Proceedings in MANUFACTURING SYSTEMS

Proceedings in Manufacturing Systems, Volume 18, Issue 2, 2023, 71-77 ISSN 2067-9238

ANALYSYS OF END MILL DURABILITY WHEN PROCESSING WOOD COMPOSITE MATERIALS

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Abstract: *This article presets an approach regarding the influence of cutting regimes of wood composite materials on the wear of end mills. The three wood composite characteristics are presented. The experimental tests on the wear of HSS end mill of 10 mm diameter (the most used in the furniture industry) are considered. Nine milling cutters are used in dry cutting for three materials. Before being introduced into processing, they are calibrated using an electronic scanner. Then these are used to process the samples, with a constant cutting speed and three feed rates. Further, the dimensional measurements are done on the same electronic scanner to emphasize the wear on diameter. The experiments continues with the use of a new set of 9 end mills that are initially measured with the same electronic scanner and introduced into processing using the same cutting regimes with the difference that a compressed air jet is used in the work area as a cooling agent. The results are compared and processed using the least squares method.*

Key words: *wood composite materials, cutting regimes, tool wear, air-cooling, least squares method, linear regression*.

1. INTRODUCTION

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.

The wear of the cutting tool consists in 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, i.e. the wear of the tool.

The least squares method was used to process the data obtained experimentally, obtaining the linear regression graphs that showed the dependence of the wear of the edge radius depending on the processing advance. The objective of this method was to adjust the coefficients of the approximation function in such a way that it best fits the data set. In general, a set of such data consists of, for example, a series of pairs of values $i = 1 \ldots n$, in which x_i is the independent variable, and $y_i = f(x_i)$ is the dependent variable, whose values were obtained experimentally.

The objective of the present work is to investigate and subsequently establish the connection between the processing regimes and the wear of the diameter of the cylindrical-front milling cutter in two work variants. The first option – the processing of composite wooden materials PAL, MDF and MULTIPLEX is done by cold milling without cooling fluid. The second option – processing is done under the same conditions as the first, but with compressed air cooling agent sent to the processing area. Thus, tool wear is studied based on the two variants in order to show the positive influence of the use of the cooling agent.

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2. EQUIPMENT USED IN THIS RESEARCH

2.1. CNC EVOLUTION 7405 4mat machine tool

CNC (Computer Numerical Control) machining machines represent a significant innovation in the woodworking and materials industry. The EVOLUTION 7405 4mat CNC machine tool is an impressive example of advanced technology in the field of panels having a thickness of 8 to 70 mm [1].

They play an essential role in the wood and material processing industry.

They bring multiple advantages:

Increased efficiency. With the help of numerical control and automation, these machines can work faster and more efficiently than manual processing, which leads to savings in time and resources.

Precision and Consistency. CNC machines offer extreme precision and consistency in machining. They can produce identical high quality parts with each iteration.

Flexibility. Thanks to multiple work axes and advanced software, CNC machines can be used in a variety of applications, from furniture production to plastic or metal processing.

2.2. ATOS ScanBox BPS System

ATOS ScanBox BPS is an advanced measurement and quality control system, developed by the GOM company, specialized in optical and 3D measurement technology. This system is a complex solution for measuring 3D objects and inspecting their quality in a range of industrial applications [2].

- High Precision 3D Scanning Technology – This system uses structured light 3D scanning technology to accurately capture the shape and dimensions of objects, providing accurate measurements of complex geometry and free surfaces.
- Advanced Automation – ATOS ScanBox BPS is equipped with a high level of automation, allowing users to perform measurements and inspections without additional human intervention. This reduces human errors and helps increase process efficiency.
- Quality Control – The system is equipped with powerful analysis software that allows users to evaluate the quality of the measured objects. It can identify deviations from desired specifications and help correct them in the production process.
- Adaptability and Flexibility – ATOS ScanBox BPS is adaptable and can be used in a variety of industries such as automotive, aeronautics, electronics, casting or machined parts manufacturing and many others.

2.3. Uses of the ATOS ScanBox BPS system

a. Quality Control in Production - One of the most common uses of this system is in quality control in production processes. It can quickly and accurately detect deviations and defects in manufactured products, ensuring that they meet quality standards.

b. Reverse Engineering – ATOS ScanBox BPS is used to create accurate 3D models of existing objects. This is useful in reverse engineering to reproduce or improve existing products.

c. Design and Development – During the design and development phase, the system can be used to perform measurements and analysis on prototypes and parts created to verify compliance with initial specifications.

d. Tool and Die Manufacturing – In tool and die manufacturing, the system helps ensure accurate dimensions and identify wear or damage.

3. COMPOSITE MATERIALS USED IN EXPERIMENTAL RESEARCH

Three types of wood composite materials with different composition and characteristics were used for this research [3].

3.1. Melamine chipboard – PAL

a) The main physical-mechanical characteristics.

Melamine chipboard (Pressed with Lignosulfonic Acid Melamine) occupies an important place in the furniture industry. is a wood composite material commonly used in the furniture, construction and interior finishing industries. This category of material has distinct physico-mechanical characteristics that make it popular for various applications [4].

Wear resistance. Melamine is a tough, scratch and abrasion resistant material, which makes melamine chipboard suitable for surfaces that are subject to constant wear and tear, such as table tops and work tables.

Moisture resistance. Due to its chemical composition and manufacturing process, this material can withstand relatively high humidity without swelling or losing its structural integrity.

Dimensional stability. This material does not undergo significant contractions or expansions under conditions of temperature and humidity variations.

Temperature resistance. Melamine chipboard can withstand high temperatures without changing its mechanical properties or appearance.

Resistance to shocks. This material is relatively resistant to minor knocks and impacts, making it suitable for use in high traffic areas such as parquet replacement or use in commercial or residential flooring

b) Chemical composition of melamine chipboard

Melamine chipboard is a composite material consisting of several main components, including:

Wood fibers. A significant part of the composition of melamine chipboard consists of wood fibers. These fibers can be obtained from wood of various essences, such as pine, birch or beech. Wood fibers give chipboard strength and structural stability.

Lignin is a complex organic substance found in wood cells. It plays an important role in binding the wood fibers and gives the melamine chipboard a certain strength and rigidity.

Melamine resin Another essential component is melamine resin. This resin is added during the manufacturing process and owes its name to its melamine content. The melamine resin is essential for imparting moisture, temperature and wear resistance to the melamine chipboard.

Melamine paper containing various patterns and colors is applied to the surface of the melamine chipboard. This layer of paper is not only aesthetic, but also helps to protect the surface and create attractive finishes.

3.2. MDF

MDF is a wood composite material widely used in the furniture, construction and interior decoration industries [5].

a) Physical-mechanical characteristics of MDF

Resistance to bending and compression. One of the most notable aspects of MDF is its resistance to bending and compression. This material is made by pressing wood fibers with a binding agent such as formaldehyde at high temperatures and under pressure.

Dimensional stability. MDF is known for its dimensional stability. It does not expand or contract significantly under conditions of temperature and humidity variations, which makes it suitable for use in varied environments.

Moisture resistance. Although standard MDF is not moisture resistant, there are treated variants that retain their integrity in humid environments. These types of MDF are often used for the construction of furniture or bathroom accessories that come into contact with water or moisture.

High quality finish. MDF has a smooth and uniform surface, which makes it suitable for the application of high-quality finishes.

b) Chemical composition of MDF

MDF (Medium Density Fiberboard) is an extremely popular wood composite material in various industries, from furniture and construction to the automotive industry. This versatile material is largely due to its complex chemical composition and advanced manufacturing methods.

MDF is mainly composed of the following:

Wood fibers. Wood fibers are the basic element of MDF. These fibers are obtained by disintegrating wood into a fibrous form, and their quality plays a crucial role in determining the quality and performance of MDF. Usually, the wood used can come from different species such as pine, birch, beech or other types of soft wood.

Glue. Glue is used to bind and strengthen the wood fibers. It serves as a cohesive element that ensures the integrity of the MDF boards. One of the common adhesives used in the manufacture of MDF is formaldehyde, but other types of adhesives such as urea-formaldehyde or melamine-formaldehyde can also be used. The choice of adhesive can influence the characteristics of MDF, including moisture resistance.

Water and auxiliary chemicals. During the manufacturing process, water and some auxiliary chemicals, such as fillers or dispersing agents, may be added to improve the processability of the materials or to adjust certain characteristics.

3.3. MULTIPLEX

Also known as plywood, it is a wood composite material that has earned a well-deserved place in the construction industry, furniture and many other fields. This impressive material is distinguished by its outstanding physico-mechanical characteristics, making it the ideal choice for a wide range of applications [6].

a) Physical-mechanical characteristics

Bending and tensile strength. One of MULTIPLEX's most notable features is its impressive flexural and tensile strength. This material is manufactured by gluing several layers of wood veneer, which are arranged so that the fibers are oriented alternately. This layered structure gives MULTIPLEX exceptional resistance to mechanical forces. Therefore, it is frequently used in the construction of furniture, shelves, worktops and even in the construction of strong structures.

Dimensional stability. The MULTIPLEX also stands out for its outstanding dimensional stability. It retains its original dimensions and shape under conditions of temperature and humidity variations.

Ease of processing. This material can be easily cut, drilled, milled or shaped, making it a preferred choice in the woodworking industry.

Resistance to humidity and variable temperatures. MULTIPLEX can be treated to make it moisture resistant, making it suitable for use in wet or marine environments.

High quality finish.The surface of the MULTIPLEX is smooth and uniform, which allows for high quality finishes. This makes MULTIPLEX an ideal choice for painting, varnishing or applying decorative veneers.

b) Chemical composition of MULTIPLEX

MULTIPLEX is a composite material, which means it is made up of several layers of wood veneer, which are glued together under pressure and heat.

The chemical composition of MULTIPLEX includes the following main components:

Wood Veneer are thin layers of wood obtained by cutting wood into sheets. These are basic materials of the MULTIPLEX and are usually made of soft wood such as pine, birch or beech.

Adhesive is used to bond the veneer layers together and form a solid structure. Throughout history, different types of adhesives have been used, but today the most commonly used are formaldehyde-based adhesives. However, adhesives with low formaldehyde emissions are currently being developed and used to meet environmental and health standards.

Pressure and heat. In the manufacturing process, veneer layers are subjected to controlled pressure and heat to activate the adhesive and ensure a strong bond between them. This process is called hot pressing.

4. ESTABLISHING THE RESEARCH METHOD

The processing is done on the CNC machine EVOLUTION 7405 4MAT, in a workshop for processing composite materials, as follows:

- two sets of 9 new end mills with a diameter of 10 mm, having two flutes, made of HSS (high speed steel) are used (Fig. 1). One is used in cutting in dry conditions (no coolant) and the other one for cutting with air as coolant (Fig. 2). The 9 cutting tools used for dry cutting are having the index *a*, the other set for cutting with coolant – index *b*.
- one set of 9 milling cutters is grouped in subsets of 3, each milling cutter being used for processing a sample of different material (PAL, MDF, MULTIPLEX).

The cutting conditions are presented as follows:

A. No coolant

Material PAL

• milling cutter 1a with cutting speed v_c = 12500 rpm, feed rate v_f = 1000 mm/min, a_p = 20 mm.

• milling cutter 2a with cutting speed v_c = 12500 rpm, feed rate v_f = 2000 mm/min, a_p = 20 mm.

• milling cutter 3a with cutting speed v_c = 12500 rpm, feed rate v_f = 3000 mm/min, a_p = 20 mm.

Material MDF

• milling cutter 4a with cutting speed v_c = 12500 rpm, feed rate v_f = 1000 mm/min, a_p = 20 mm.

Fig. 1. Two flutes end mill of 10 mm diamater.

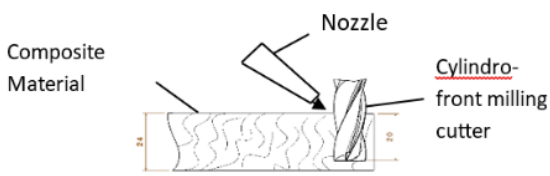


Fig. 2. Machining scheme using cooling fluid (compressed air).

• milling cutter 5a with cutting speed v_c = 12500 rpm, feed rate v_f = 2000 mm/min, a_p = 20 mm.
• milling cutter 6a with cutting speed v_c = 12500 rpm, feed rate v_f = 3000 mm/min, a_p = 20 mm.

Material MULTIPLEX
• milling cutter 7a with cutting speed v_c = 12500 rpm, feed rate v_f = 1000 mm/min, depth of cut a_p = 20 mm.
• milling cutter 8a with cutting speed v_c = 12500 rpm, feed rate v_f = 2000 mm/min, a_p = 20 mm.
• milling cutter 9a with cutting speed v_c = 12500 rpm, feed rate v_f = 3000 mm/min, a_p = 20 mm.

B. With coolant
Material PAL
• milling cutter 1b with cutting speed v_c = 12500 rpm, feed rate v_f = 1000 mm/min, a_p = 20 mm.
• milling cutter 2b with cutting speed v_c = 125000 rpm, feed rate v_f = 2000 mm/min, a_p = 20 mm.
• milling cutter 3b with cutting speed v_c = 12500 rpm, feed rate v_f = 3000 mm/min, a_p = 20 mm.

Material MDF
• milling cutter 4b with cutting speed v_c = 12500 rpm, feed rate v_f = 1000 mm/min, a_p = 20 mm.
• milling cutter 5b with cutting speed v_c = 12500 rpm, feed rate v_f = 2000 mm/min, a_p = 20 mm.
• milling cutter 6b with cutting speed v_c = 12500 rpm, feed rate v_f = 3000 mm/min, a_p = 20 mm.

Material MULTIPLEX
• milling cutter 7b with cutting speed v_c = 12500 rpm, feed rate v_f = 1000 mm/min, a_p = 20 mm.
• milling cutter 8b with cutting speed v_c = 12500 rpm, feed rate v_f = 2000 mm/min, a_p = 20 mm.
• milling cutter 9b with cutting speed v_c = 12500 rpm, feed rate v_f = 3000 mm/min, a_p = 20 mm.

The milling cutters are calibrated before being introduced into processing, with the help of the ATOS ScanBox BPS electronic scanner.

The samples to be processed, 3 for each material, have the size of 1100 × 320 × 24 mm (Fig. 3).

The milling cutter processes along a path consisting of forward and backward moves on 10 segments of 1000 mm and short perpendicular passages for passing to the next segment up to a total stroke of 1000 mm.

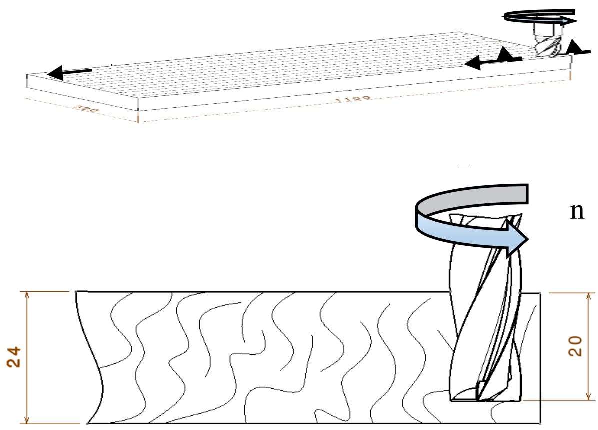


Fig. 3. General sample processing scheme.

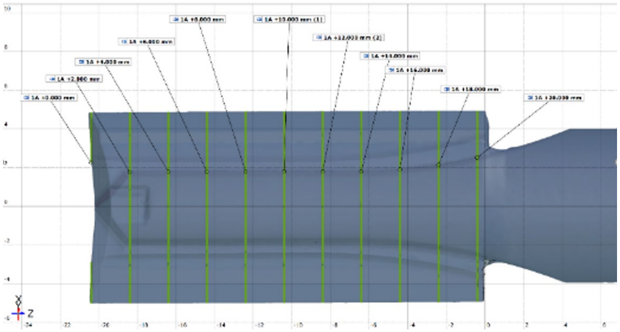


Fig 4. Diameter measurement points.

5. DATA PROCESSING USING THE MATHEMATICAL MODEL

The measurement consists in establishing the values of the cutter diameter in points belonging to 10 cross sections placed at axial distance of 2 mm from each other according to Fig. 4. Due to the straight direction of the teeth, the measurements of the diameter are done on the cutting edges of the milling cutter keeping the same orientation of the tool about its axis.

After processing, the tool diameters are measured, recorded and compared with the reference diameter of 10 mm. The evolution of tool diameter wear along the tool axis is presented as a linear function obtained by the least square method [7, 8].

The graphs in Figs. 5–10 presents the results for tool diameter measurements in case of chipboard (PAL), in both cases of dry machining (Figs. 5, 7 and 9) and machining with air cooling (Figs. 6, 8 and 10).

Figures 11–16 show the results in case of MDF material. Figures 11, 13 and 15 presents the graphs for dry processing, while Figs. 12, 14 and 16 – the graphs for processing with air-cooling.

Similarly, Figs. 17–22 are dedicated to the material MULTIPLEX. The graphs for dry processing are presented in Figs. 17, 19 and 21. The results for processing with air jetng are shown in Figs. 18, 20 and 22.

For all graphs, the wear evolution in the axial direction has an increasing tendency from the extremity to the body of the tool. The explanation could consist of variable temperature in the axial direction during processing. Also, a possible explanation could be related to the inhomogeneity of the material in depth with the possible higher hardness towards the outer layers.

For the two situations – without cooling and with cooling, the results show lower wear values for processing with cooling compared to the one with cooling by approximately 20%.

In a comparative analysis of the materials, the wear variation from one material to another shows a slight increase in the wear of the chipboard – PAL (average values of 45 µm, 55 µm and 60 µm – without cooling and 40 µm, 43 µm, 36 µm – with cooling), to MDF (average values of 52 µm, 85 µm and 40 µm – without cooling and 40, µm, 35 µm, 40 µm – with cooling) and then to MULTIPLEX (average values - breakage, 50 µm, 88 µm – without cooling and 46 µm, 42 µm and 43 µm – with cooling) for processing under the same conditions.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	25.4
2-4	24.9
4-6	40.2
6-8	33.3
8-10	49.2
10-12	56.6
12-14	53.3
14-16	67.4
16-18	69
18-20	59.2

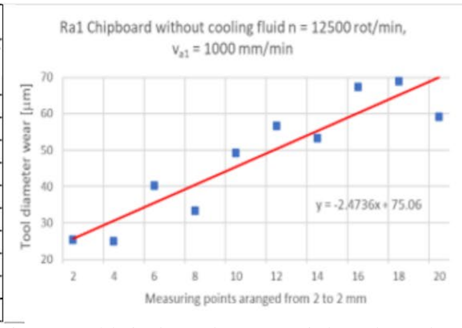


Fig. 5. Diameter wear for PAL with feed speed 1000 mm/min and speed 12500 rpm without cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	46.7
2-4	45
4-6	33.8
6-8	38.7
8-10	37.8
10-12	25.8
12-14	34.9
14-16	29.3
16-18	40.3
18-20	61.7

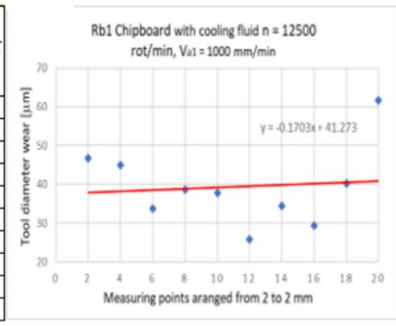


Fig. 6. Diameter wear for PAL with feed speed 1000 mm/min and speed 12500 rpm with cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	57
2-4	44.2
4-6	51.4
6-8	57.9
8-10	68.5
10-12	63.7
12-14	46.4
14-16	55.5
16-18	58.3
18-20	51.6

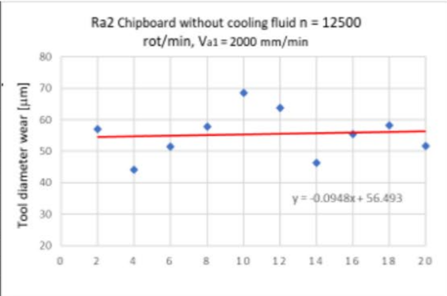


Fig. 7. Diameter wear for PAL with feed speed 2000 mm/min and speed 12500 rpm without cooling fluid.

Diameter measurement cross sections	Tool wear [µm]
0-2	21.1
2-4	22.9
4-6	41.6
6-8	50.1
8-10	55.6
10-12	48.4
12-14	61.3
14-16	44.9
16-18	46
18-20	44.3

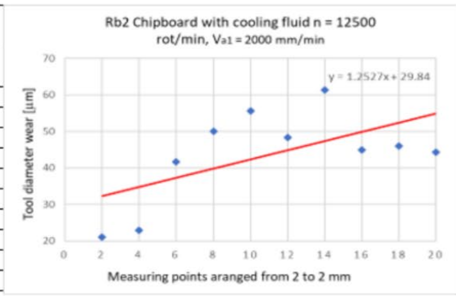


Fig. 8. Diameter wear for PAL with feed speed 2000 mm/min and speed 12500 rpm with cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	14.4
2-4	64.7
4-6	48.1
6-8	77.8
8-10	86.1
10-12	71.9
12-14	79.6
14-16	83.6
16-18	69.8
18-20	34.4

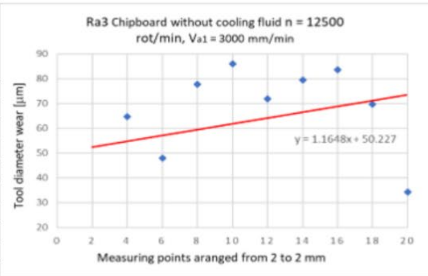


Fig. 9. Diameter wear for PAL with feed speed 3000 mm/min and speed 12500 rpm without cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	20.7
2-4	37.3
4-6	39.3
6-8	18
8-10	29.7
10-12	43.7
12-14	46.2
14-16	48.3
16-18	30
18-20	19.6

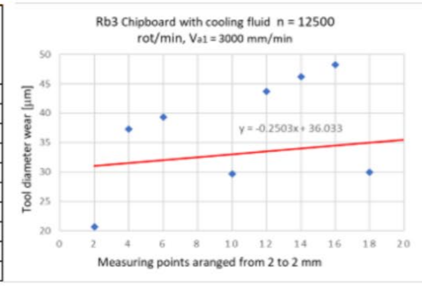


Fig. 10. Diameter wear for PAL with feed speed 3000 mm/min and speed 12500 rpm with cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	26.3
2-4	71
4-6	71.7
6-8	78.6
8-10	63.9
10-12	75
12-14	79.8
14-16	69.9
16-18	55.7
18-20	55.8

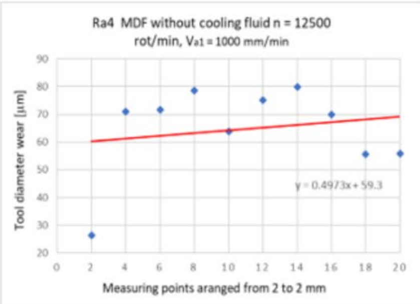


Fig. 11. Diameter wear for MDF with feed speed 1000 mm/min and speed 12500 rpm without cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	33.4
2-4	46.7
4-6	44.3
6-8	49.2
8-10	18.9
10-12	36.3
12-14	32.3
14-16	38.5
16-18	58
18-20	40.5

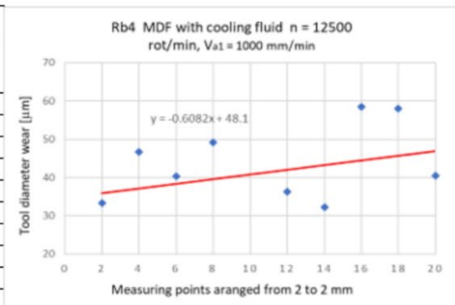


Fig. 12. Diameter wear for MDF with feed speed 1000 mm/min and speed 12500 rpm with cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	68.9
2-4	82.4
4-6	79.5
6-8	94,2
8-10	87.7
10-12	90.1
12-14	91.3
14-16	89.5
16-18	89
18-20	78.8

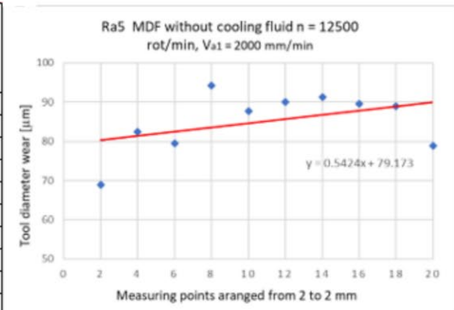


Fig. 13. Diameter wear for MDF with feed speed 2000 mm/min and speed 12500 rpm without cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	5.3
2-4	5.9
4-6	45.3
6-8	69.5
8-10	50.8
10-12	42.5
12-14	50.2
14-16	30.4
16-18	31.3
18-20	29.1

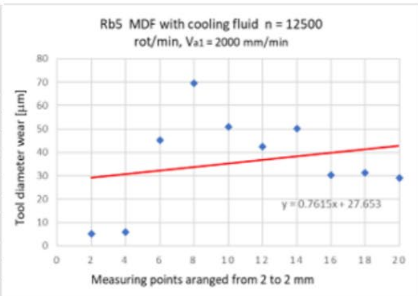


Fig. 14. Diameter wear for MDF with feed speed 2000 mm/min and speed 12500 rpm with cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	19
2-4	40.4
4-6	45
6-8	47
8-10	36.3
10-12	45.9
12-14	45
14-16	50.6
16-18	25.6
18-20	62.3

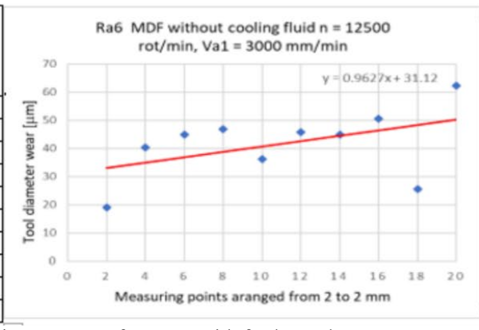


Fig. 15. Diameter wear for MDF with feed speed 3000 mm/min and speed 12500 rpm without cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	35.7
2-4	41.6
4-6	35.7
6-8	58
8-10	34
10-12	7.3
12-14	28.2
14-16	38.2
16-18	54.9
18-20	46.1

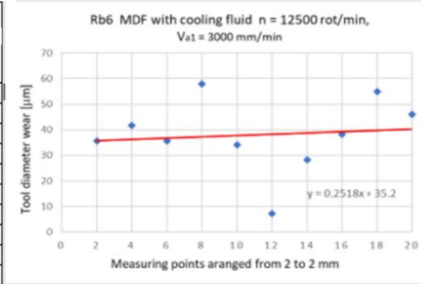


Fig. 16. Diameter wear for MDF with feed speed 3000 mm/min and speed 12500 rpm with cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	54,9
2-4	81.6
4-6	682.5
6-8	fracture
8-10	-
10-12	-
12-14	-
14-16	-
16-18	-
18-20	-

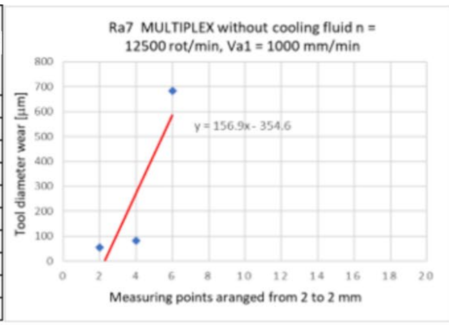


Fig. 17. Diameter wear for MULTIPLEX with feed speed 1000 mm/min and speed 12500 rpm without cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	40
2-4	36.9
4-6	43.2
6-8	54.4
8-10	62.8
10-12	48.9
12-14	39.5
14-16	50.6
16-18	36.6
18-20	48.2

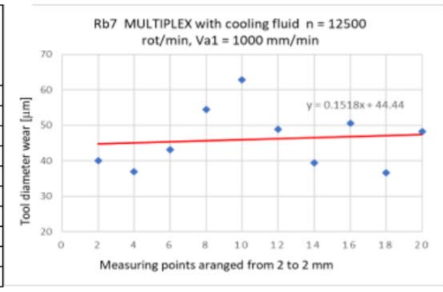
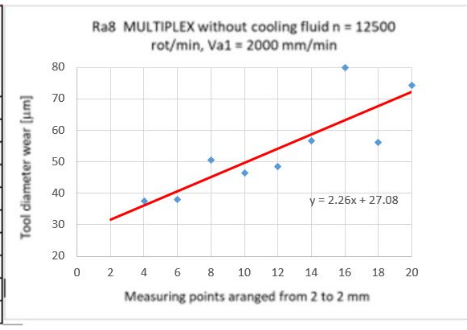


Fig. 18. Diameter wear for MULTIPLEX with feed speed 1000 mm/min and speed 12500 rpm with cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	89.1
2-4	37.4
4-6	38
6-8	50.6
8-10	46.4
10-12	48.4
12-14	56.6
14-16	79.8
16-18	56.2
18-20	74.4



Diameter measurement cross sections	Tool diameter wear [µm]
0-2	12.8
2-4	36.9
4-6	31.6
6-8	33.6
8-10	61.5
10-12	55.6
12-14	52.7
14-16	41.4
16-18	57.6
18-20	50.6

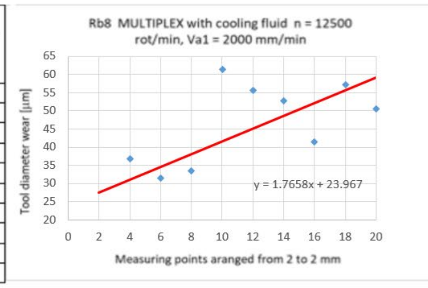


Fig. 19. Diameter wear for MULTIPLEX with feed speed 2000 mm/min and speed 12500 rpm without cooling fluid.

Fig. 20. Diameter wear for MULTIPLEX with feed speed 2000 mm/min and speed 12500 rpm with cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	87.1
2-4	84.3
4-6	90.5
6-8	85.5
8-10	82.6
10-12	54.7
12-14	87.8
14-16	92.6
16-18	110.8
18-20	107.8

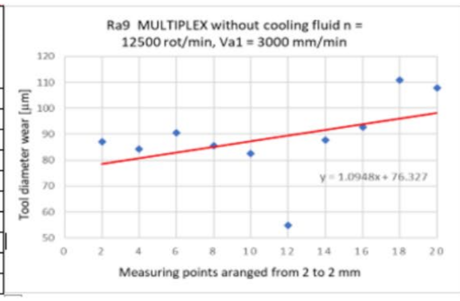


Fig. 21. Diameter wear for MULTIPLEX with feed speed 2000 mm/min and speed 12500 rpm without cooling fluid.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	13.5
2-4	63.8
4-6	57.9
6-8	55.2
8-10	62.7
10-12	56.9
12-14	61.8
14-16	77.7
16-18	57.5
18-20	52.8

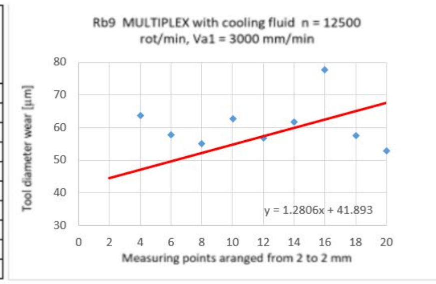


Fig. 22. Diameter wear for MULTIPLEX with feed speed 2000 mm/min and speed 12500 rpm with cooling fluid.

6. CONCLUSIONS

Analyzing the wear of the front cylinder cutters, we distinguish the following:

For chipboard, it can be seen from the first graphs (Figs. 5 and 6) that the wear of the cutter diameter is much more pronounced in the version without cooling fluid than with cooling fluid. We observe the same thing in the graphs in Figs. 7–10, in other words the slope of the line in the case without cooling fluid is higher than in the case with cooling fluid.

For MDF, the analysis of graphs Figs. 11–16 shows that the range of values related to tool wear are greater in the version without cooling fluid than in the version with cooling fluid.

For MULTIPLEX we notice that in graph in Fig. 17a fracture of the milling cutter occurred due to the high cutting forces. The slope of the right is very high, which leads to the explanation that it is recommended to change the processing regime. In the case of graphs in Figs. 19 and 20, by changing the cutting regime, more pronounced wear is also observed in the case without cooling fluid compared to the one with cooling fluid.

From the general analysis of tabular data and graphs, it can be said that the present research has highlighted the fact that regardless of the cutting regime used, tool wear is more pronounced in the case of "cold" processing, i.e. without coolant, than in the case with cooling fluid (compressed air). Thus, it can be recommended to users in the industry of processing wooden composite materials, the use of a cooling agent in all cases of processing, in order to reduce the wear of tools and in this way increase their durability.

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