allowed the exact determination and plot, if required, of the temperature at different specified time moments.

The regression analysis, pointed out that the most important factor in influencing cutting zone's temperature is the cutting speed. Also, it showed that the lower the speed, the higher the temperature.

The other machining parameters studied, such as feed speed and radial cutting depth, have lower influence on the cutting zone temperature but, the higher their values are, the higher the temperature's value is.

The software used in regression analysis allows, the setup of input variables' values as to get the optimum output variable's value (cutting zone temperature).

5. Conclusion

In milling glass fiber reinforced polymeric composites, the cutting zone temperature, while the process, is important to be determined.

The regression analysis, performed by DOE KISS software, proved that the proposed model was adequate. It also showed the effect of independent variables considered – cutting speed (v), cutting feed (v_f) and radial cutting depth (a_r) - as well as its interactions, on temperature.

The obtained model can be used to determine optimum values for machining parameters so as to maintain within specific limit (above vitrifying temperature) the cutting zone temperature.

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