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STUDY OF TEMPERATURE IN PROCESSING WOOD COMPOSITE MATERIALS USING END MILLS

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Abstract: *The processing of composite wood materials is done with high-speed steel tools, diamond-coated or reinforced with metal carbide-plated tools. In the present research, we approached the processing of wood composite materials with high-speed steel end mill using compressed air as a cooling agent. Parallel to this new processing method, a thermal imaging camera is used that monitors the temperature in the tool, throughout the processing. A database is thus created which, later processed with the least squares method, highlighted the increase in tool durability compared to the classical method (without air-cooling). An electronic scanner that measures the end mill parameters before and after processing, a thermal imaging camera and three types of wood composite materials (PAL, MDF, and MULTIPLEX) are also used.*

Key words*: temperature measurement, least squares method, wooden composite materials, cutting regime.*

1. INTRODUCTION

The study of temperature in cutting composite wood materials is very important from the point of view of end mill life and production costs. There are important articles that analyze temperature for such processes [1].

The results of the study by Pei et al. made for wood-plastic composite [2] showed that "the cutting temperature increases with the increase of spindle speed and cutting depth, but decreases with the increase of feed rates in processing".

Guo et al., in the work [3] studies the machinability of composite materials based on wood and plastic. Regarding the temperature, it is found that an increase in the temperature in the cutting area has harmful effects on the edge of the cutting tool, leading to a reduction in the durability of the milling cutter. This leads to an increase in production costs.

The results in work of Kminiak [4] show a significant trend where the temperature of the tool decreases with increasing feed speed, primarily due to an increase in chip thickness. This occurs in the cutting edge by entering colder material during subsequent cuts. The friction surface remains the same with the speed increase. This trend is most noticeable at the largest radial depth of cut.

This article analyzes, based on practical experiments, the dependence between temperatures and the processing length of cylindrical-front milling cutters. For this, three wooden composite materials were chosen: PAL, MDF and MULTIPLEX. For chipboard, three material samples of dimensions 320 mm × 1100 mm were used, in which a length of 10000 mm was milled along a meander path consisting of segments of 1000 mm. Every 1000 mm, the temperature developed in the mill was measured with the help of a thermal imaging camera mounted on a tripod outside the CNC machine. Ten temperature values were recorded. For the three samples, three feed speeds of 1000, 2000 and 3000 mm/min were used at a milling cutter speed of 12500 rpm. The same was done for the other samples of MDF and MULTIPLEX. Thus, a database was created that was analyzed and interpreted using the least squares method.

2. EQUIPMENT USED IN THIS RESEARCH

The equipment and machines used in this research are the following:

a) Milling machine CNC Evolution 7405 4 MAT. This computer numerically controlled machine tool is used in the processing of wood and composite materials [5]. The experiments in this research were done in a company processing furniture elements, and it mainly uses composite materials, the most used being chipboard, MDF and MULTIPLEX.

b) End mill with a diameter of 10 mm, made of high-speed steel with two cutting edges HSSCo8 DIN844.

c) FLIR CX series high-resolution digital thermal camera that measures the temperature in the machining area based on the non-contact principle. This camera is equipped with an advanced analysis software that allows detailed analyzes of temperatures and the creation of personalized reports.

d) Scanner ATOS Scan Box BPS [6] with the help of which data were collected regarding the dimensional and angular parameters of the cylindrical-front milling cutters (set of 9 milling cutters), as well as the resulting dimensional parameters after using them in the

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processing process. The ATOS system represents a complex solution for measuring 3D tools and for inspecting their wear after use.

e) Pneumatic compressor that produces the cooling agent in the tool processing area.

f) Samples of composite material (PAL, MDF, MULTIPLEX. The mechanical characteristics of the wood composites are given in the works [7, 8].

3. RESEARCH METHOD USED

The experiments were conducted in two variants:

Variant A – without cooling using aset of nine tools for the three composite materials.

Variant B – with cooling using a jet of compressed air and using another set of nine tools.

Both for version A and for version B, three processing regimes were used, respectively speed n = 12500 rpm and three feed speeds: 1000 mm/min, 2000 mm/min and 3000 mm/min.

4. TOOL TEMPERATURE MEASUREMENT DURING PROCESSING

The total processing length for each sample, with a single milling cutter, is 10,000 mm. With the help of the thermal imaging camera, 10 values were measured in ten points, respectively after machining 1000 mm, 2000 mm...10000 mm. The temperature recording was done with the help of the thermal imaging camera, mounted on a tripod at a distance of approx. 1 meter from the work area.

5. THE MATHEMATICAL MODEL OF THE RESULTS OF EXPERIMENTAL RESEARCH

During the cutting process, due to high contact pressures, high temperatures, relative velocities and shocks between the tool-workpiece contact surfaces, wear of the cutting tool occurs [9].

The wear of the cutting tool consists of the gradual removal of material from the active surfaces of the tool, having the effect of changing the geometry as well as reducing its cutting capacity.

It i obvious that temperature in cutting influences the tool life of the milling cutter in processing wood composites. For predicting the tool temperature during cutting different mathematical model could be use, having different levels of complexity [10].

In this article, the least squares method was used to process the data obtained experimentally, obtaining the graphs of linear regression showing the dependence of temperature on processing length.

The objective of this method was to adjust the coefficients of the approximation function in such a way

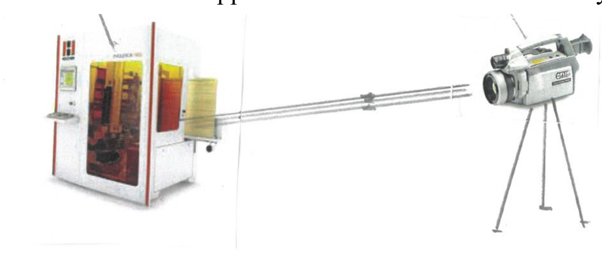

Fig 1. Experimental setup for process thermal monitoring.

that it best fits the data set. In general, a set of such data consists, for example, of a series of pairs of values i = 1,..., n, in which is the independent variable, and $y_i = f(x_i)$ is the dependent variable, whose values were obtained experimentally.

The model function is of the form $f(x, \beta)$, having m parameters (coefficients), placed in the vector $\{\beta\}$. The goal of the method is to find the values of the parameters so that the values calculated using the model function best match the experimental values. The optimal solution according to the method of least squares is when the sum S of the squares of the residuals:

$$s = \sum_{i=1}^{n} r_i^2$$

is minimal. The residual represents the deviation (difference) between the value of the dependent variable and the value given by the model function:

$$r_i = y_i - f(x, \beta),$$

so

$$\sum_{i=1}^{n} [y_i - f(x, \beta)]^2 \rightarrow minimum,$$

or

$$\sum_{i=1}^{n} [y_i - (\beta_0 - \beta_1 x)^2],$$

in which $f(x, \beta)$ represents the chosen interpolation polynomial.

Matrixly, it can be written that:

$$[X]\{\beta\} = \{Y\},$$

in which:

$$[X] = \begin{bmatrix} n & \sum_{i=1}^{n} x_i \\ \sum_{i=1}^{n} x_i & \sum_{i=1}^{n} x_i^2 \end{bmatrix},$$

$$\{\beta\} = \begin{Bmatrix} \beta_0 \\ \beta_1 \end{Bmatrix}$$

and:

$$\{Y\} = \begin{Bmatrix} \sum_{i=1}^{n} y_i \\ \sum_{i=1}^{n} x_i y_i \end{Bmatrix}.$$

An example of a model function is a straight line, considering the ordinate at the origin β_0 and sloap β_1, the model function is of the form: $f(x, \beta) = \beta_0 + \beta_1 x$.

6. DATA PROCESSING USING THE MATHEMATICAL MODEL

The values measured were organized and intrepreted in a series of tables giving the temperatures together with the trend lines (linear interpolation). The following tables and figures show the temperature dependence on the processing length (along 10000 mm) for three types of composite wood materials – PAL (without cooling – Figs. 2, 4 and 6, with air-cooling – Figs. 3, 5 and 7), MDF (without cooling – Figs. 8, 10 and 12, with air-cooling – Figs. 9, 11 and 13) and MULTIPLEX (without cooling – Figs. 14, 16 and 18, with air-cooling – Figs. 15, 17 and 19).

During the processing of the materials without cooling, it is found that the maximum values are increasing with the increase of the feed speed. On the other hand, according to the type of material, the final temperatures (test 10) increase in the order MDF, PAL, MULTIPLEX.

Cutting length [mm]	Temperature [°C]
1000	85.5
2000	84
3000	85
4000	85.4
5000	87
6000	92
7000	94
8000	108
9000	104
10000	105

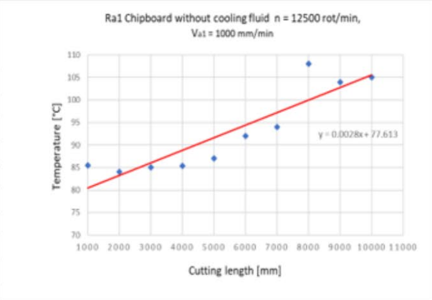

Fig. 2. Dependence of the temperature in the tool depending on the length traveled by the tool, without cooling fluid, with cutting mode va1 = 1000 mm/min and *n* = 12500 rpm for PAL.

Cutting length [mm]	Temperature [°C]
1000	39.7
2000	50
3000	77.2
4000	76
5000	75.4
6000	74
7000	86.5
8000	80
9000	76
10000	75.5

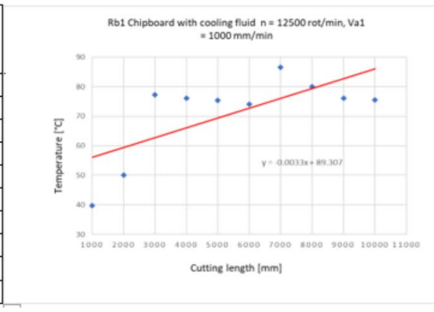

Fig. 3. Dependence of the temperature in the tool depending on the length traveled by the tool, with cooling fluid, with cutting mode va1 = 1000mm/min and *n* = 12500 rpm for PAL.

Cutting length [mm]	Temperature [°C]
1000	92
2000	92.84
3000	95
4000	101
5000	100
6000	102
7000	56
8000	57
9000	137
10000	139

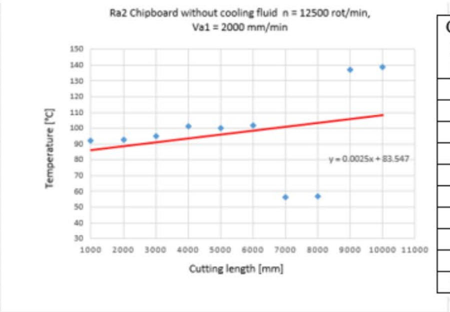

Fig. 4. Dependence of the temperature in the tool depending on the length traveled by the tool, without cooling fluid, with cutting mode va1 = 2000 mm/min and *n* = 12500 rev/min for PAL.

Cutting length [mm]	Temperature [°C]
1000	96.5
2000	97.5
3000	96
4000	97.6
5000	93
6000	94.9
7000	100
8000	102
9000	96
10000	95

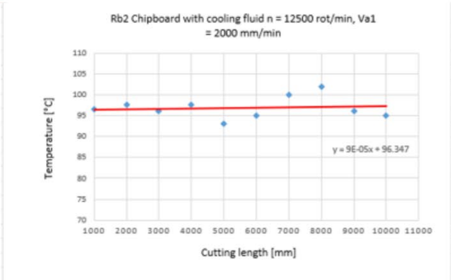

Fig. 5. Dependence of the temperature in the tool depending on the length traveled by the tool, without cooling fluid, with cutting mode va1 = 2000 mm/min and *n* = 12500 rev/min for chipboard PAL.

Cutting length [mm]	Temperature [°C]
1000	87
2000	88
3000	90
4000	112
5000	111
6000	100
7000	101
8000	102
9000	114
10000	115

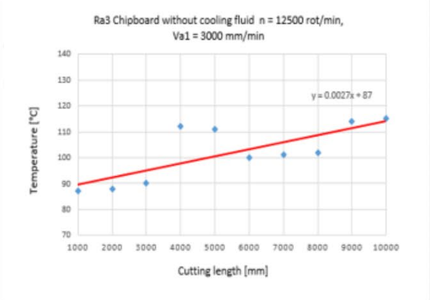

Fig. 6. Dependence of the temperature in the tool depending on the length traveled by the tool, without cooling fluid, with cutting mode va1 = 3000 mm/min and *n* = 12500 rpm for chipboard PAL.

Cutting length [mm]	Temperature [°C]
1000	93
2000	92.7
3000	96.5
4000	105
5000	105.5
6000	106
7000	105
8000	107
9000	106
10000	100

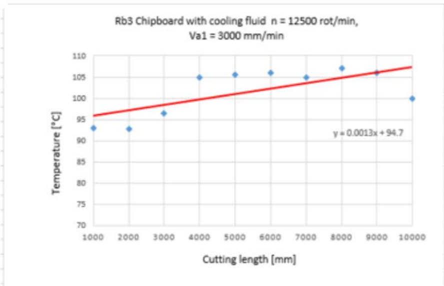

Fig. 7. Dependence of the temperature in the tool depending on the length traveled by the tool, with cooling fluid, with cutting mode va1 = 3000 mm/min and *n* = 12500 rev/min for chipboard PAL.

Cutting length [mm]	Temperature [°C]
1000	60
2000	61
3000	64.9
4000	65
5000	62.5
6000	63
7000	62
8000	60.5
9000	60
10000	61

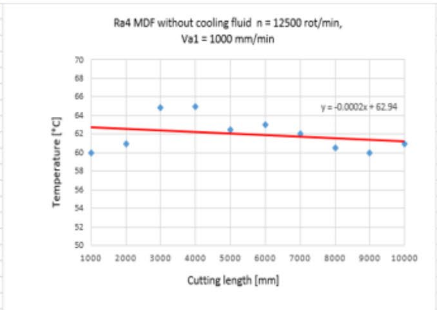

Fig. 8. Dependence of the temperature in the tool depending on the length traveled by the tool, without cooling fluid, with cutting mode va1 = 1000 mm/min and *n* = 12500 rpm for MDF.

Cutting length [mm]	Temperature [°C]
1000	56
2000	56.5
3000	56.2
4000	58.9
5000	56
6000	55.3
7000	55
8000	55.6
9000	57
10000	60

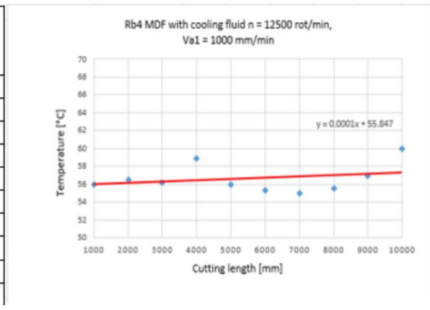

Fig. 9. Dependence of the temperature in the tool depending on the length traveled by the tool, with cooling fluid, with cutting mode va1 = 1000 mm/min and *n* = 12500 rpm for MDF.

Cutting length [mm]	Temperature [°C]
1000	37
2000	37.5
3000	66
4000	67.5
5000	75
6000	75.8
7000	67
8000	68
9000	69
10000	69.3

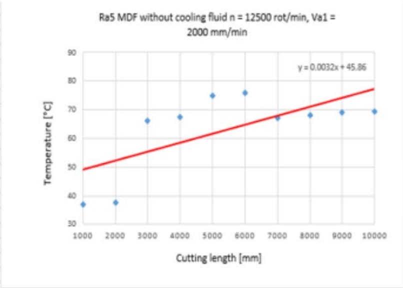

Fig. 10. Dependence of the temperature in the tool depending on the length traveled by the tool, without cooling fluid, with cutting mode va1 = 2000mm/min and *n* = 12500 rpm for MDF.

Cutting length [mm]	Temperature [°C]
1000	69.3
2000	69.7
3000	71.5
4000	72
5000	74,6
6000	75
7000	76.2
8000	75.3
9000	78
10000	79.3

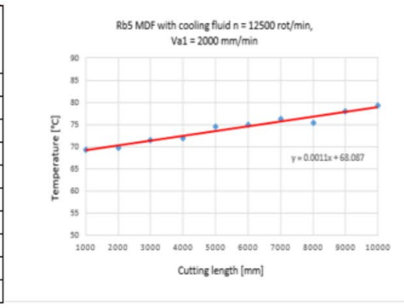

Fig. 11. Dependence of the temperature in the tool depending on the length traveled by the tool, with cooling fluid, with cutting mode va1 = 2000mm/min and *n* = 12500 rpm for MDF.

Cutting length [mm]	Temperature [°C]
1000	80
2000	81.8
3000	65.5
4000	66.9
5000	67
6000	75
7000	77
8000	78
9000	84
10000	85.1

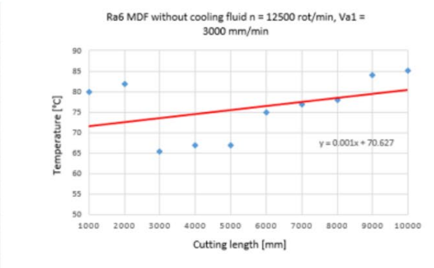

Fig. 12. Dependence of the temperature in the tool depending on the length traveled by the tool, without cooling fluid, with cutting mode va1 = 3000mm/min and *n* = 12500 rpm for MDF.

Cutting length [mm]	Temperature [°C]
1000	71
2000	72
3000	61.2
4000	59
5000	53
6000	55.8
7000	75,2
8000	77.6
9000	86.2
10000	87.5

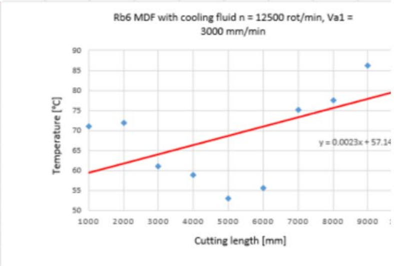

Fig. 13. Dependence of the temperature in the tool depending on the length traveled by the tool, with cooling fluid, with cutting mode va1 = 3000mm/min and *n* = 12500 rpm for MDF.

Cutting length [mm]	Temperature [°C]
1000	108
2000	110
3000	breakage
4000	breakage
5000	-
6000	-
7000	-
8000	-
9000	-
10000	-

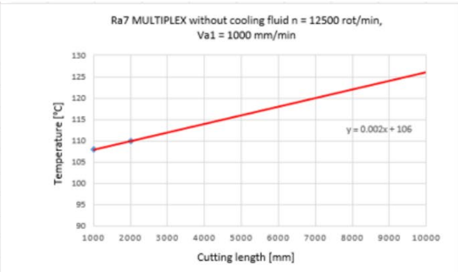

Fig. 14. Dependence of the temperature in the tool depending on the length traveled by the tool, without cooling fluid, with cutting mode va1 = 1000mm/min and *n* = 12500 rot/min for MULTIPLEX.

Cutting length [mm]	Temperature [°C]
1000	80.8
2000	82.2
3000	81.2
4000	84.4
5000	80.7
6000	81.6
7000	92.2
8000	93.6
9000	91
10000	91.3

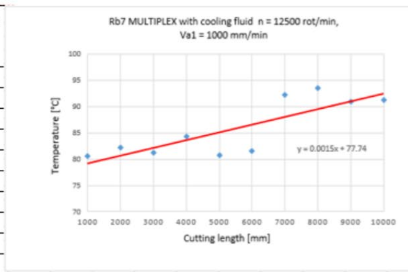

Fig. 15. Dependence of the temperature in the tool depending on the length traveled by the tool, with cooling fluid, with cutting mode va1 = 1000 mm/min and *n* = 12500 rot/min for MULTIPLEX.

Cutting length [mm]	Temperature [°C]
1000	88
2000	89.5
3000	102
4000	103
5000	101
6000	100
7000	105
8000	108
9000	106
10000	105

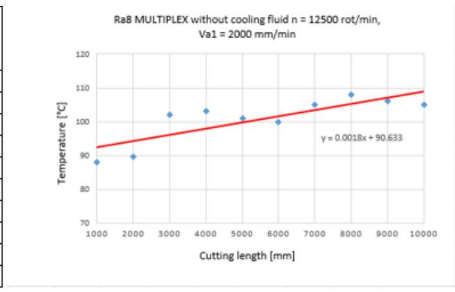

Fig. 16. Dependence of the temperature in the tool depending on the length traveled by the tool, without coolant, with cutting mode va1 =2 000mm/min and *n* = 12500 rpm for MULTIPLEX.

Cutting length [mm]	Temperature [°C]
1000	88.4
2000	88.3
3000	95.5
4000	95
5000	92
6000	90.7
7000	90.4
8000	90.5
9000	92
10000	97

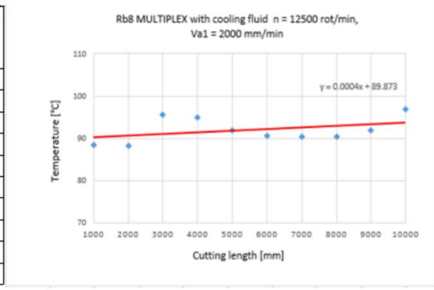

Fig. 17. Dependence of the temperature in the tool depending on the length traveled by the tool, with cooling fluid, with cutting mode va1 = 2000 mm/min and *n* = 12500 rot/min for MULTIPLEX.

Cutting length [mm]	Temperature [°C]
1000	93
2000	93.8
3000	92
4000	89.4
5000	110
6000	112
7000	111
8000	108
9000	120
10000	121

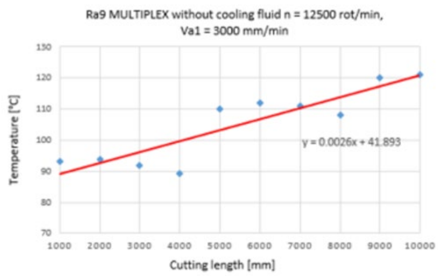

Fig. 18. Dependence of the temperature in the tool depending on the length traveled by the tool, without coolant, with cutting mode va1=3000 mm/min and *n* = 12500 rpm for MULTIPLEX.

Cutting length [mm]	Temperature [°C]
1000	88
2000	89.5
3000	90
4000	103
5000	99
6000	100
7000	105
8000	108
9000	106
10000	105

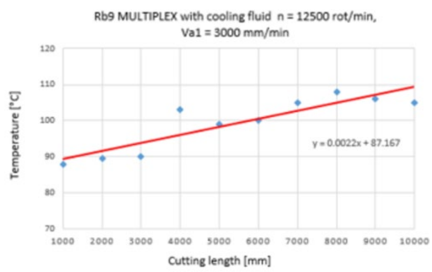

Fig. 19. Dependence of the temperature in the tool depending on the length traveled by the tool, with cooling fluid, with cutting mode va1= 3000mm/min and *n* = 12500 rot/min for MULTIPLEX.

Table 20

Average temperature in processing without cooling

v_f (mm/mim)	PAL	MDF	MULTIPLEX
1000	87	62	–
2000	100	65	100
3000	105	70	103

Table 21

Average temperature in processing with air-cooling

v_f (mm/mim)	PAL	MDF	MULTIPLEX
1000	75	58	85
2000	92	75	92
3000	102	65	99

Regarding the average temperatures (test 5), they are present in Table 20 for processing without cooling and in Table 21 for processing under air jet.

During processing without cooling, for the three materials there is an increasing tendency of the average values depending on the feed speed. According to the average temperature values, the hierarchy is MDF, MULTIPLEX, PAL.

When processing under an air jet, for the three matarials there is an increasing tendency of the average depending on the feed speed. The hierarchy in ascending order of the average temperature of the three materials is – MDF, PAL, MULTIPLEX.

For the cooling processing of three materials, it is found that there is a tendency of relative stabilization of the temperature regardless of the feed speed.

7. CONCLUSIONS

The analyzes were carried out at three different advance speeds – 1000, 2000 and 3000 mm/min, with or without the use of a cooling fluid (air under pressure). Water was not used as a cooling fluid, because, as is well known, wood has a hygroscopic behavior, swelling under the effect of humidity.

Regarding the three wooden materials, it was found in the case of chipboard that at feed speeds of 1000 mm/min, the temperatures obtained in the case of using a cooling fluid were lower than in the case of not using it. At higher feed speeds (2000, 3000) mm/min there is a uniformity of temperatures (these being roughly in the same range of values).

In the case of the composite material MDF, the situation in the case of speed speeds of 1000 mm/min is similar to that for chipboard, a decrease in temperatures is observed in the case of using a cooling fluid. At high feed speeds (of 2000 rpm), the temperatures obtained in the case of using a cooling fluid are significantly higher than in the case of not using the fluid. At speeds of 3000 mm/min, a uniformity of temperatures is observed, the cooling fluid in this case not having a special role.

In the case of the MULTIPLEX composite material, the experimental researches failed in the case of using a cutting speed of 1000 mm/min, but from the first three measurements, obtained before the cutter broke, it can be concluded that the cooling fluid had an essential role. This trend was also noted in the case of using a feed speed of 2000 rpm, reaching a uniformity of temperatures in the case of high feed speeds (of 3000 rpm).

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