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STUDY ON THE FORCES AT REAMING OF POLYMERIC COMPOSITE MATERIALS

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Abstract: *Bolting of composite materials reinforced with fiber glass is a key operation when it comes to assembly. For this, drilling and reaming holes in the materials is necessary. When drilling and reaming into such materials, many problems may appear, very high temperatures at the contact zone between the tool and the material, delaminating of the material, tool wear etc. The result of research on the variation of the cutting force when reaming are being presented in this paper; during the experiments, three types of composite materials reinforced with fiber glass were used.*

Key words: *composites, cutting, drilling, machining, forces.*

1. INTRODUCTION

The category of composite materials consists of a large array of products because of the ability to modify the base components, the “assembly” techniques.

Metal alloys present better properties than the composing elements; the same thing is for polymeric composite materials.

Polymeric composite materials present a real scientific and technical interest, which justifies the development of research in this field, as well as the increase in the production of such materials [1].

Because of this, polymeric composite materials have become indispensable for the development of some top fields like microelectronics, medical equipment, aerospace constructions.

Following this trend, there is the need to optimize the way these materials are machined, that is to determine, both in theory and in the lab, of a global indicator to define and hold all the factors that may influence the machining process. This paper tries to determine this indicator as complete as possible and to open new windows for research in this field.[2]

2. METHOD, MEANS AND CONDITIONS FOR THE REAMING WHEN DETERMINING THE FORCES

The devices used for the research on the methods of determining the machining indicators:

Drilling machine used:

Drilling machine GU 25
- Power of work: 2.3 KW;
- Gamma of rotations:
  28, 90, 355, 1120 rot/min;
  56, 180, 710, 2240 rot/min;
- Gamma of advances: 0.08; 0.125; 0.250 mm/rot.

Specifications drilling tools:

From the catalogs of companies that produce drills, the following have been chosen for laboratory experiments:

Drills: Φ6, Φ8, Φ10, Φ12, made by DORMER, (Germany), (Fig. 1)

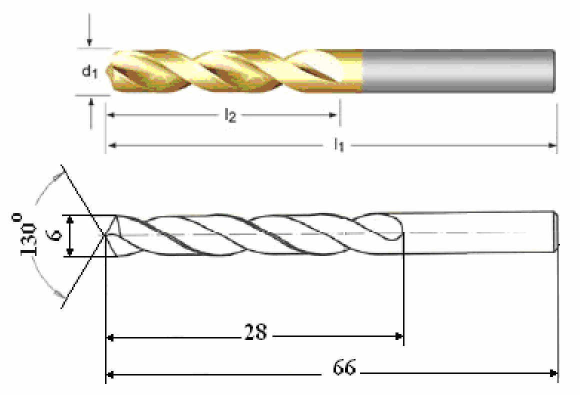

Fig. 1. Drill made by DORMER.

Material properties are the fallowing:

Materials of which the composite material is made of:

- *Reinforcement element*: glass fiber EC12-2400-P1800(65), produced by S.C.FIROS SA; (Romanian);

The product code of EC12-2400-P1800 (65), according with ISO 2078, is the following:

E - glass type;
C - continual process;
12 - diameter of the monofilament;
2400 - length density - finesse;
P1800 - FIROS cod;
(65) - length density - finesse;

- *Matrix*: polyester resin AROPOL S 599.

In order to measure axial cutting forces, we used force-measuring equipment, which was designed and implemented by the T.C.M Department of the I.M.S.T. Faculty, Bucharest

The computer system consisting of the following (Fig. 2):

- A transducer for measuring forces, made by the T.C.M. Desk, of the I.M.S.T Faculty. Bucharest;
- MGC amplifier, produced by Hottinger Baldwin Messtechnic;
- Data acquisition board type DAQ Pad 6020E;
- PC;
- Lab VIEW software.

Table 1

Experimental results Det. No.	Initial diameter, D_i, mm	Final diameter, D_f, mm	Deptf of splintering, *t*, mm	Feed rate *s*, mm/rot	Rotation *n*, rot/min	Drilling speeds *v*, m/min	Forces	
							V	*N* real
1	8	12	2	0,25	355	13,38	2,58	17,85
2	10	12	1	0,25	355	13,38	2,43	16,80
3	10	12	1	0,125	355	13,38	1,90	13,12
4	10	12	1	0,25	710	26,76	2,28	15,75
5	8	10	1	0,25	355	11,15	1,93	13,32
6	6	10	2	0,125	710	22,30	1,56	10,82
7	6	8	1	0,25	355	8,92	1,48	10,26

Fig. 2. The registration system.

In order to calibrate de force-measuring equipment, we used a lab dynamometer which bears a maximum loading of 10 kN compression read on a comparator with dial with the division value of 0.01 mm, serial 9723.

Having the experiment stand to measure the forces, the variation of these could be recorded, when different types of materials were being drilled (20%, 30% and 40% concentration of fiber glass) [3].

The real forces were obtained by multiplying the recorded values by the elasticity constant: $K_F = 6.9$ N/V.

It can be noticed that, by multiplying the values displayed by the computerized measuring system [V] with a measuring constant [NV], real forces are obtained [N].

3. EXPERIMENTAL RESULTS AND DATA PROCESSING

Technical literature [4, 5] provided equation (1), which has been the starting point in the analysis of cutting forces:

$$F = C_F \cdot t^{x_F} \cdot s^{y_F} \cdot D^{z_F} \text{ [N]}. \quad (1)$$

This equation has proved to be inappropriate since after the practical estimation of the polytrophic exponents and constants, several tests determinations has been performed and have showed a wide result scattering under the same cutting conditions.

During the machining at various speeds, different parameter values were recorded even if all the other machining conditions are kept constant. It was introduced a speed factor:

$$F = C_F \cdot t^{x_F} \cdot s^{y_F} \cdot D^{z_F} \cdot v^{w_F} \text{ [N]}. \quad (2)$$

In order to the C_F constant and the x_F, y_F, z_F, polytrophic exponents were estimated; the equation (2) has been linear zed by using the logarithm

$$\lg C_F + x_F \cdot \lg t + y_F \cdot \lg s + z_F \cdot \lg D + w_F \cdot \lg v = \lg F. \quad (3)$$

Table 1 shows a selection of the most conclusive machined.

In the data included in Table 1 are substituted in the equation (3), a linear inhomogeneous system of 5 equations with 5 unknowns (x_F, y_F, z_F, $\lg C_F$) is obtained:

$$\begin{cases} \mathbf{lg}\ C_F + x_F \cdot \mathbf{lg}\ 2 + y_F \cdot \mathbf{lg}\ 0{,}25 + z_F \cdot \mathbf{lg}\ 12 + w_F \cdot \mathbf{lg}\ 13.38 = \mathbf{lg}\ 17.85 \\ \mathbf{lg}\ C_F + x_F \cdot \mathbf{lg}\ 1 + y_F \cdot \mathbf{lg}\ 0{,}25 + z_F \cdot \mathbf{lg}\ 12 + w_F \cdot \mathbf{lg}\ 13.8 = \mathbf{lg}\ 16.80 \\ \mathbf{lg}\ C_F + x_F \cdot \mathbf{lg}\ 1 + y_F \cdot \mathbf{lg}\ 0{,}125 + z_F \cdot \mathbf{lg}\ 12 + w_F \cdot \mathbf{lg}\ 13.38 = \mathbf{lg}\ 13.12 \\ \mathbf{lg}\ C_F + x_F \cdot \mathbf{lg}\ 1 + y_F \cdot \mathbf{lg}\ 0{,}25 + z_F \cdot \mathbf{lg}\ 12 + w_F \cdot \mathbf{lg}\ 26.76 = \mathbf{lg}\ 15.75 \\ \mathbf{lg}\ C_F + x_F \cdot \mathbf{lg}\ 1 + y_F \cdot \mathbf{lg}\ 0{,}25 + z_F \cdot \mathbf{lg}\ 10 + w_F \cdot \mathbf{lg}\ 11.15 = \mathbf{lg}\ 13.32 \end{cases} \quad (4)$$

The system has the following solution:

$C_F = 1.518$; $x_F = 0.087$; $y_F = 0.356$;
$z_F = 1.263$, $w_F = -0.093$.

The axial cutting force formula for the reaming is obtained by inserting this solution in the equation (2):

$$F = 1.518\ t^{0,087} \cdot s^{0,356} \cdot D^{1,263} \cdot v^{-0,093}\ [\mathrm{N}]. \quad (5)$$

Experiments 6 and 7 were conducted to test the relation of regression (5). Calculation errors were lower than 2%.

3. ANALYSIS OF THE RESULTS

Figures 3 to 13 represent the variation of the cutting forces and their dependence to the parameters of the reaming of the polymeric composite material with 20% fiber glass.

Figure 3 shows the variation of the axial force as a function of feed rate *s*, where *v* = 13.38 m/min, *t* = 1 mm, for different drill diameters, *D*.

From the diagrams, one can notice that the cutting forces grow at an exponential rate if the diameter of the drill is increased or if the feet rate is increased, keeping *v*, *t* = const.

Figure 4 shows the variation of the axial force as a function of feed rate s, where *D* = 12 mm, *t* = 1 mm, for different drilling speeds of the tool.

By analyzing the diagram, it can be noticed that reaming forces grow at an exponential rate if the feed rate grows, the values of these forces being higher for lower reaming speed, with the depth and tool diameter being constant.

Figure 5 shows the variation of the axial force as a function of feed rate s, where *v*=13.38 m/min, *D* = 12 mm, for different depth of splintering.

Figure 6 shows the variation of the axial force as a function of drill diameter *D*, for different feed rates *s*, where *v* = 13.38 m/min, *t* = 1 mm.

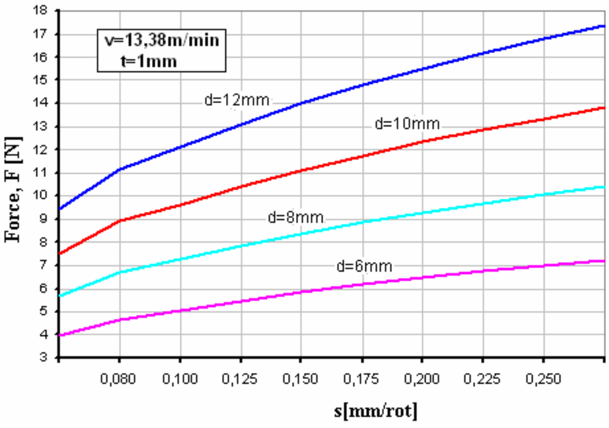

Fig. 3. Shows the variation of axial force as a function of feed rates, for different drill diameter.

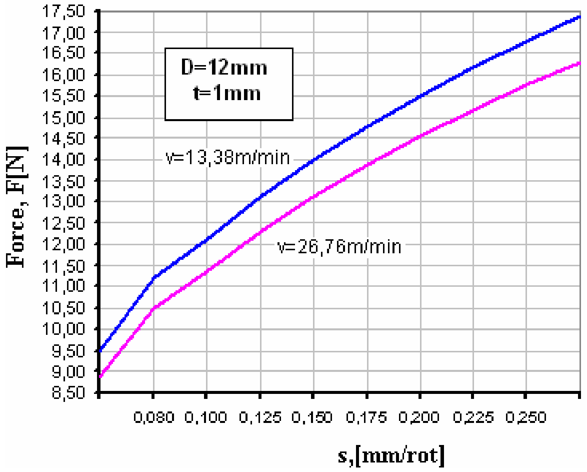

Fig. 4. Shows the variation of axial force as a function of feed rates, for different drilling speeds of the tool.

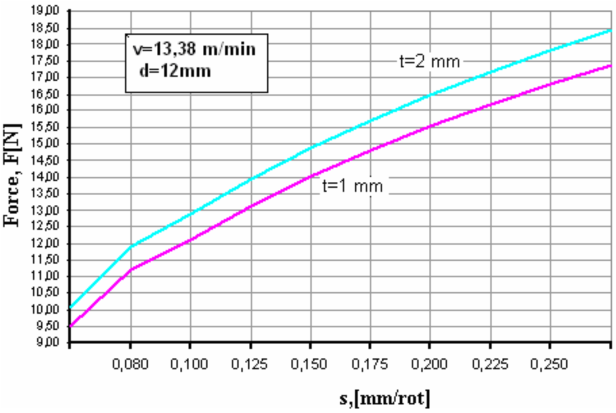

Fig. 5. Shows the variation of axial force as a function of feed rates, for different depth of splintering.

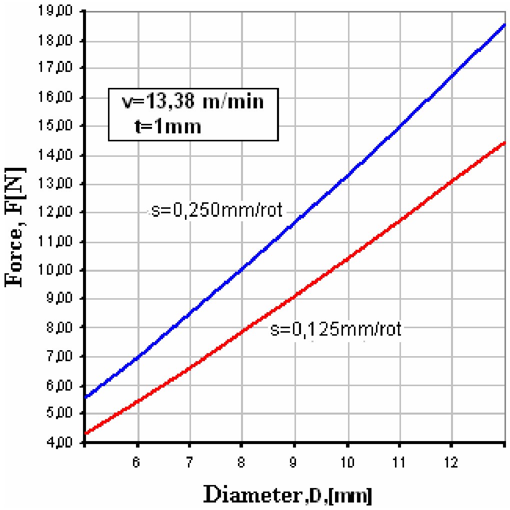

Fig. 6. Show the variation of axial force as a function of drill diameter, for different feed rates.

It can be noticed that reaming forces grow at an exponential rate if the feed rate grows, the values of these forces being higher for greater depth, with the reaming speed and tool diameter being constant.

When the reaming speed and depth remain constant, reaming forces grow exponentially if the diameter of the tools grows.

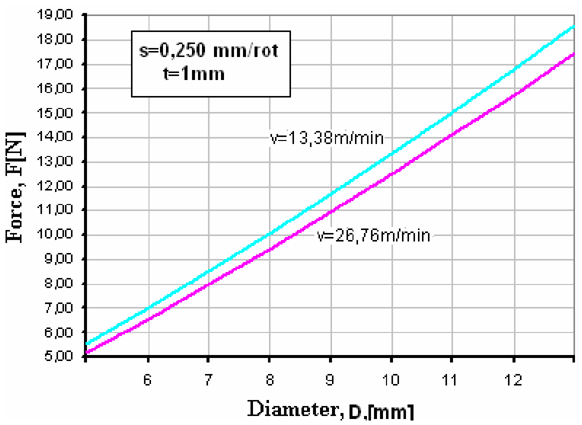

Fig. 7. Shows the variation of axial force as a function of drill diameter, for different drilling speeds of the tool.

Figure 7 shows the variation of the axial force as a function of drill diameter *D*, for different drilling feed speed *v*, where $s = 0.25$ mm/rot, $t = 1$ mm.

Figure 8 shows the variation of the axial force as a function of drill diameter, *D*, where $s = 0.25$ mm/rot, $v = 13.38$ m/min, for different depth of splintering, *t*.

Figure 9 show dependence on the axial force as a function of drilling speed *v*, where $D = 12$ mm, $t = 1$ mm, for different feed rates *s*.

When the feed rate and depth remain constant, reaming forces grow exponentially if the diameter of the tools grows or if the reaming speeds decrease

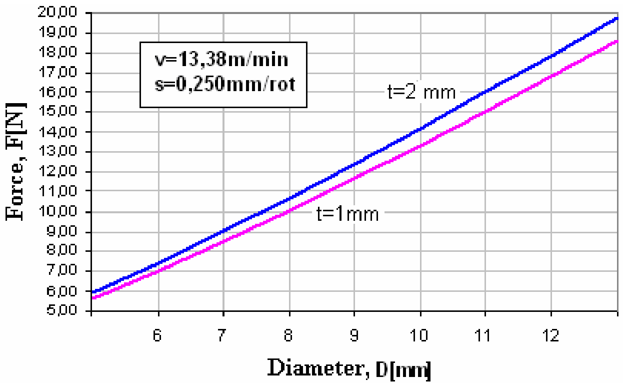

Fig. 8. Shows the variation of axial force as a function of drill diameter, for different depth of splintering.

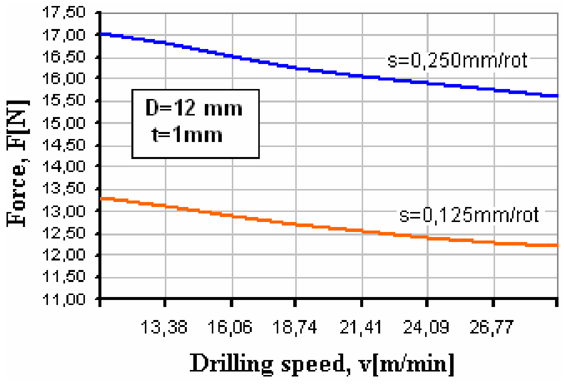

Fig. 9. Shows the variation of axial force as a function of drilling speed, for different feed rates.

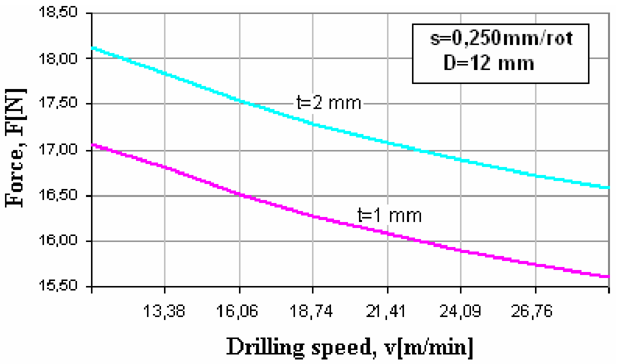

Fig. 10. Shows the variation of axial force as a function of drilling speed, for different depth of splintering.

From the diagrams, it can be noticed that reaming forces grow exponentially if the diameter of the drills increase and have higher values if the depth increases, when the speed and feed rate remain constant.

If the diameter of the tool and depth remain constant, reaming forces drop exponentially if reaming speed increases or if feed rate increases.

Figure 10 show dependence on the axial force as a function of drilling speed *v*, for different depth of splintering t, where $D = 12$ mm, $s = 0.250$ mm/rot.

Diagrams show that reaming forces decrease exponentially if the drilling speed and depth increase, when feed rate and diameter remain constant.

Figure 11 shows the variation of the axial force as a function of depth of splintering *t*, where $s = 0.25$ mm/rot, $v = 13.38$ m/min, for different drill diameter, *D*.

From the diagrams, it can be noticed that the reaming forces grow at an exponential pace with the growth of the drilling depth and the diameter of the drills, when feed rate and speed are kept constant.

Figure 12 shows the variation of the axial force as a function of depth of splintering *t*, where $v = 13.38$ m/min, $D = 12$ mm, for different feed rates.

If the drilling speed and diameter of the tools are constant, reaming forces grow exponentially with the growth of the drilling depth and feed rate.

Figure 13 shows the variation of the axial force as a function of depth of splintering *t*, where $s = 0.25$ mm/rot, $D = 12$ mm, for different drilling speeds of tool *v*.

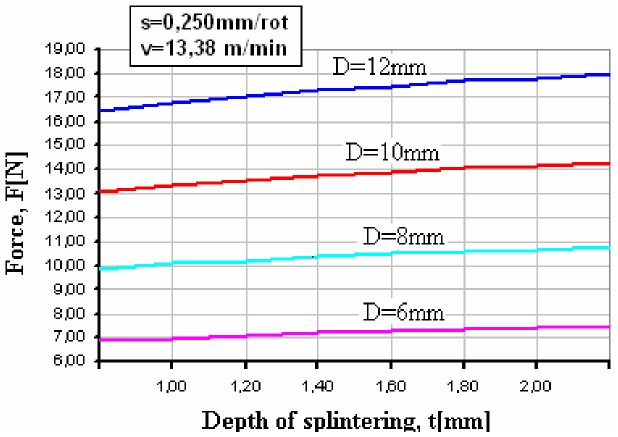

Fig. 11. Shows the variation of axial force as a function of depth of splintering, for different drill diameter.

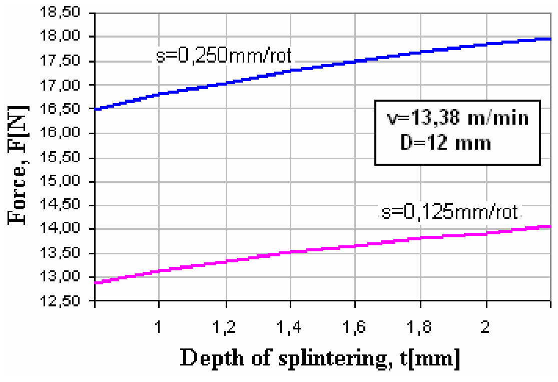

Fig. 12. Shows the variation of axial force as a function of depth of splintering, for different feed rates.

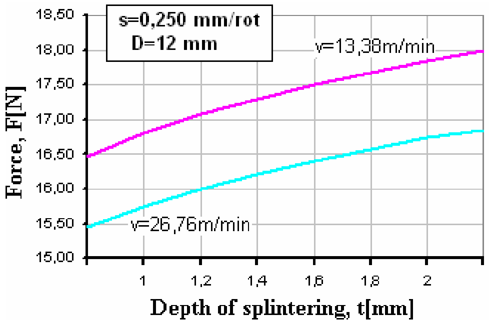

Fig. 13. Shows the variation of axial force as a function of depth of splintering, for different drilling speeds of the tool.

By analyzing the diagrams we can notice that the reaming forces grow exponentially with the growth of depth and drilling speed, feed rate and tool diameter remaining constant.

4. CONCLUSIONS

From the analysis of the variation of the cutting forces for the three types of polymeric composite materials (20%, 30% and 40% fiber glass) the following conclusions can be drawn:

- reaming these materials with a classical tool require higher forces, the higher the concentration of glass fiber is higher; the maximum value is of 20 N;

- from analyzing the diagram obtained from recording the reaming forces, it has been noticed that the density of maximum values of the reaming forces is higher if the material has a higher concentration of glass fiber;

- the diagrams have two perfectly horizontal zones, where the reaming forces have the maximum and minimum values. The former is present when the tool drills through the glass fiber; the latter is when the tool cuts through the matrix;

- form the diagrams it can be noticed that there are situations when, at the entry point in the material, there is a zone of random values; this is the moment when the tool, besides it's cutting action, also tears the fiber apart (Fig. 14);

- there are situations where random values have also been recorded at the exit point; then, the tool again tears the fibers (Fig. 15);

- the cutting forces grow at an exponential rate if the diameter of the drill is increased or if the feet rate is increased;

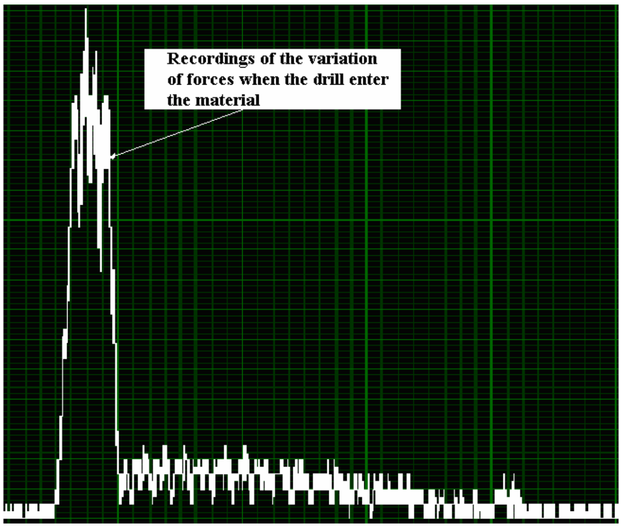

Fig. 14. Diagram of the fariation of forces at the tool entry whn enlarging holes into composite materials.

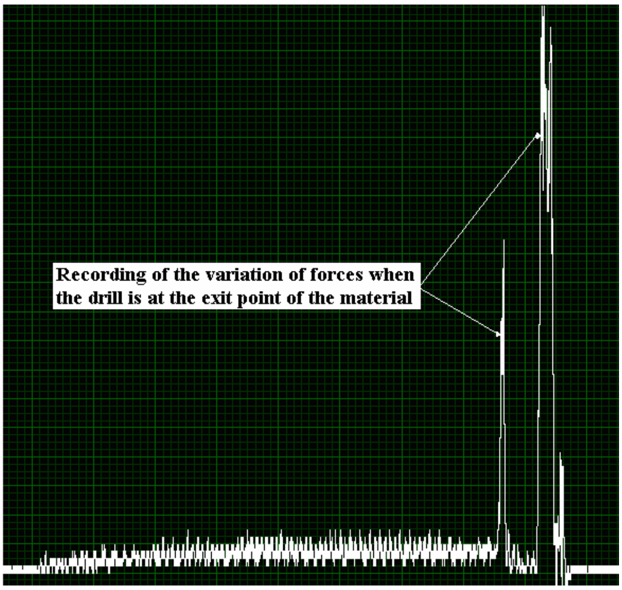

Fig. 15. Diagrams of the forces at the exit point.

- reaming forces grow at an exponential rate if the feed rate grows, the values of these forces being higher for lower reaming speed, with the depth and tool diameter being constant;

- reaming forces grow at an exponential rate if the feed rate grows, the values of these forces being higher for greater depth, with the reaming speed and tool diameter being constant;

- when the reaming speed and depth remain constant, reaming forces grow exponentially if the diameter of the tools grows;

- when the feed rate and depth remain constant, reaming forces grow exponentially if the diameter of the tools grows or if the reaming speeds decrease;

- reaming forces grow exponentially if the diameter of the drills increase and have higher values if the depth increases, when the speed and feed rate remain constant;

- there are situations where the diagram has perfectly horizontal zones at those moments, the forces have either maximum values (when the tool cuts trough the glass fiber) or minimal values (when the tool curs through the matrix) (Fig. 16);

- the result of the reaing does not satisfy from the quality point of view of the machinned surfaces, expecially at the entry and exit points; however, it must be considered that very low values for the forces were recorded.

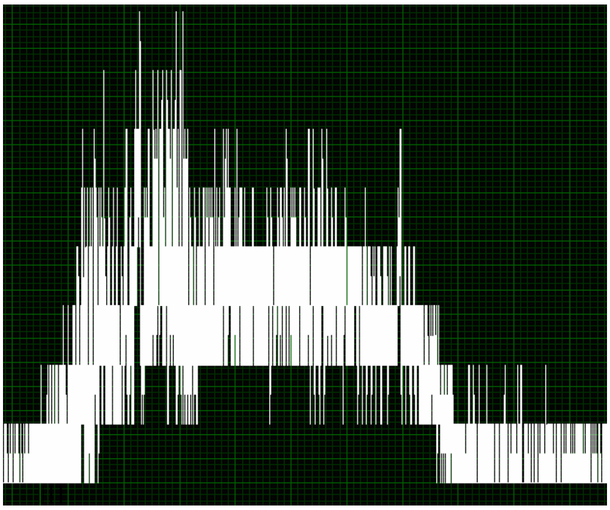

Fig. 16. Minimum and maximum values of the forces.

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