Modelling and Controlling of Machining Forces when Milling Polymeric Composites

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Polymeric matrix composite materials are used when high characteristics are needed, good resistance under severe working conditions and low specific weight. Implementing polymeric matrix composite materials, specially, glass reinforced ones, resulted in the substituting of classical materials, whose quantities are more, and more, limited. Composite material products can be obtained to their final shape when manufacturing or, when necessary, can be submitted to further machining processes. Polymeric matrix composite materials can be conventionally machined (cutting, turning, drilling, milling or broaching) or / and non-conventionally machined (laser, ultrasound, etc.). Researches on milling machinability of glass fibers reinforced polymeric composites are at their very beginning, in our country, this paper pointing out some important aspects of research on cutting forces in cylindrical-face milling. There is also presented a data measuring, acquisition and processing system for the experimental model, as well as a real time control scheme designed to determine the measuring errors.

Keywords: polymeric matrix, glass fibers, milling, cutting forces, automation system

Specific literature presents many definitions of the composite material [10], [11] a synthesis of these being that composites are artificial materials made of two, or more, different non-mixing materials. Various constituent elements can be added to so that composite properties should be improved. The two basic consituent materials are called „matrix" and „reinforcing element".

Matrix is the basic component of a composite material and can be made of: metals, polymers, ceramics. Most of the times, the matrix' rigidity and mechanical resistance are lower than the ones of reinforcing material contained [7, 3].

Reinforcing elements are chosen according to composite material characteristics needed [1, 8] and can be made of: metals, ceramics, polymers, glass, carbides, carbon, aramides (kevlar). In composite materials industry, the highest rate (90%) is that of glass fibers [12].

One of the decisive aspects when manufacturing a composite material is represented by the interface bonds' nature and quality of the reinforcing elements to the matrix [5, 8].

Polymeric matrix composite materials *are used* when high mechanical performances, high resistance under severe working conditions and low specific wieght are required. So, composite materials products can be „discovered" in: navy, automotive and aircrafts industries, tele-communcations, medeicne, sport equipments, etc.

Composite products can be manufactured to their final shape, using „near net shape" technologies or, by further machining, specially, on their edges – that can not be directly obtained according to the technical prescribed conditions, when manufacturing involves specific procedures as: hand made manufacturing by succesivelt layered deposition or, mould transfer resin, etc. [2].

Polymeric matrix materials can be machined by conventional cutting procedures (turning, drilling, milling, broaching) and/or by non-conventional procedures (laser, ultrasounds, etc.).

In figure 1 there is presented a glass fibers random reinforced composite product (made by SC ROMTURINGIA SRL) before, and after, edge cutting by milling procedure.

with hip -after manufacturing

without hip -after milling

Fig.1 Products made by SCROMTURINGIA SRL

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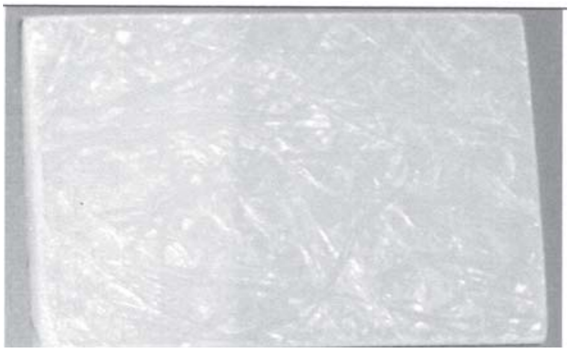

Fig. 2. Glass fibers reinforced polymeric materials sample

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Fig. 3 Cutting tool

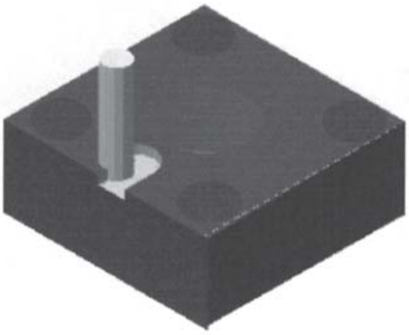

Fig. 4 Milling simulation by IsyCAM

Composite materials machinability is considered to be: good, medium, difficult and very difficult [9].

Specific literature presents general informations on polymeric matrix composite material machinability,. So, detailed researches on polymeric composites machinability involved aspects should be done.

Experimental part

The studied materials are composites whose matrix is a polymeric resin, AROPOL S 599, and the reinforcing element is representd by random oriented glass fibers, EC 12-2400 of about 30% percentage.

The samples were manufactured at SC ROMTURINGIA SRL, plate shaped, with dimensions of 200 x 200 x 10 mm (this company is certified in polymeric composites manufacturing) and accompanied by Conformity Certificate (fig. 2).

The cutting tool was a special one – for milling glass fibers reinforced polymeric matrix composite materials, its material being wolfram carbide with cobalt binder and recommended by SGS TOOLS company catalogue. A picture of the cutting tool can be noticed in figure 3, while simulation of the cylindrical-face milling process on CNC Isel-automation machining system [13] is shown in figure 4.

The stand used for researches on cutting forces consists in:

- FUS 22 miling machine-tool;
- dynamometric system with 6 resistive transducers, positioned along directions of the studied force components, and connected in a complete Wheastone electronic bridge;
- 6 channels tension bridge;
- data acquisition computer aided system, with DAQPad-6020E type data acquisition component..

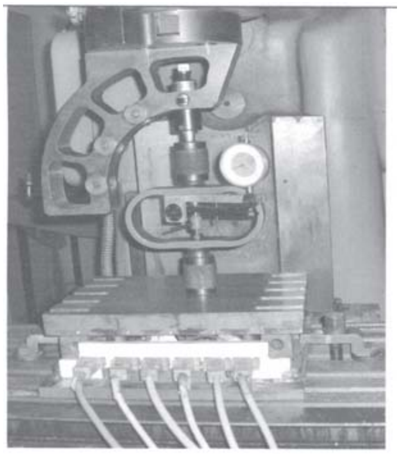

Fig. 5 Calibrating the dynamometric device

For each of the transducers, it is considered *Ci* (i = 1 ... 6), to be the deformation value read on each of the 6 channels tension bridge.

Measuring domain of the dynamometric device [15] is up to 200 [daN]. Calibrating this device was done with an etalon dynamometer, oval shape, M9723 series, whose maximum compression load is 10 kN and with a comparator instrument of 0.01 mm precision (fig. 5).

As result of specific calculi, there were obtained the device calibrating equation for each of the milling force components, as:

$$F_x = 0{,}0121422 \cdot (C_1 + C_2 + C_3) + 0{,}3200064 \cdot (C_4 + C_5) + 1{,}2371117 \cdot C_6;$$
$$F_y = 0{,}2152018 \cdot (C_1 + C_2 + C_3) - 1{,}870736 \cdot (C_4 + C_5) - 0{,}350344 \cdot C_6;$$
$$F_z = 0{,}4945444 \cdot (C_1 + C_2 + C_3) + 0{,}5800217 \cdot (C_4 + C_5) + 0{,}046008 \cdot C_6. \quad (1)$$

Images taken while the machining process was on can be seen in figure 6, while the architecture of data measuring, acqusition and processing system is shown in figure 7. It should be noticed that it is based on similar measuring and control systems mentioned by specific literature [16,17].

So, the signals due to δ_i deformations of the ressistive gauges, connected to the measuring bridges channels, PM_i (i = 6 according to measuring channel number) are amplified and scaled in order to correct reading error, by A_i amplifiers. So, there are obtained, $C_i(\delta_i)$ signals, within the measuring field of the numerical-analogue converter (quantizer) CAN. By multiplexor Mx there is ensured a cvasi-simultaneous conversion on 12 bits of the signals tranmitted by the 6 transducers, which are converted into numerical signals by CAN module and processed by Lab_View system so as to generate a data base of forces $F_{x,y,z}$ $C_i(\delta_i)$. There were used methods of processing experimental phisical data that lead to a significant noise reduction and an increasing of measuring precision [18, 19].

The regression analysis has been done using a performant PC system, with mathematic processor and high capacity data storage unit, where the input data are introduced as table, off-line. A specialized software, REGS [14] was used, as a PC system task and thus, fast statistical processing of the experimental data could be performed, the obtained parameters dealing with adecquacy coefficient, R*, significance coefficients R_i; coded model coefficients b_i; natural model coefficients a_i; confidence intervals for 95%. significance level, etc.

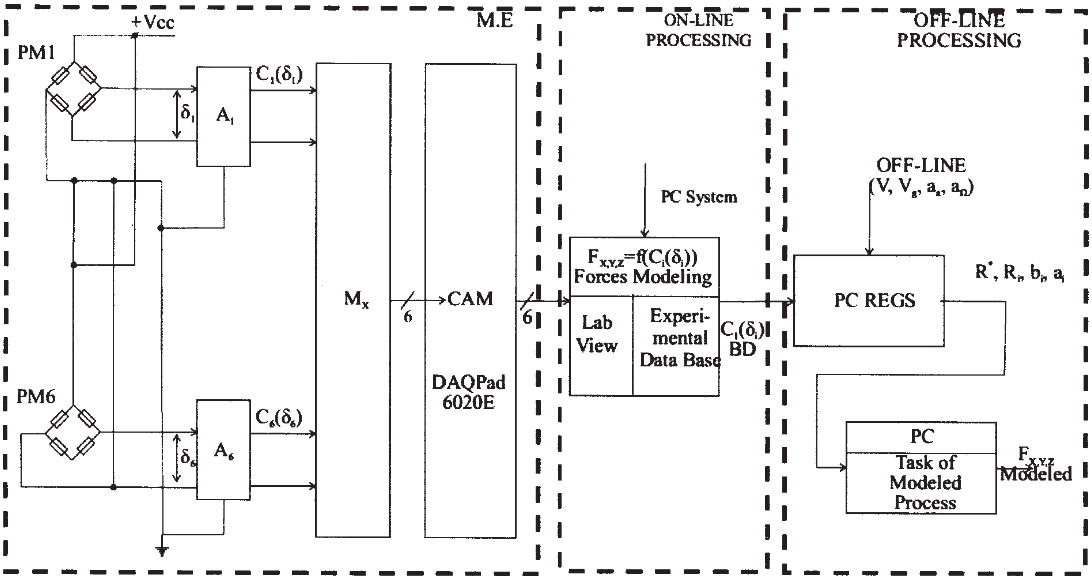

Fig. 6 Architecture of data measuring, acqusition and processing system

Table 1
VALUES – NATURAL AND CODED – INDEPENDENT VARIABLES

Natural variable	Coded variable	Value		
		-1	0	1
v [m/min]	x_1	18.84	37.69	75.39
v_f [mm/min]	x_2	100	160	250
a_a [mm]	x_3	1	2	4
a_r [mm]	x_4	3	6	12

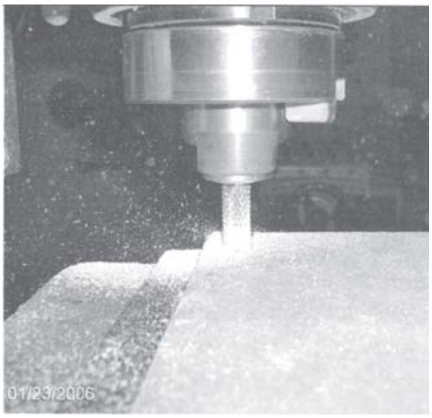

Fig.7. Cylindrical-face milling

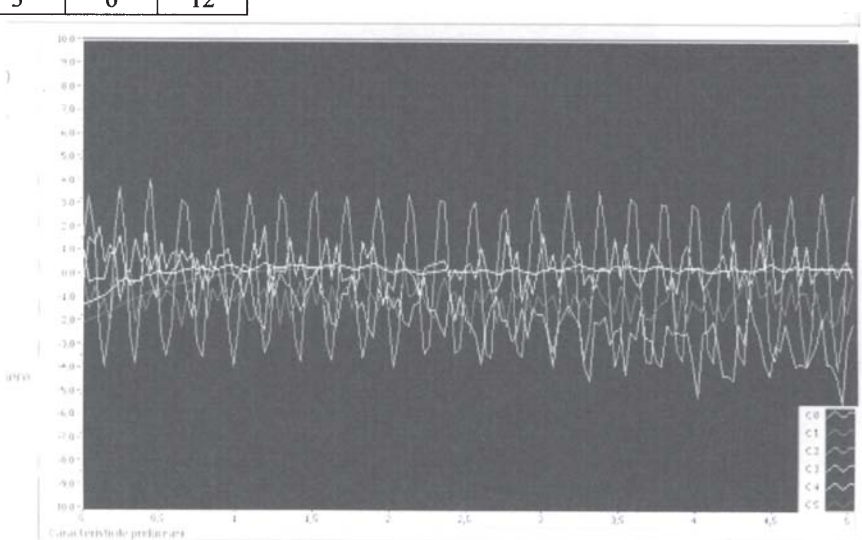

Fig. 8 Cutting force components – image taken while milling

The result of all above mentioned is represented by new regression models of cutting force components, when cylindrical-face milling a polymeric composite material, random glass fiber reinforced.

Result and discussions

Cutting force is evaluated by its three components, meaning:

- F_x – radial cutting force's component;
- F_y - tangential cutting force's component;
- F_z - axial cutting force's component

In cutting forces' study, meaning determining interactions of forces and specific milling process parameters – cylindrical face milling – there is considered [6] a dependence relation as:

$$F = f(v, v_f, a_a, a_r) \quad [\text{daN}] \tag{2}$$

where, the independent variables studied are:

v – cutting speed [m/min];
v_f – cutting feed speed [mm/min];
a_a – axial cutting depth;
a_r – radial cutting depth [mm]

Natural and coded values of the above mentioned variables are presented in table 1.

An example of how each cutting force components is measured can be seen in figure 8, the data acquisition system being LabVIEW.

Experimental results and regression analysis results – for F_y component of the cutting force are presented in table 2 and, respectively, table 3.

So, the resulting regression models of each cutting force components are:

$$Fx = A_0 \times v^{a1} \times v_f^{\,a2} \times a_a^{a3} \times a_r^{a4} = 15.54904 \times v^{-0.028} \times v_f^{\,0.030} \times a_a^{0.052} \times a_r^{0.053}$$

$$Fy = A_0 \times v^{a1} \times v_f^{\,a2} \times a_a^{a3} \times a_r^{a4} = 16.13513 \times v^{-0..020} \times v_f^{\,0.055} \times a_a^{0.085} \times a_r^{0.084}$$

$$Fz = A_0 \times v^{a1} \times v_f^{\,a2} \times a_a^{a3} \times a_r^{a4} = 13.43683 \times v^{-0.020} \times v_f^{\,0.035} \times a_a^{0.038} \times a_r^{0.037} \tag{3}$$

Table 2
EXPERIMENTAL RESULTS

Cutting force's components							
Exp. no.	Fractional factorial program P2.1				F_x [daN]	F_y [daN]	Fz [daN]
1.	-1	-1	-1	-1	17.512	21.235	15.614
2.	+1	-1	-1	+1	18.003	23.452	16.011
3.	-1	+1	-1	+1	19.168	25.521	16.896
4.	+1	+1	-1	-1	17.109	21.843	15.508
5.	-1	-1	+1	+1	20.013	27.006	17.149
6.	+1	-1	+1	-1	17.901	23.658	15.943
7..	-1	+1	+1	-1	19.216	25.421	17.015
8.	+1	+1	+1	+1	19.994	27.437	17.421
9.	0	0	0	0	18.652	24.667	16.002
10.	0	0	0	0	18.957	24.791	16.851
11.	0	0	0	0	18.432	24.009	16.168
12.	0	0	0	0	18.301	24.136	16.194

Table 3
REGRESSION ANALYSIS RESULTS - FOR F_x COMPONENT

REGRESSION ANALYSIS RESULTS

Orthogonal program
Model adequacy = 0.162
R* = 0.015< 1 ==> Adequate model

Coefficients significance

R 0 = 75400.15 > 1 ==> Significant variable
R 1 = 2.29 > 1 ==> Significant variable
R 2 = 1.10 > 1 ==> Significant variable
R 3 = 7.53 > 1 ==> Significant variable
R 4 = 7.87 > 1 ==> Significant variable

B coefficients		A coefficients	
b 0 =	2.922	a 0 =	2.744
b 1 =	-0.020	a 1 =	-0.028
b 2 =	0.014	a 2 =	0.030
b 3 =	0.036	a 3 =	0.052
b 4 =	0.037	a 4 =	0.053

Exp.. no.	Y VALUES MEASURED	COMPUTED	ERRORS ABS.	REL.	CONFIDENCE INTERVALS Lower limit	Upper limit
1	17.512	17.393	0.12	0.68	15.842	19.095
2	18.003	17.988	0.01	0.08	16.384	19.749
3	19.168	19.231	-0.06	-0.33	17.516	21.113
4	17.109	17.183	-0.07	-0.43	15.651	18.865
5	20.013	20.100	-0.09	-0.43	18.308	22.067
6	17.901	17.960	-0.06	-0.33	16.358	19.718
7	19.216	19.200	0.02	0.08	17.488	21.080
8	19.994	19.858	0.14	0.68	18.087	21.802
9	18.652	18.584	0.07	0.36	17.940	19.252
10	18.957	18.584	0.37	1.97	17.940	19.252
11	18.432	18.584	-0.15	-0.83	17.940	19.252
12	18.301	18.584	-0.28	-1.55	17.940	19.252

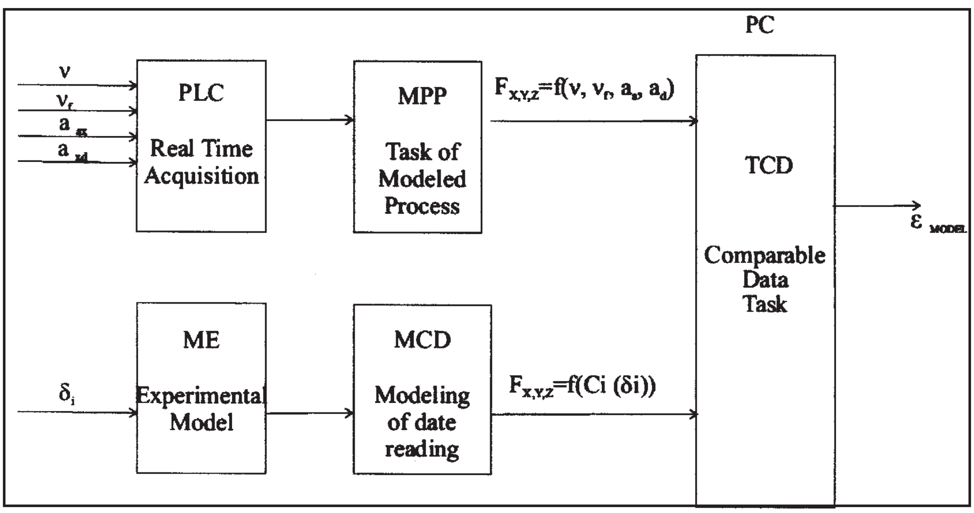

Fig. 9. Measuring error real time control scheme

Automation

In order to validate the results, there has been conceived a measuring error real time control scheme – see figure 9, thus being possible to compare experimental values with the ones generated by regression models determined.

One measuring channel is assigned to the classic method, where deformations generated by machining forces are measured, through the experimental module, ME (shown in fig. 6) and, then, these forces are determined, by correction of the deformation values received from the measuring bridge, through the reading-modelling module, MCD. So, it is possible to real time generate the values of machining forces as $F_{x,y,z} C_i(\delta_i)$.

A second channel has been used for signals' acquisition – specific parameters of the milling process (v, v_f, a_a, a_r) - from a PLC system (Programmable Logical Controller) at high sampling rate and processing speed, by rejecting noise signals, the measuring precision being, at least, 11 bits. These signals are numerically processed, according to regression models obtained – see equations (3) – through a machining process modelling module, MPP and, so, machining force's values are real time generated as function of the milling process parameters values $F_{x,y,z}(v, v_f, a_a, a_r)$ (fig. 9).

By comparing the two channels generated signals, through a data comparing task, TCD, of the PC, there have been obtained the modelling errors generated by article's proposed study .

The measuring errors values less than 1%, obtained by real time data acqusition point out the fact that both experimental results as well as regression models obtained results are correlated. This suggests that there are real possibilities of implementing the described method in order to determine machining force values when milling process is involved.

Conclusion

Composite materials products are used when special characteristics are involved and they can be manufactured to their final shape or, can be further submitted to various machining procedures – cylindrical-face milling being often required.

Specific literature presents general guiding information on polymeric matrix composite materials machinability so that detailed research on aspects involved by these materials type machinability is nedeed.

This paper points out some research results on glass fibers reinforced polymeric matrix materials' machinability – the aspect involved being that of determinig cutting force components while cylindrical-face milling. The importance of this study is that it allows both experimentally and theoretical evaluation of each cutting force's component. Good correlation of exeprimental and regression model results has to be evidenced

The obtained results point out the fact that, once cutting speed value increases, the cutting force components values decreases. Also, there can be noticed that cutting depth values (axial and radial) have a stronger influence on forces values than cutting feed speed values do. All of these variables do directly influence milling force componnets values.

Unlike metals, when milling polymeric matrix composite materials, cutting force's values are much lower, so that, there can be stated that their values do not restrictively limit the machining process

Further research development could involve cutting tool durability (life time) and / or resulting surface quality when milling random glass fibers reinforced polymeric matrix composite materials, etc.. Also, method development could be done in order to validate analytical models in various machining processes type.

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