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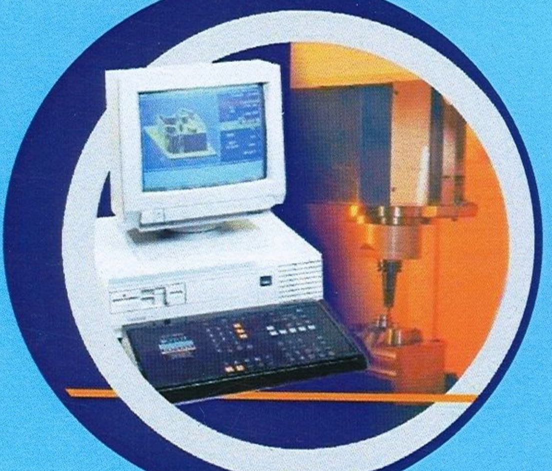

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DISTRIBUTED CONTROL SYSTEM FOR MACHINING PROCESS OPTIMIZATION IN DRILLING MINERAL COMPOSITES REINFORCED BY 3% GLASS FIBERS

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Abstract: *Development of mineral composites has been continuous while the last decades, due to their impressive characteristics and, therefore, application to various constructions, such as bridges, buildings, pavements, etc. This article is aimed at evidencing aspects of the drilling process of mineral composites reinforced by 3% glass fibers. The focus is on drilling experiments for determination of regression models of force and moment, as well as on the decentralized and distributed control system for monitoring force and moment values.*

Keywords: *mineral composite, glass fiber, regression model, control system, decentralized.*

1.Introduction

The high impact of products made of mineral composites is, mainly, in construction industry where glass fiber reinforced mineral composite materials have successfully been used in bridge building or civil building (see Fig. 1) due to their key features [3] that are: environmentally friendly; products reduce loadings on buildings leading to significant savings in superstructures and foundations; excellent for reproduction and renovation.

FiberlineBridge, using the pultruded profiles [1]

Wall panel of glass fiber reinforced mineral matrix[2]

Figure 1: *Application of glass fiber reinforced mineral composites*

Reinforcing elements of mineral composites can improve the mechanical characteristics of these materials from the point of view of tensile strength, hardness, rigidity, dimensional stability, etc.

Still, high attention should be given to the nature, type and orientation of the reinforcing element as, if not appropriate, it can induce significant increase in material fragility, brittleness and viscosity. Also, high expenses in production are also possible.

Strictly from the economical point of view, based on the above mentioned aspects, there has been estimated and, not the least, noticed the requirement for optimizing the machining processes of glass fiber reinforced mineral composites. The machining process optimization in drilling mineral composites apply the virtual projection method, known as Vladareanu-Munteanu method [4, 5, 6], in order to develop real-time control system. It is based on statistical methods for experimenting and data processing, as well as on decentralized and distributed control system for monitoring force's values by optimization of process parameters.

As many of the mineral composites reinforced by glass fibers panels have to be fixed on / by other products, many times it is necessary to have holes in this panels. This is why the drilling process has been studied and evidenced by this article. The mineral composite studied is 3% glass fiber reinforced.

2.Research Method

The method used for this research is based on statistics, more specifically, design of experiments and regression analysis [7]. This required the identification and set-up of drilling process variables as follows next.

2.1 Independent variables (inputs)

a. Material studied – it is mineral composite material reinforce by 3% glass fibers (E-glass). The concrete is B250 HOLCIM [8]. The samples were prepared manually (see Fig. 2).

Figure 2: *Sample preparation*

b. Machining procedure and equipment

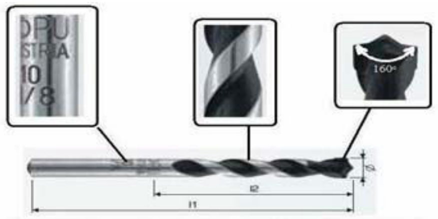
As previously stated, the focus of this study is on drilling of mineral composites glass fiber reinforced materials.

Consequently, the equipment does fit all conditions required for drilling process (see Fig. 3). So, the machine-tool is a vertical CNC machining center, FIRST MCV 300.

The drilling tools used are special designed for this type of materials. In fact, they are DIN 8039 ISO 5468, high-speed SDS, covered with tungsten type YG8 (equivalent K20). producer ALPEN/MAZKESTAG. One important geometric characteristic is the peak angle value, of 160°.

In order to measure process outputs values, it was used a Kistler dynamometric structure, type-9257B, triaxial quartz force sensor. All components of the drilling force and moment can be measured by this structure, still the highest and most important values are that of the axial components.

FIRST MCV 300 [9] Kistler 9257B [10]



ALPEN/MAZKESTAG drilling tool [11]

Figure 3: *Equipment components*

c. Process parameters

According to ALPEN/MAZKESTAG tool manufacturer, the recommended values for drilling glass reinforced mineral composites are: tool rotation of 200 ÷ 2,000 rev/min and cutting feed of 0.02 ÷ 0.2 mm/rev.

The common diameter of drilled holes is in the range of 5÷12 mm.

There is no special need for cooling fluid.

2.2 Dependent variable (output)

For this study, there is only one dependent variable considered, that is the axial component of the drilling force, F_z and moment, M_z. In fact, the relationships of the studied dependent and independent variables, are expressed by Eqs. (1) and (2)

$$F_z = f\,(D, f, v_c)\ [\mathrm{N}]. \tag{1}$$

$$M_z = f\,(D, f, v_c)\ [\mathrm{Nm}]. \tag{2}$$

where:

F_z is the axial component of force, in N;

M_z is the component of moment about vertical axis, OZ, in Nm

D – tool diameter, in mm;
f - feed rate, in mm/rev;
v_c–cutting / drilling speed, in m/min(it is correlated with tool rotation, n, by the well known relation: $v_c = \pi n D / 1000$).

The research method is based on statistical designed experiments and computer aided data processing for regression (DOE PRO XL software).

3. Experiments and results

Based on previous knowledge [12] and the research method mentioned, it was considered fit an experiment design with three independent natural variables, each of two levels of variation (minimum / maximum), So, the input variables and their values are presented in Table 1.

Table 1: *Independent variables values*

Variable		Values	
Real	Coded	-1	1
D [mm]	x_1	5.00	12.00
f [mm/rot]	x_2	0.08	0.16
v_c, [m/min]	x_3	9.42	30.16

It was used a central composite, CCD, with 8 runs, CCD. Each experience was identically repeated five times and for regression analysis it was considered the arithmetic mean of each of the five values [13].

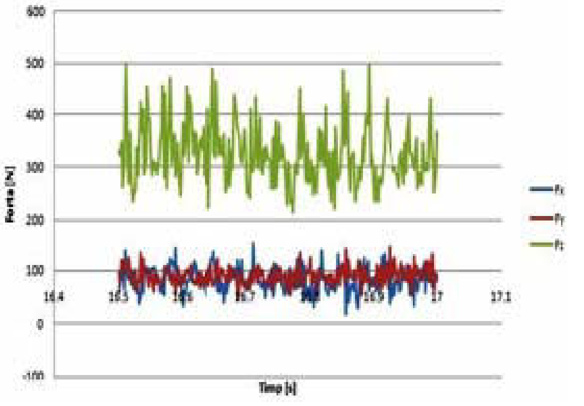


Figure 4: *Drilling force's components values*

Variation of each of the three components of the drilling force (F_x, F_y and F_z), while experimenting is evidenced in Fig. 4. One can notice the fact that the axial component, F_z, is the one with higher and relevant values.

Experiments were run and the obtained data are presented in Table 2. As previously mentioned, it was possible to have the acquisition of drilling force and moment values due to the Kistler structure.

Table 2: *Experimental results*

Exp. no	Inputs (X) coded values			Outputs (Y) real values	
	x_1	x_2	x_3	F_z [N]	M_z [Nmm]
1	-1	-1	-1	163.45	0.30
2	-1	-1	1	137.39	0.26
3	-1	1	-1	182.80	0.34
4	-1	1	1	153.65	0.29
5	1	-1	-1	228.46	1.02
6	1	-1	1	192.02	0.86
7	1	1	-1	255.51	1.14
8	1	1	1	214.76	0.96

The DOE PRO XL software used for regression analysis generates polynomial models, generically expressed by Eq. (3).

$$Y= const+Ax_1+Bx_2+Cx_3+ABx_1x_2+ \\ +ACx_1x_3+BCx_2x_3+ABCx_1x_2x_3. \tag{3}$$

Once regression completed, there resulted the models for axial drilling force, F_z, and moment about vertical axis, M_z, for mineral composites 3% glass fiber reinforced These regression models are presented by Eqs. (4) and, respectively, (5).

$$F_z= 110.625+8.781D+185.720f- \\ -0.792v_c+14.739Df-0.063Dv_c- \\ -1.337fv_c-0.105Dfv_c \quad [\mathrm{N}] \tag{4}$$

$$M_z= -0.219+0.098D-0.198f+ \\ +0.023v_c+0.150Df- \\ -0.0007Dv_c-0.0017fv_c-0.0008Dfv_c \quad [\mathrm{Nm}] \tag{5}$$

Observation: The relationship of the coded variable, x_j, and natural variables, $z_j(D, f, v_c)$ is expressed by Eq. (6).

$$x_j = \left(z_j - \frac{z_{\min} + z_{\max}}{2} \right) / \frac{z_{\max} - z_{\min}}{2} \qquad (6)$$

where:

z_{min} is the minimum experimental value for real variable;

z_{max}- maximum experimental value for real variable

A relevant image of the influence of each of the studied independent variables on the output is that of 2D graph. For example, the drilling speed, v_c, was „set" to its minimum value and the variation graphs for each of the dependent variables studied, Fz and M_z, have been plotted (see Figs. 5 and, respectively, 6), as function of tool diameter value, D (the one with strongest influence on the output).

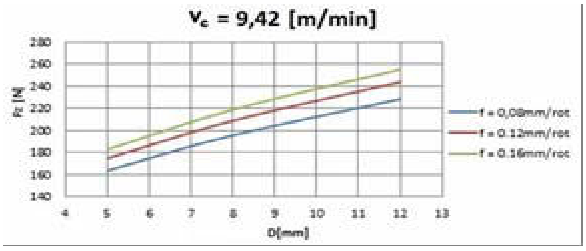


Figure 5: *Graph of F_z drilling force (dependence on tool diameter, D)*

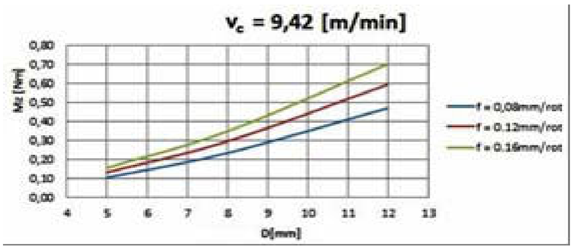


Figure 6: *Graph of M_z drilling moment (dependence on tool diameter, D)*

For another example, the diameter value, D, was „set" to minimum and the variation graphs of each of the dependent variables studied, Fz and M_z) have been plotted (see Figs. 7 and, respectively, 8).

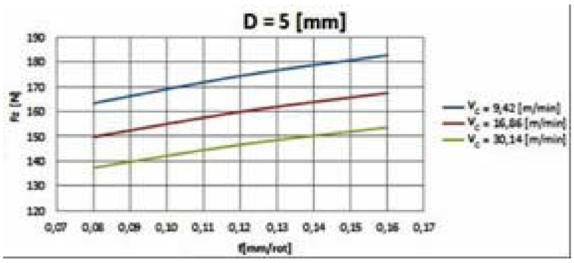


Figure 7: *Graph of F_z drilling force (dependence on cutting speed, f)*

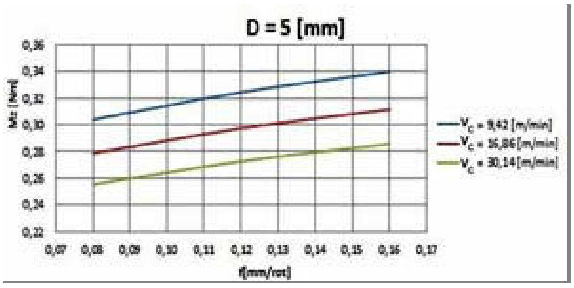


Figure 8: *Graph of M_z drilling moment (dependence on cutting speed, f)*

DOE PRO XL software enables to plot specific graphs as: marginal means plot and Pareto chart. The marginal means plot evidences how strong the influence of each independent variable on the studied output is. For the F_z component of the drilling force, this plot is evidenced in Fig.9.

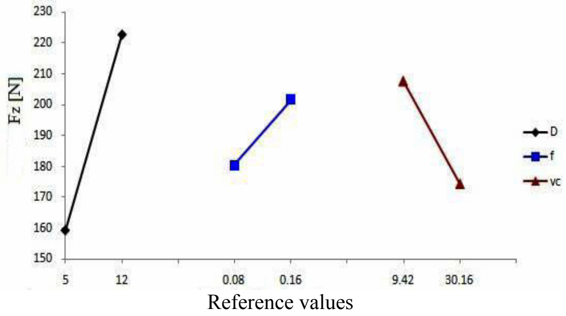


Figure 9: *Marginal means plot for F_z drilling force*

The Pareto chart of coefficients, proofs the influence of each independent variable (D, f and v_c), as well as of their interaction, on the output. The chart in Fig. 10 evidences this influence for, F_z component of drilling force.

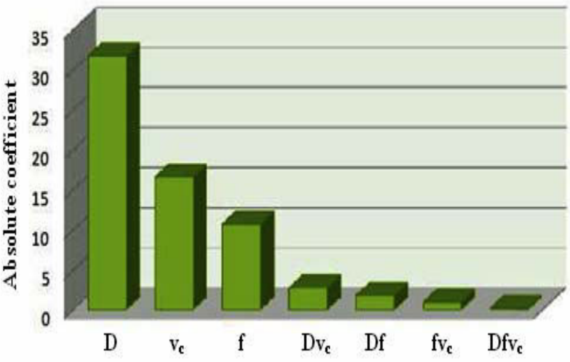


Figure 10: *Pareto chart of coefficients for F_z drilling force*

4. Work sequence control of the machining process

The distributed control system (Fig. 11), developed by applying the virtual projection method [4,5] is initially used for the machining process optimization phase, then for the work phase of drilling coordination and monitoring for the concrete samples placed on Kistler table by using the above described procedures and methodology. RTOS robotic controllers [14] with modified Mbus communication are used. The robotic controllers are monitored at the PC supervisor station level, where software configuring and monitoring application is running. The software application is developed in Visual Studio development environment and uses DMQX language extension function set (see Fig. 12).

For this configuration of the distributed control system, during the machining process parameters optimization phase, the robotic controllers acquire and transmit the read values for each drilling operation correlated with the dynamometric measuring platform noted Ki, where i=1..3.

As previously presented, each platform provides as analog signal the information regarding drilling force orthogonal components values: F_x, F_y, F_z.

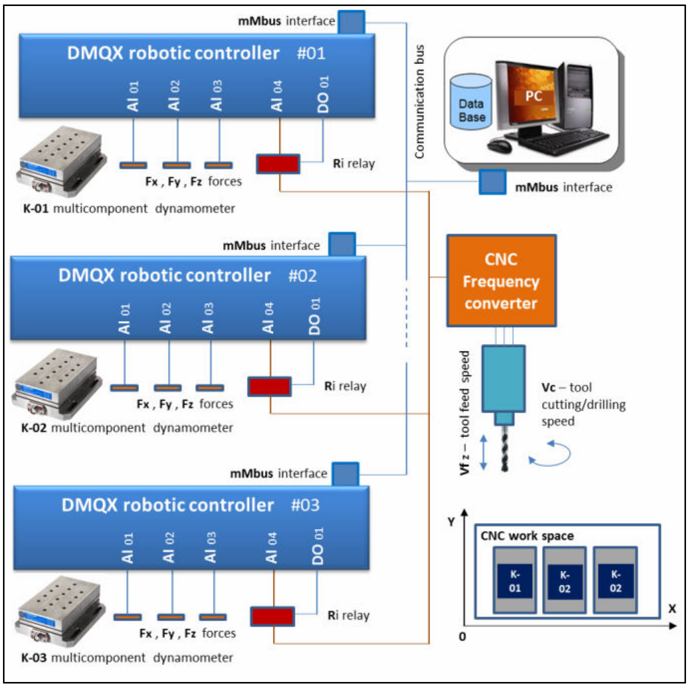
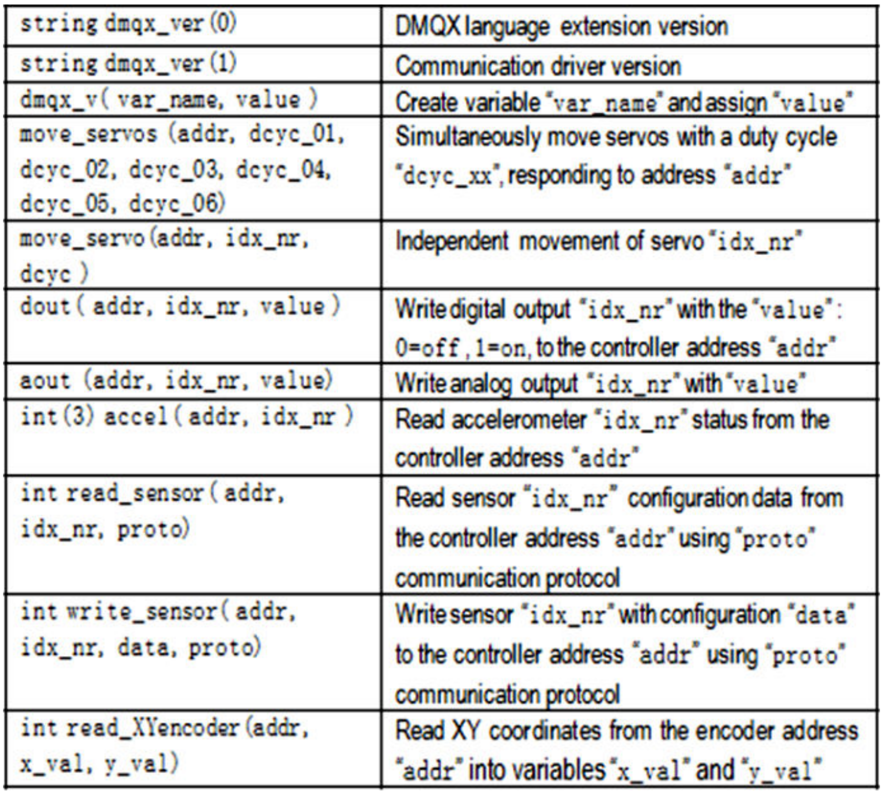


Figure 11: *Distributed control system of the machining process*

For each controller were used 3 analog inputs *AI-01…AI-03*, and for the reading of the tool cutting/drilling speed was used the *AI-04* analog input, selectively connected at the CNC frequency converter output through intermediary relays *Ri*. The switching of the relays is ensured by each controller's*DO-01* digital output. Three work sequences are configured for the machining process, and finally there are obtained three 200x100x30 mm rectangular samples.

From DMQX extension language function set (figure 12) were used the following : *dout(addr, idx_nr, value)* function for the *Ri* intermediary relays command, *read_sensor(addr, idx_nr, "mMbus")* function for reading of the drilling force orthogonal components values F_x, F_y, F_z and *aout(addr, idx_nr, value)* function for the CNC frequency converter parameterization. The controllers inside mMbus communication [15] are identified with addresses from 01 to 03.



string dmqx_ver(0)	DMQX language extension version
string dmqx_ver(1)	Communication driver version
dmqx_v(var_name, value)	Create variable "var_name" and assign "value"
move_servos (addr, dcyc_01, dcyc_02, dcyc_03, dcyc_04, dcyc_05, dcyc_06)	Simultaneously move servos with a duty cycle "dcyc_xx", responding to address "addr"
move_servo(addr, idx_nr, dcyc)	Independent movement of servo "idx_nr"
dout(addr, idx_nr, value)	Write digital output "idx_nr" with the "value": 0=off, 1=on, to the controller address "addr"
aout (addr, idx_nr, value)	Write analog output "idx_nr" with "value"
int(3) accel(addr, idx_nr)	Read accelerometer "idx_nr" status from the controller address "addr"
int read_sensor(addr, idx_nr, proto)	Read sensor "idx_nr" configuration data from the controller address "addr" using "proto" communication protocol
int write_sensor(addr, idx_nr, data, proto)	Write sensor "idx_nr" with configuration "data" to the controller address "addr" using "proto" communication protocol
int read_XYencoder(addr, x_val, y_val)	Read XY coordinates from the encoder address "addr" into variables "x_val" and "y_val"

Figure 12: *DMQX extension language function set*

For the concrete samples processing phase, optimized process parameters are used from previously write operation into the PC's database. For the openness of the system regarding future applications with a higher complexity level, a *relational* type database was used, which ensures the use of tables with links between data fields and also the interrogation through *query* type commands.

5. Conclusion

Products made of mineral composites have a high impact, mainly, in construction industry, such as bridges, building, pavements. As many times, there is the need of obtaining holes in these type of products, the drilling process has been studied and evidenced by this article.

The mineral composite studied is 3% glass fiber reinforced.

There have been obtained the force and moment regression models by means of statistic methods.

Some important aspects are mentioned below.

→ All the regression models are adequate.

→ All the independent variables studied do significantly influence the outputs values.

→ The drilling process parameters that mostly influence axial drilling force, F_z,values are the tool diameter, D, and cutting speed, v_c.

→ The drilling process parameters that mostly influence moment about vertical axis, OZ, M_z,values are the tool diameter, D, and feed rate, f.

→ The decentralized and distributed control system was designed for monitoring force and moment values by optimizing the drilling process parameters: D, f and v_c;

The results presented by this paper are worth to be applied in industrial drilling of products made of 3% glass fiber reinforced mineral composites.

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