UNIVERSITATEA NAȚIONALĂ DE ȘTIINȚĂ ȘI TEHNOLOGIE POLITEHNICA BUCUREȘTI

THESIS

THESIS SUMMARY

Studies and experimental research on the optimisation of processing regimes for wood composite materials

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Introduction

As a result of my work as an entrepreneur of a processing company in the furniture industry, I have always encountered problems related to tool wear in the machining of wood composite materials.

Most of the time the wear of the tools created a majordifficulty for us and we had to look for solutions to increase their durability.

We also chose melamine chipboard, MDF and MULTIPLEX as working materials, each with different physical and mechanical characteristics.

The importance of the current PhD thesis lies in finding, on an experimental basis, the factors that determine tool wear. I used as experimental method a scenario in which the experiments were done once "*cold*", i.e. normal machining under different machining regimes and another set of experiments using as coolant compressed air under the same machining regimes.

The second situation arose as a result of the experience accumulated over time and inspired by the similarity of machining by metal cutting using cooling emulsion, so in our case water being excluded we turned to *compressed air* coolant.

The results of the experiments showed an increase in tool life due to the use of *air* coolant.

The experiments were done on the CNC machine EVOLUTION 7405 4 mat. The use of the CNC machining machine allowed us to use those machining regimes most often encountered and recommended by the machine manufacturer. The samples used in the experiments were randomly cut from large slabs of 2800 mm x 2100 mm material with dimensions of 300 mm x1100 mm. We set the machining length to be approx. 10000 mm for each machining regime.

So three cylinder-front milling cutters were used for three different machining regimes and three different materials (melamine-faced chipboard, MDF and MULTIPLEX) in the two versions proposed without coolant and with coolant.

The entire set of experiments was done using a FLIR CX Series thermal imaging camera, which allowed the measurement of the temperature of the milling cutter in the machining area throughout the experimental process. (2).

Thus, the dependence of the machining speed (speed, feed rate) on the temperature developed by the milling cutter in the vicinity of the machining process for different composite materials was revealed.

The objectives of the experimental research are to find a dependence relationship of working parameters for wood composite materials used in the furniture industry. The tool wear is related to the tool wear and at the same time the heat released in the machining process indicates the degree of tool wear, thus determining the tool durability.

This paper therefore presents part of a study of high-speed steel tools, the most commonly used in the woodworking industry, determining the dimensional wear of their diameter and the radius of the cutting edge as a function of speed, feed rate and materials of different densities.

Thus, a base of experimental data presented in the content of the thesis was obtained and processed using the *least squares method*, with the idea of obtaining an interdependence relationship between wear variation and different chipping regimes.

The originality of the PhD thesis lies in the fact that I came up with this idea of using cooling fluid in the machining process in the form of compressed air sent to the work area by means of a nozzle. It was found that there is a clear dependence between cold machining and coolant machining, thus contributing to increase the durability of the tooling (high speed steel tools).

The research was limited to the use of some of the most commonly used wood composite materials in the furniture industry, using different machining regimes, highlighting the increase in temperature developed in the tool, thus leaving the possibility of establishing new machining regimes in the future for other types of tools (reinforced with metal carbide or diamond-tipped inserts).

Part I.

Current state of the market for furniture, wood composites and processing equipment used in the furniture industry

Chapter 1.

1.1. General. Internal and external market

From the latest reports presented by the specific bodies of the furniture industry, an almost constant growth from year to year has been observed, on average 7%, so that in 2022 the furniture industry has grown by 95% compared to 2021, both in domestic production and export. [1].

The furniture market has evolved in recent years even as we have faced the global pandemic[2].

Romania exports massively to Germany (18.5%), France (13.8%), Italy (8.9%), the Netherlands (7.3%), Slovakia (7.3%), the UK (5.3%), the Czech Republic (4.9%), and a significant increase is recorded in furniture exports to the United States of America, of about 3% of total Romanian furniture production. Exports are also increasing to Switzerland, Hungary, Portugal, etc.

In 2023, production for the first 6 months of the year increased by 3% compared to the same period in 2022, which leads us to expect a slight increase despite the fact that raw materials have become more expensive[3].

1.2. The competitive environment of the Romanian furniture market

The furniture industry at national level represents exports of about two billion euros per year. It is considered the second sector after IT in terms of added value in production. The unjustified increase in the price of wood and the rise in the price of energy have led to some companies making losses and some even closing down. At the same time due to the war in Ukraine we lost many export markets (Russia, Ukraine Belarus, Latvia, Estonia, Lithuania etc.).

The Association of Furniture Manufacturers in Romania (A.P.M.R.) has asked the competent authorities to declare the furniture industry as a strategic sector for the Romanian economy and to support this sector by issuing laws to cap the price of wood.

Conclusion

The furniture industry market is booming. Woodworking equipment is evolving and automating year by year.

The tools used to machine composite materials are evolving from high-speed steel tools, carbide-tipped tools, diamond powder-tipped tools and tools based on laser technology**.**

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Chapter 2.
Main wood composite materials and wood processing equipment used in experimental studies and research

2.1 Wood composite materials

2.1.1 Melamine coated chipboard

Wood composite materials have become increasingly popular in the construction industry and furniture production due to their outstanding strength, durability and versatility. Among these materials, melamine-laminated particleboard (Melamine Lignosulphonic Acid Pressed) occupies an important place. This paper aims to explore the physico-mechanical characteristics, marketing, chemical composition and manufacturing of this woody composite material.

a) **Physical and mechanical characteristics of melamine-faced chipboard**

Melamine (Melamine Lignosulphonic Acid Pressed) chipboard is a wood composite material commonly used in the furniture, construction and interior finishing industries. This category of material has distinct physical-mechanical characteristics that make it valued for various applications.

Wear resistance

Melamine chipboard is characterised by a remarkable wear resistance. This property is due to the melamine surface layer covering the chipboard. Melamine is a tough, scratch and abrasion resistant material, making melamine chipboard suitable for surfaces that are subject to constant wear, such as table tops and worktops.

Moisture resistance

Another important aspect of the physical-mechanical characteristics of melamine chipboard is its resistance to moisture. Due to its chemical composition and manufacturing process, this material can withstand relatively high humidity without swelling or losing its structural integrity. This quality makes it suitable for use in damp spaces such as kitchens and bathrooms.

Dimensional stability

Melamine chipboard is known for its dimensional stability. This material does not undergo significant shrinkage or expansion under temperature and humidity variations. This is particularly important in construction and furniture, where it is necessary to maintain the original dimensions and shape to ensure proper long-term functioning.

Temperature resistance

Melamine chipboard can withstand high temperatures without changing its mechanical properties or appearance. This characteristic makes the material suitable for use in kitchens, where surfaces may come into contact with hot objects such as dishes with freshly cooked food.

Melamine chipboard offers good deformation stability, which means it is unlikely to bend or buckle under load. This property makes melamine chipboard an excellent option for shelving, cabinets and other structural furniture components.

Impact resistance

This material is relatively resistant to minor dents and impacts, making it suitable for use in high traffic areas, such as replacing flooring or for use in commercial or residential floors.

b) **Chemical composition of melamine chipboard**

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

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

Lignin: Lignin is a complex organic substance found in wood cells. It plays an important role in binding wood fibres and gives melamine-treated chipboard a certain strength and stiffness.

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

Melamine paper A melamine paper containing various patterns and colours is applied to the surface of the melamine chipboard. This layer of paper is not only aesthetically pleasing but also helps to protect the surface and create an attractive finish.

c) The role of components in the properties of melamine chipboard

Wood fibres provide structure and mechanical strength. They are responsible for the stability and durability of the material. Wood fibres in chipboard are often small in size and evenly distributed to ensure homogeneity and strength of the material.

Lignin is responsible for the adhesion of the wood fibres and gives the melamine chipboard a certain rigidity. However, the excessive presence of lignin can lead to a lower quality of the chipboard.

Melamine resin is a key element in making melamine chipboard moisture and temperature resistant. It acts as a bonding agent between the wood fibres and prevents the penetration of moisture or other substances.

Melamine paper adds to the aesthetic appeal of melamine chipboard. It offers a wide range of surface finish patterns and colours, making chipboard visually attractive.

The chemical composition of melamine particleboard is essential for defining the characteristics and performance of this woody composite material. Wood fibres, lignin, melamine resin and melamine paper work in concert to give melamine chipboard strength, stability and attractive appearance. This combination of components makes melamine chipboard a popular choice in the furniture and interior finishing industry.

2.1.2 MDF (Medium Density Fibreboard)

Wood composite materials - MDF

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

a) Physical and mechanical characteristics of MDF

MDF has a number of physical and mechanical characteristics that make it attractive for various applications:

Bending and compressive strength

One of the most notable aspects of MDF is its resistance to bending and compression. This material is made by pressing wood fibres with a binding agent such as formaldehyde at high temperatures and under pressure. This processing gives MDF a dense and uniform structure, which allows it to resist bending well. This makes MDF ideal for use in the manufacture of doors, table tops, shelving and other furniture components that need to withstand significant loads.

Dimensional stability

MDF is known for its dimensional stability. It does not expand or contract significantly under variations in temperature and humidity, making it suitable for use in a variety of environments. This dimensional stability also makes MDF an excellent option for interior finishes, such as decorative wall panels or panelling, which need to retain their appearance over time.

Moisture resistance

Although standard MDF is not moisture resistant, there are treated versions that retain their integrity in wet environments. These types of MDF are often used for the construction of furniture or bathroom fittings that come into contact with water or moisture. Treatment with hydrophobic agents or the use of moisture-resistant resins helps to improve this characteristic.

High quality finish

MDF has a smooth and even surface, making it suitable for the application of high quality finishes. This uniform finish allows the application of paints, varnishes and other finishing agents to achieve superior aesthetic results. The MDF surface can also be easily sanded to achieve a perfect finish.

Ease of processing

Another notable advantage of MDF is its ease of processing. This material can be cut, punched, milled and shaped with ease, making it suitable for a wide range of applications and creative projects. It is highly adaptable to various processing techniques, making it a favourite in woodworking and woodworking workshops.

In conclusion, the physical and mechanical characteristics of MDF make it an extremely valuable material in various industries. Its strength, dimensional stability, moisture resistance, high quality finish and ease of processing contribute to its continued popularity and versatility in a variety of applications, from furniture to interior finishing and construction. MDF continues to be a preferred material for manufacturers and builders looking to combine durability with aesthetics.

b) Chemical composition of MDF

MDF (Medium Density Fibreboard) is a wood composite material that is extremely popular 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 components:

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

- Adhesive - Adhesive is used to bind and strengthen wood fibres. 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 chemical compounds - During the manufacturing process, water and some auxiliary chemicals, such as fillers or dispersing agents, may be added to improve the processability of materials or to adjust certain characteristics.

c) The role of components in the properties of MDF

Wood fibres form the structural backbone of MDF. They give the material mechanical strength, dimensional stability and density. The quality and size of these fibres have a significant impact on the final properties of MDF.

The glue is the binding element that ensures cohesion between the wood fibres. The type of adhesive used can determine the moisture resistance, temperature resistance and formaldehyde emission levels of MDF. To reduce environmental impact and meet safety standards, more and more adhesive formulations with low formaldehyde emissions are being developed.

Water and auxiliary chemicals can affect the manufacturing process and the properties of MDF, such as density and surface texture. Fillers can be added to improve strength or reduce production costs.

d) Impact of chemical composition on MDF properties

-Mechanical strength - The wood fibres and the type of adhesive used are essential in determining the mechanical strength of MDF. A high quality MDF will have uniform wood fibres and a strong adhesive, making it suitable for use in construction or furniture production.

-Dimensional stability - The composition of MDF and the manufacturing process directly influence its ability to maintain its dimensions under various environmental conditions. A well-manufactured MDF with uniform fibres will be more stable in environments with variations in temperature and humidity.

-Humidity resistance - The right choice of adhesive and the right treatment can make all the difference to the moisture resistance of MDF. This is an important feature when using MDF in wet environments or near water.

-High quality finish - The smooth and uniform surface of MDF allows for high quality finishes. This makes MDF the preferred choice for applying paints, varnishes or other decorative finishes.

In conclusion, the chemical composition of MDF plays a fundamental role in determining its properties and performance. Wood fibres, adhesive and other auxiliary factors influence the strength, stability, moisture resistance and finish of the material. The right composition and proper processing contribute to MDF's versatility and durability, making it a preferred material in a wide range of applications.

Conclusion

MDF is a wood composite material with outstanding physical and mechanical characteristics, available in various sizes and thicknesses. Its chemical composition and the way it is manufactured make it a versatile material for the furniture, construction and interior decoration industries.

As requirements for MDF become more varied and specific, the industry continues to develop advanced technologies to improve the manufacturing process and the quality of the end products. For example, work is underway to develop adhesives with low formaldehyde emissions to meet environmental and health regulations. It is also experimenting with more energy-efficient manufacturing processes and the use of recycled fibres or alternative lignocellulosic materials to make MDF more sustainable.

Quality control and technological innovations continue to improve the quality and performance of MDF, making it a preferred choice in a wide range of industrial and commercial applications.

2.1.3 MULTIPLEX

MULTIPLEX, also known as plywood, is a wood composite material that has earned a well-deserved place in the construction, furniture and many other industries. This impressive material is distinguished by its outstanding physical and mechanical characteristics, making it the ideal choice for a wide range of applications.

a) Physical and mechanical characteristics of MULTIPLEX:

MULTIPLEX's impressive physical and mechanical properties make it a preferred material in many industrial and commercial fields. Its bending and tensile strength, dimensional stability, ease of processing and versatility in various environmental conditions make it a staple material in furniture, construction and many other applications.

We explore the key features of MULTIPLEX that make it shine in the world of composite materials.

- Bending and tensile strength

One of the most notable features of MULTIPLEX is its impressive bending and tensile strength. This material is manufactured by bonding several layers of wood veneer, which are arranged so that the fibres are alternately oriented. This layered structure gives MULTIPLEX exceptional resistance to mechanical forces. It is therefore frequently used in the construction of furniture, shelving, worktops and even in building for strong structures.

- Dimensional stability

MULTIPLEX is also distinguished by its outstanding dimensional stability. It retains its original dimensions and shape under conditions of temperature and humidity variations. This is particularly important in applications such as furniture, where dimensional changes can lead to damage or deformation of parts.

- Ease of processing

Another notable advantage of the MULTIPLEX is its ease of processing. This material can be cut, drilled, milled or shaped with ease, making it a preferred choice in the woodworking industry. This adaptability to different processing techniques makes it suitable for custom or mass production projects.

- Resistance to humidity and variable temperatures

MULTIPLEX can be treated to give it moisture resistance, making it suitable for use in wet or marine environments. It also resists temperature variations well, making it suitable for both indoor and outdoor projects.

- High quality finish

The MULTIPLEX surface is smooth and uniform, allowing for high quality finishes. This makes MULTIPLEX an ideal choice for painting, varnishing or applying decorative veneers.

b) Chemical composition of MULTIPLEX

The chemical composition of MULTIPLEX is an essential aspect in understanding the characteristics and properties of this versatile material. In this article, we explore the chemical composition of MULTIPLEX and its role in determining the qualities of this material.

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

The chemical composition of MULTIPLEX includes the following main components:

1. Wood veneer - Veneers are thin layers of wood obtained by cutting the wood into sheets. They are the basic material of MULTIPLEX and are usually made of softwood such as pine, birch or beech.

2. Adhesive - Adhesive is used to bond 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, low formaldehyde adhesives are now being developed and used to meet environmental and health regulations.

3. 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.

c) Role of components in MULTIPLEX properties

- Wood veneer:
Wood veneers give MULTIPLEX mechanical strength and dimensional stability. The layered structure of the veneers, with alternately oriented wood fibres, contributes to the strength of the material.

- Adhesive
The adhesive is the bonding element that ensures the cohesion and strength of the MULTIPLEX structure. The type and quality of adhesive can influence the strength, moisture resistance and formaldehyde emissions of the material.

d) Properties of MULTIPLEX derived from the chemical composition

-Mechanical strength
The layered structure and the strong bond provided by the adhesive give MULTIPLEX excellent mechanical strength, making it suitable for use in applications requiring increased strength, such as construction or furniture manufacture.

-Dimensional stability:
The chemical composition and manufacturing process contribute to the dimensional stability of MULTIPLEX, which means that it retains its original dimensions under varying environmental conditions.

-Humidity resistance:
Many types of MULTIPLEX are treated to give them moisture resistance, allowing them to withstand wet or marine environments.

-Ease of processing:
Its composition allows MULTIPLEX to be easily cut, drilled, milled or shaped, making it suitable for various woodworking applications.

In conclusion, the chemical composition of MULTIPLEX is fundamental in determining its characteristics and properties. Wood fillers, adhesive and the hot pressing process are key factors contributing to the strength, stability and versatility of this material. MULTIPLEX remains a staple material in the construction industry, furniture and many other areas due to its unique combination of durability and adaptability.

Conclusion
MULTIPLEX is a wood composite material appreciated for the outstanding physical-mechanical characteristics it offers. Its strength, stability, ease of

processing and versatility make it a popular choice in various industries. Its composition of layers of wood veneer and adhesive gives MULTIPLEX strength and durability, and the manufacturing process ensures the quality and uniformity of this material.

Chapter 3.

THE DYNAMICS OF THE CUTTER GEOMETRY USED IN THE RESEARCH

3.1 Choosing the right equipment.

In the PhD thesis an analysis of the wear phenomena occurring during the machining of different types of pale conglomerate materials using cylindrical-frontal (finger) milling cutters will be developed. In the process of furniture production, the wood boards of the pale type are subjected to a complex processing, of which, this study will focus on the processing with finger milling cutters of ϕ 10mm. These pre-machining operations lead to a number of problems related to tool wear. The determination of the study data was done using GOM Software 2021. This system requires minimum:

- Intel Core i3, recommended Intel Core i7,
- 4GB Ram, recommended 16GB Ram,
- OpenGL compatible graphics station,
- Windows 10, 64Bit with Security.

One of the main features of the GOM INSPECT software [1] is the possibility to compare the measured *mesh* object with the theoretical CAD model. 3D scanned objects digitally represented in 3D by polygonal meshes, can include complex surfaces with organic shape (free-form), or with simple surfaces (flat or curved). These can be compared with the drawing or directly with the CAD dataset using a surface comparison.

It can perform a 3D inspection of surfaces as well as a 2D analysis of sections or points. The parametric approach ensures traceability of all process steps, thus guaranteeing process reliability for measuring results and reporting. *Trend* analysis, statistical analysis, allows the comparison of several parts in a single project. SPC (Statistical process control) parameters are also included.

With GOM software [1] surface defects can be easily assessed. Optical measurement technology allows reproducible assessment of surface defects in series production. To ensure that the representation of surface defects is directly adapted to the shape of the part, GOM software offers the possibility to inspect surface defects even on a curved part. The software also automatically calculates the orientation of the surface normals.

ATOS Capsule systems [1] are used for the high accuracy they confer in the analysis of small and medium-sized landmarks.

ATOS Capsule is useful in industrial environments [1], for the quality of the data obtained. The blue light projector ensures accurate measurement in a short time and regardless of ambient lighting conditions. With a resolution of 8 or 12 Megapixels, ATOS Capsule provides clear, precise and repeatable images of details.

Fig 3.1 - ATOS Blue Light Capsules

ATOS Capsule achieves maximum efficiency on GOM ScanCobot and in ATOS ScanBox 4105 [2]. It is a system that ensures optimal productivity and reliability in serial dimensional inspection.

The ATOS Capsule system can be configured in many variations. The 2 resolution variants (8 or 12 MegaPixels) with 5 measuring volumes (MV40, MV70, MV120, MV200, MV320) allow detailed measurement for a dimensional range of parts from 50mm to 500mm.

Fig 3.2 - ATOS system with GOM Touch Probe.

The ATOS system, combined with the GOM Touch Probe, displays the position of the measured items in real time on the GOM Touch Probe PC screen [2].

ATOS Plus is an add-on device for all ATOS 5 and ATOS Capsule configurations in an automated environment. The system can only be used in conjunction with a robot in ATOS Scanbox measuring cells. It allows the measurement of reference points with a deviation from 3 μm to 30 μm. These reference points create a 3D volume, in which the detailed individual measurements of the ATOS sensors are automatically transformed. This allows reference marks on the surface of the object to be measured to be captured using photogrammetry cameras.

3.2 Wood processing.

The most common method of processing wood is by removing part of the material [3]. There are four main ways of processing wood:

- By cutting (with a sharp tool - turning, milling, planing, or without sharp tools - water jet),
- By abrasion (grinding, shaping),
- By deformation (bending, shrinking),
- By combustion (laser).

3.2.1 Chipping modes. A two-number naming system is frequently used to describe the main situations that may arise in the machining process. The first number represents the angle between the cutting edge of the tool and the wood grain, while the second number indicates the angle between the cutting direction and that of the wood grain. (Fig. 3.3):

There are three basic cuts:

- 90°-0° present in several woodworking processes, such as crosscutting, hand planing, i.e. in any woodworking carried out parallel to the grain. In the case of rotary tools, the cutting mode is never 100% 90°-0°, but may be similar to planing, sanding, longitudinal milling (peripheral breaking or "contouring"). This mode of machining is the most commonly used.
- 90°-90° requires much greater cutting efforts,

0°-90° requires less cutting effort as the fibre is not severed [4].

Cutting of the 90°-0° type can only be done in three ways: by compression splitting or by buckling.

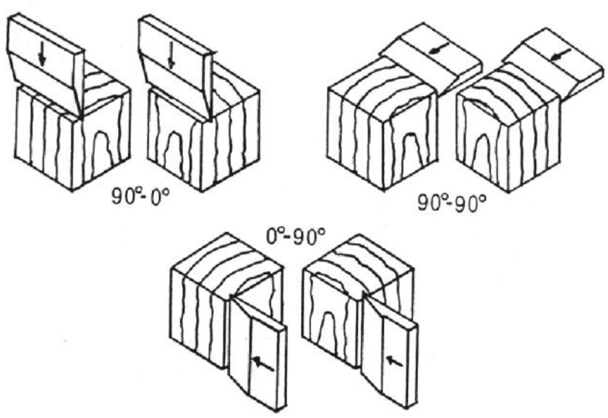

Fig. 3.3 - Main types of orthogonal cutting.

3.2.2 Chip types in longitudinal and circular machining.

In general, three types of chips can be distinguished [5], highlighted in Fig. 3.4:

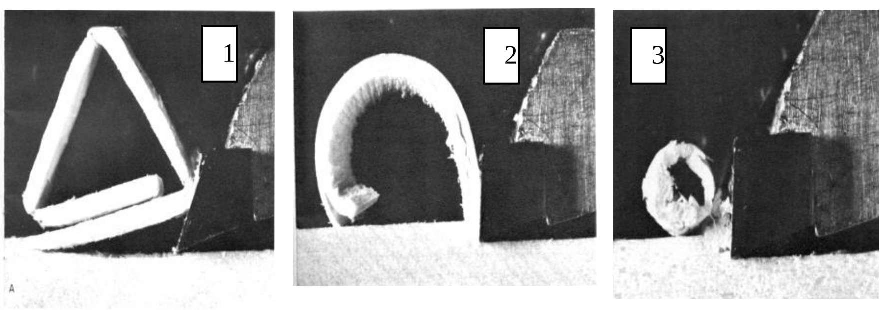

Fig. 3.4 - Chip formation in 90°-0° mode with rectilinear movement.

There are two fundamental differences between straight and circular motion chipping: in the latter, the chip thickness is variable and the direction of the cutting forces changes at any time. These two effects influence chip formation, but the three types of chip described above coexist during a cycle.

Figure 3.5 shows the formation of the chip in 90°-0° mode in circular motion and the correspondence with the classification of chip types. Chipping parameters related to the tool geometry (angles of attack, draft and edge inclination) are also chosen to limit defects and reduce cutting efforts to save energy consumed during machining. A high angle of attack promotes sharp edge penetration and causes fibre breakage, on the other hand, a low angle of attack increases the forces due to tool friction.

In our thesis the chipping parameters will be chosen to promote the formation of chip type 2 in order to avoid as much as possible inherent defects during machining. The notations used are

F_c: chipping force
F_f : t
F_{fN} : n

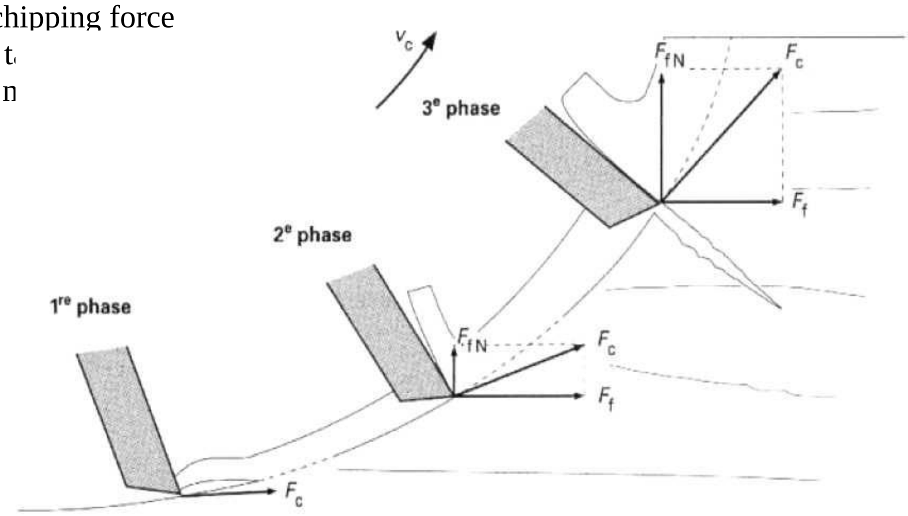

Fig. 3.5 - Chip formation in 90°-0° mode in circular motion and correspondence with classification of chip types

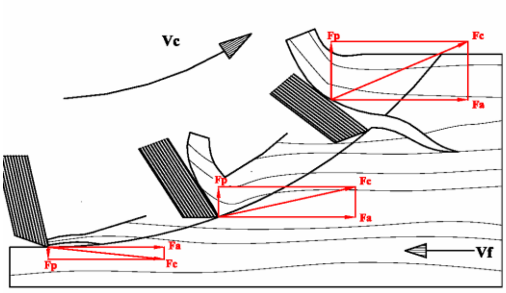

Fig. 3.6 a - Opposite chipping

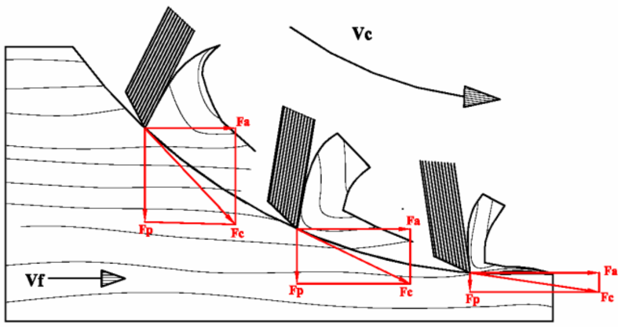

Fig. 3.6 b - Matching the slippage

Beyond that, we believe we are in the business of high-speed processing. Given the wear of chipping tools that increases with speed, it is reasonable to set an average speed of 50 m/s, with the possibility of reducing it slightly to 40 m/s for low wear resistant tools (high speed steel) or hardwoods and increasing it slightly (60 to 70 m/s) for softwoods**.** In practice and given the values (Vc of the order of 50 m/s and Vf rarely exceeding 100 m/min), it is usual to neglect the influence of feed speed on cutting speed.

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Chapter 4.
Woodworking equipment used in the experiments in this thesis

4.1 CNC EVOLUTION 7405 4mat (Computer Numeric Control)

CNC (Computer Numerical Control) machining machines represent a significant innovation in the wood and materials processing industry. The Evolution 7405 4mat CNC machine is an impressive example of advanced technology in this field.

Key features of the Evolution 7405 4mat CNC machining machine:

1. *Advanced Numerical Control* - The Evolution 7405 4mat is equipped with an advanced numerical control system that allows precise programming and monitoring of machining operations. This feature provides extreme accuracy in working with materials and consistent reproduction of shapes and dimensions.

2. Equipment - *4* independent *working axes*, which gives it extraordinary versatility in processing materials. With these four axes, the machine can perform a wide range of operations, including milling, cutting, punching and chipping.

3. *Advanced Gripping and Fixing System* - Evolution 7405 4mat has a powerful gripping and fixing system. This allows secure clamping of workpieces during machining, which reduces vibration and ensures high quality machining.

4. *Touchscreen Control* - The machine is equipped with an intuitive touchscreen control panel that makes programming and operation easier. Users can enter parameters and instructions directly on the screen, which reduces human error.

5. *Advanced Software* - The Evolution 7405 4mat comes with advanced software that allows complex programming of operations and provides additional functionality to optimise the machining process.

Conclusion

The Evolution 7405 4mat CNC machining machine is an outstanding example of state-of-the-art technology in the wood and materials processing industry. With its advanced functionality and versatility, it brings increased efficiency, precision and flexibility to production processes and is crucial in achieving high quality results in this industry.

4.2 ATOS ScanBox BPS system

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

1. *High Accuracy 3D Scanning Technology* - This system uses structured light 3D scanning technology to accurately capture the shape and dimensions of objects. This technology provides accurate and detailed results, including measurements of complex geometry and free surfaces.

2. *Advanced Automation* - The 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 error and helps increase process efficiency.

3. *Quality Control* - The system is equipped with powerful analysis software that allows users to assess the quality of measured objects. It can identify deviations from desired specifications and help to remedy them in the production process.

4. *Adaptability and Flexibility* - The ATOS ScanBox BPS is adaptable and can be used in a variety of industries such as automotive, aerospace, electronics, cast or machined parts production and more. This versatile system can address diverse user needs.

4.3 Uses of the ATOS ScanBox BPS system

1. *Production Quality Control* - 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.

2. *Reverse Engineering* - ATOS ScanBox BPS is used to create accurate 3D models of existing objects. This is useful in reverse engineering for reproducing or improving existing products.

3. *Design and Development* - In the design and development phase, the system can be used to perform measurements and analysis on prototypes and parts created to verify conformance to original specifications.

4. *Tool and Die Making* - In tool and die making, the system helps ensure accurate dimensions and identify wear or damage.

Conclusion

The ATOS ScanBox BPS is a leading solution in the 3D measurement and quality control industry. With its advanced technology, it helps increase the efficiency of production processes while ensuring that products and components comply with specifications and quality standards. This system is essential in the development and production of high quality products.

4.4 FLIR CX SERIES Thermal Imaging Camera

FLIR CX-Series is a line of thermal cameras developed by FLIR Systems, a global leader in thermal technology. These thermal cameras are designed for temperature measurement in a variety of industrial and commercial applications. They use infrared technology to detect and display object temperatures, allowing users to quickly identify and assess temperature variations in a given environment.

4.4.1 Main features of the FLIR CX-Series temperature meter

1. *High resolution* - The CX series cameras are equipped with high-quality thermal sensors that provide excellent image resolution. This high resolution allows users to clearly distinguish subtle details and take accurate temperature measurements.

2. *Real-time thermal images* - The FLIR CX-Series temperature meter provides real-time thermal images, which means users can see temperature

variations dynamically on-screen in real time. This is a valuable feature for monitoring processes and quickly identifying potential problems.

3. *Accurate, non-contact measurements* - CX series instruments allow the temperature of objects to be measured without the need for direct contact. This is particularly important in industrial applications where access can be difficult or dangerous.

4. *Analysis and Reporting* - CX-Series cameras are equipped with advanced analysis software that allows users to perform detailed temperature analysis and create custom reports. This is useful in evaluating quality and performance in a variety of applications.

5. *Connectivity and integration* - CX series thermal chambers are designed to be easily integrated into existing systems. They can be connected to communication networks and communicate with other devices or software for more efficient monitoring.

Conclusion

The FLIR CX-Series temperature meter is a high-quality solution for temperature measurement and monitoring in various industrial and commercial applications. With its ability to provide real-time thermal imaging, advanced analysis and non-contact, it is a valuable tool for improving efficiency, safety and quality in a variety of fields.

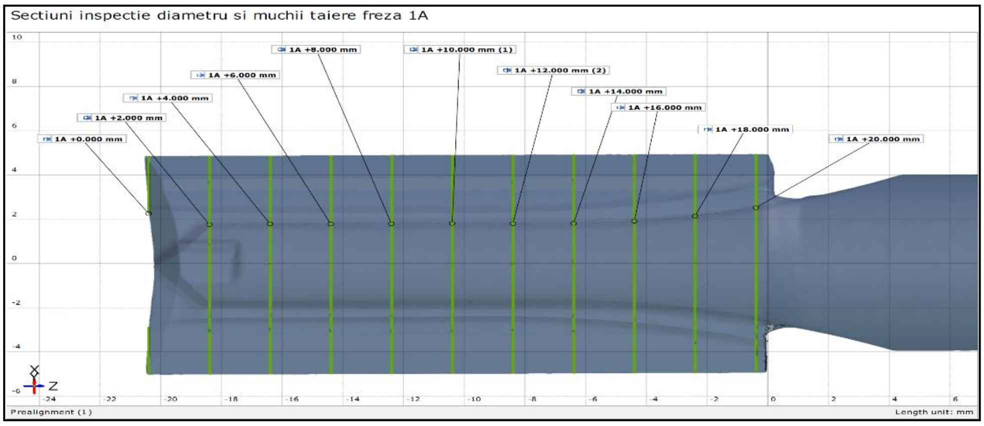


Fig. 4.1. Sections where the cutter diameter dimensions were measured

Part II.

Experimental research on the optimization of processing regimes for wood composite materials

Chapter 5.

CHIPPING REGIME RESEARCH METHODOLOGY

5.1 Description of the set of cutters used during the research.

Using the ATOS Capsule system, measurements were made in the initial state before use for a batch of nine Ø10 cylinder-front milling cutters, the decision on the equipment to be used was made after trials with three ATOS variants, fig 5.1, the best results being obtained with ATOS Capsule MV 70) :

The parametric approach ensures the traceability of all process steps, thus guaranteeing the reliability of the measurement process. Trend (statistical) analysis, allows comparison of several tools.

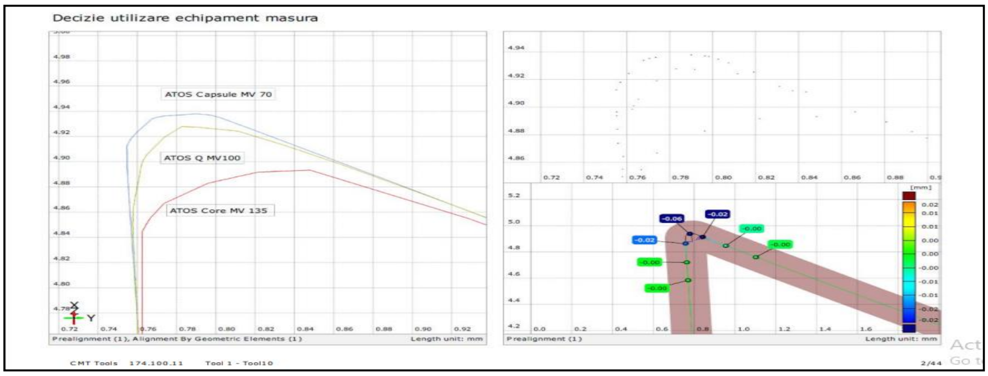


Fig 5.1. - Comparison between the three usable equipment.

SPC (Statistical Process Control) parameters, (Pp, Ppk, Cp, Cpk), are included. Results are displayed using tables, charts and graphs. An extract of Trend analysis from the set is shown in Fig. 5.2 and 5.3. For each milling cutter, the areas and their sizes were determined for measurement purposes. Reference dimensions and active angles were followed as follows, Fig. 5.2.

The two batches of nine cutters measured (one without cooling air jet -A, the other with cooling air jet-B) each went through several steps, exemplified in each case by the measurement results, within or outside the permissible limits. Two angles of the active edges were measured, specifying the position of the measuring section, the radius of the edge, the angle at the tip, after which summary tables of the results obtained were compiled.

The cylinder-front milling cutters under experiment have the diameter of the cylinder circumscribed to the active cutting part, ϕ 10mm, which is the diameter of the channel to be machined with this milling cutter, and that of the cylinder at the bottom, ϕ 8.5mm - noted cylinder 1. The length of the active part is 20mm. Two active angles, 1 and 2, of 58° each, will be measured in this area. The angle at the tip of the cutter, measured in two positions, noted 5 and 6, is 142°.

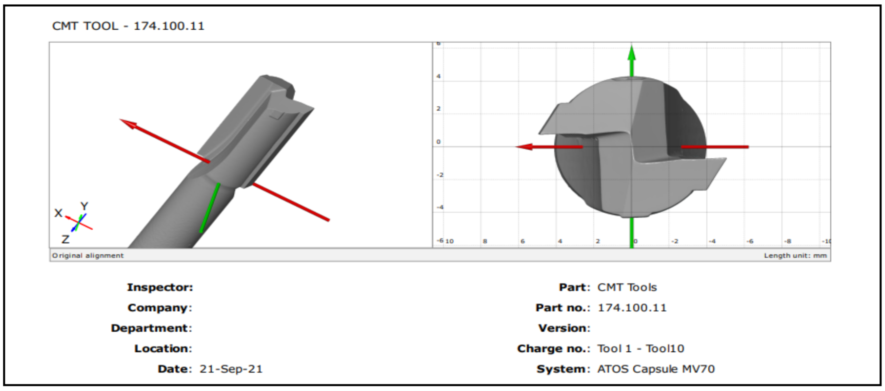


Fig. 5.2 - Reference section for measurements.

The length of the active part of the cutter was divided into 10 zones, resulting in 10 measurement sections, Fig 5-3:

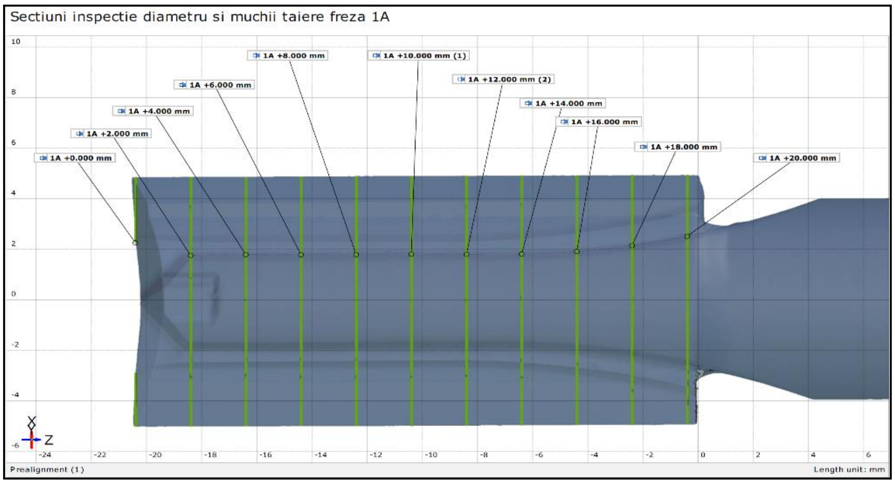


Fig. 5.3 - Diameter measurement sections and cutting edges.

After machining (Fig. 5.4) with the set of nine cutters, which we will note S-1a, S-2a..., S-9a, in groups of three, corresponding to the material machined (type of composite) and the cutting speed, we will remeasure the parameters of each tool and highlight the wear produced.

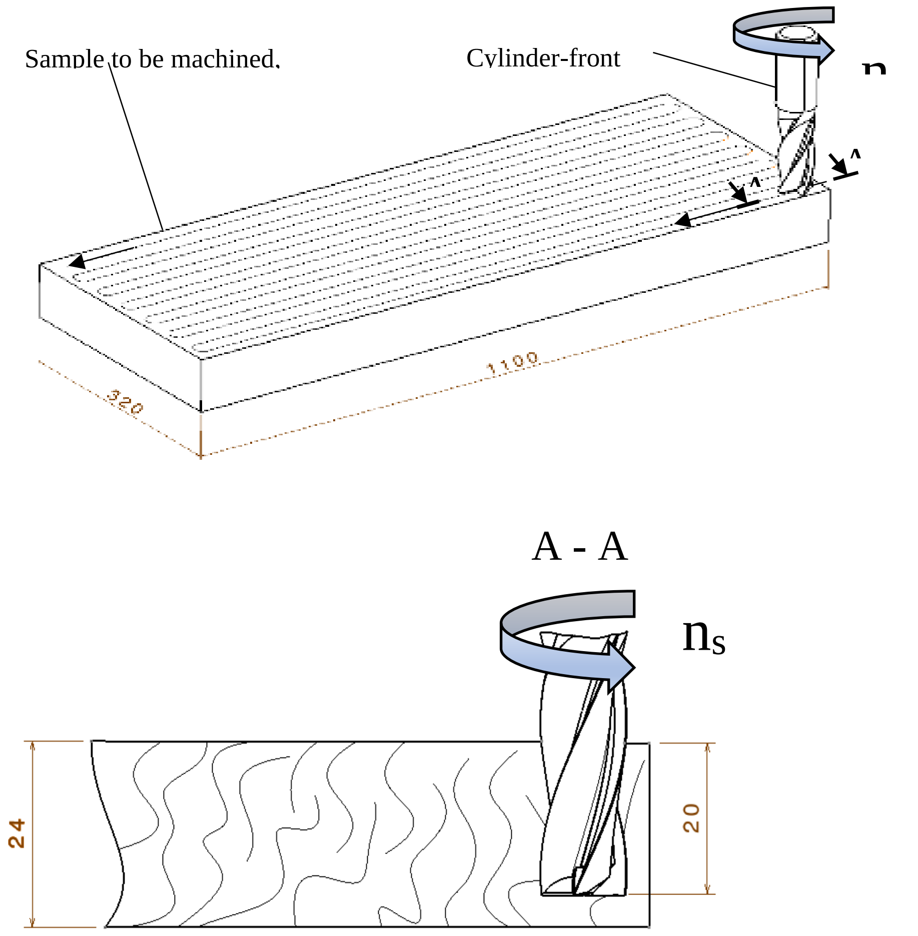


Fig 5.4 - General scheme for processing composite samples.

During machining, the 7405 CNC machine is monitored by the Terma CAM 640 camera.

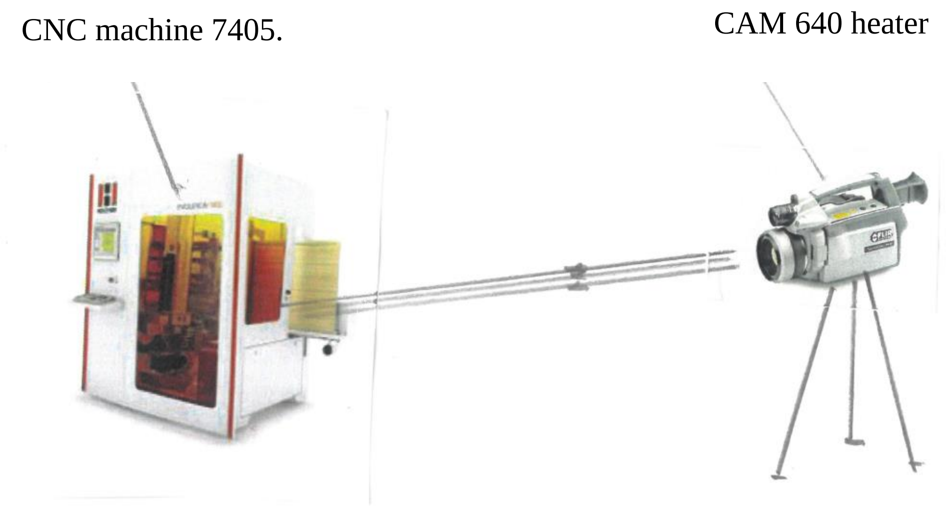


Fig 5.5 - Thermal monitoring scheme of the machining process.

To improve the machining process, we propose the use of a tool cooling system (cylinder-front milling cutter), using a cold air jet, as in Fig 5-6.

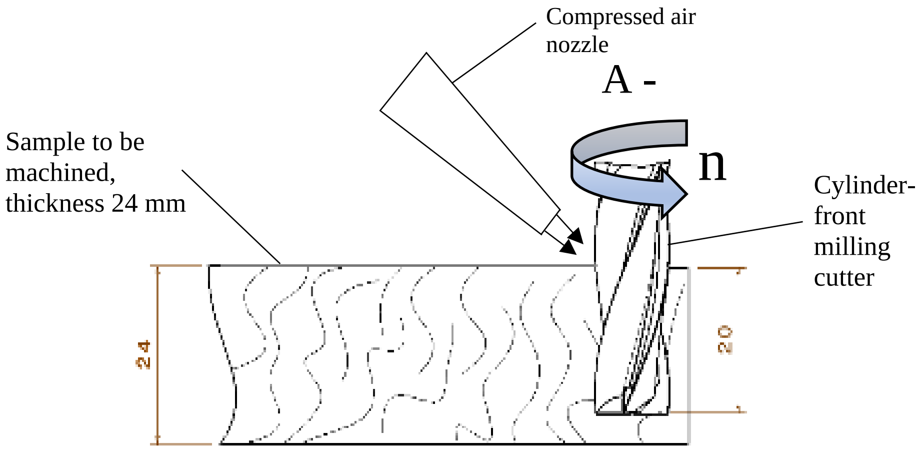


Fig 5.6 - Schematic diagram using cooling fluid (air).

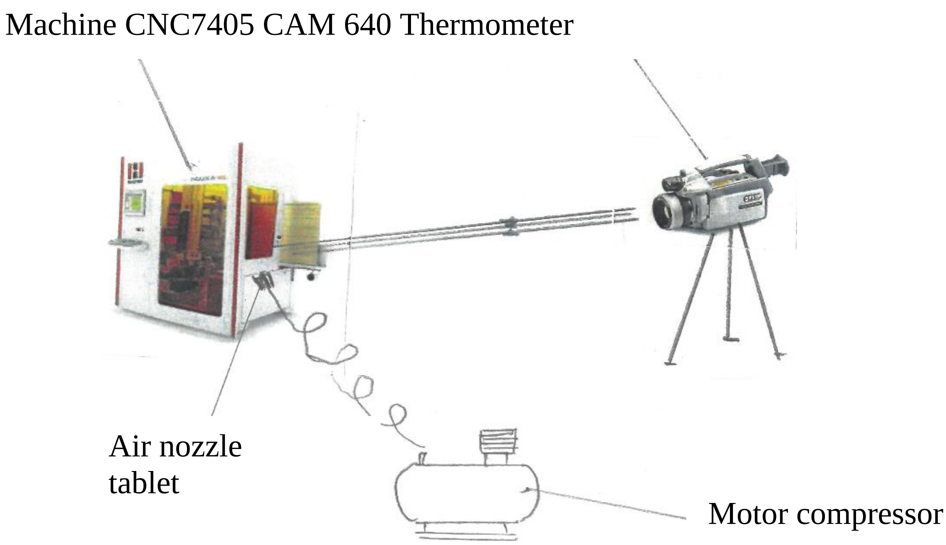


Fig. 5.7 - Thermal monitoring scheme of the machining process, when cooling with a cold air jet is used.

Moments during the acquisition and recording of processing data are shown in Fig. 5-8, 9, 10.

Fig. 5.8

Fig. 5.9 Fig. 5.10

The set of tools, S-1b, S-b..., S-9b, will be measured in their initial condition and after machining, in this case showing the resulting wear. Comparisons between the two machining systems can be made and conclusions drawn.

Chapter 6.
METHODOLOGY OF RESEARCH ON CHIPPING REGIMES IN WOOD PROCESSING

6.1 Scheme of approach to the investigation of the behaviour of milling cutters during the machining of different wood materials.

We divided the analysed tools into two large groups **A and B,** which machined the three types of wood materials without and with cooling, respectively, as shown in Fig. 6.1:

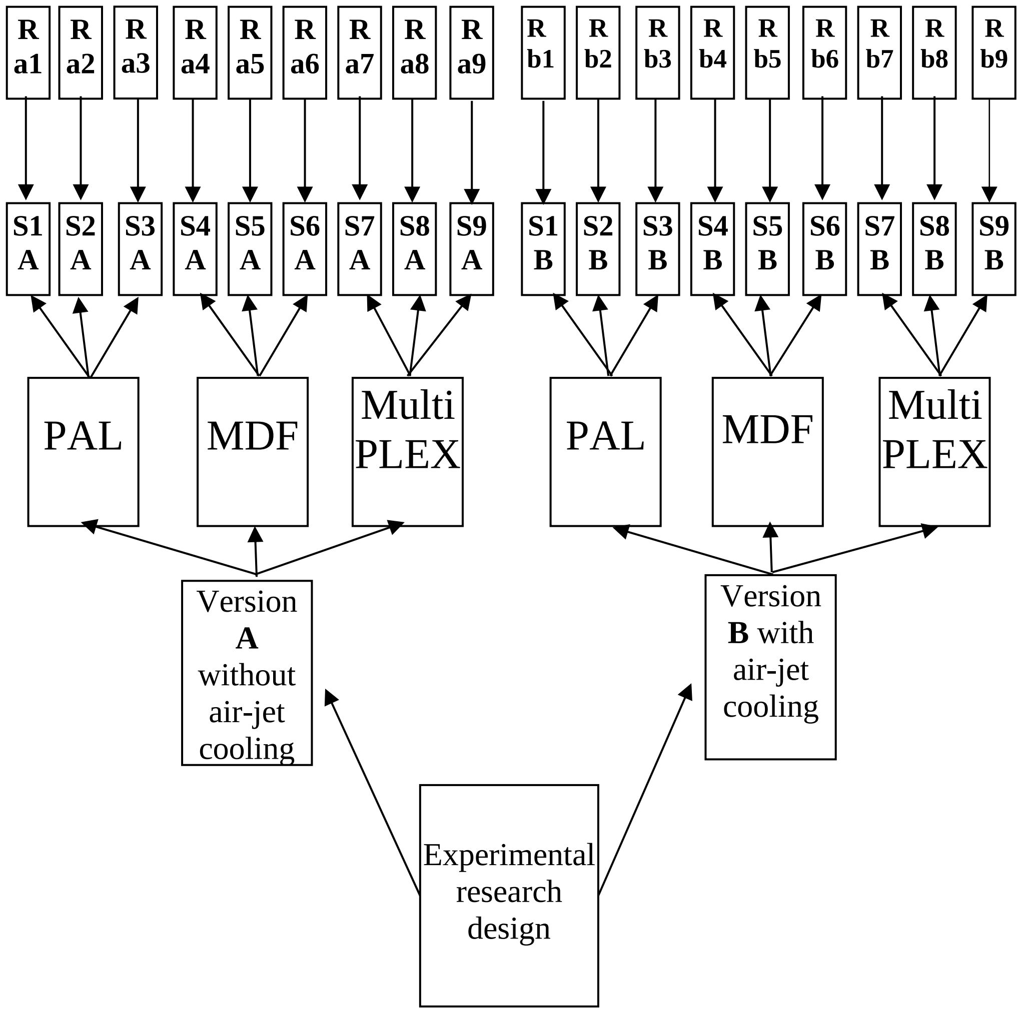


Fig. 6.1 Block diagram of the experimental research approach, chipping with and without cooling jet, material processed, tools used and chipping regimes.

Chaper 7.

MATHEMATICAL MODEL OF EXPERIMENTAL RESEARCH RESULTS OBTAINED IN THE PROCESSING OF WOODY COMPOSITE MATERIALS

7.1 Introduction

During the chipping process, due to high contact pressures, high temperatures, relative speeds and shocks between the tool-workpiece contact surfaces, wear of the chipping tool occurs.

Wear of the chipping tool consists of the gradual removal of material from the active surfaces of the tool, resulting in a change of geometry and a reduction of its chipping capacity.

The least squares method was used to process the experimentally obtained data, resulting in linear regression plots showing the dependence of edge radius wear on temperature or edge radius wear on cutter feed.

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, such a data set consists for example of a series of pairs of values i = 1...n, where x_i 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 formf(x,β), having *m* parameters (coefficients), placed in the vector β }. 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 least-squares method is when the sum of the squares of the residuals:

$$S = \sum_{i=1}^{n} r_i^2 \tag{7.1}$$

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

$$r_i = y_i - f(x,\beta) \qquad (7.2)$$

So:

$$\sum_{i=1}^{n} [y_i - f(x,\beta)]^2 \to minim \qquad (7.3)$$

or:

$$\sum_{i=1}^{n} [y_i - (\beta_0 + \beta_1 x)^2] \qquad (7.4)$$

where $f(x,\beta)$ is the chosen interpolation polynomial.

Matrix-wise, we can write that:

$$[X] \cdot \{\beta\} = \{Y\} \qquad (7.5)$$

in which:

$$[X] = \begin{bmatrix} n & \sum_{i=1}^{n} x_i \\ \sum_{i=1}^{n} x_i & \sum_{i=1}^{n} x_i^2 \end{bmatrix} \qquad (7.6)$$

$$\{\beta\} = \begin{Bmatrix} \beta_0 \\ \beta_1 \end{Bmatrix} \qquad (7.7)$$

and again:

$$\{Y\} = \begin{Bmatrix} \sum_{i=1}^{n} y_i \\ \sum_{i=1}^{n} x_i y_i \end{Bmatrix} \qquad (7.8)$$

An example of a model function is a straight line, considering ordered at the origin β_0 and slopeβ_1, the model function is of the form: $f(x,\beta) = \beta_0 + \beta_1 x f(x,\beta) = \beta_0 + \beta_1 x$..

The following tables and figures show the dependence of chipping tool edge wear on temperature for three types of composite wood materials - chipboard, MDF and MULTIPLEX, where a coolant (pressurised air) was used or not, and the dependence of edge wear on tool feed (of a circular cutter) for the same three types of wood materials.

These dependencies (temperature - wear or chipping length - wear) were made for three different chipping speeds: 1000 mm/min, 2000 mm/min and 3000 mm/min.

Graphs showing these dependencies are plotted in the following figures.

7.2. Establishing the research method

Processing is done on the EVOLUTION 7405 4MAT CNC machine in a composite processing shop as follows:

- two sets of 9 new 10 mm diameter, double-fluted milling cutters made of HSS (high-speed steel) are used (Fig. 1). One is used for cutting in dry conditions (without coolant), and the other for cutting with air as coolant (Fig. 2). The 9 cutting tools used for cutting in dry conditions have index a, and the other set for cutting with coolant - index b.
- a set of 9 cutters is grouped into subsets of 3, each cutter being used to process a different material sample (chipboard, MDF, MULTIPLEX).

The cutting conditions are presented as follows:

A. No coolant

PAL material

- cutter 1a with cutting speed v_c = 12500 rpm, feed speed v_f = 1000 mm/min, a_p = 20 mm.
- cutter 2a with cutting speed v_c = 12500 rpm, feed v_f = 2000 mm/min, a_p = 20 mm.
- 3a cutter with cutting speed v_c = 12500 rpm, feed v_f = 3000 mm/min, a_p = 20 mm.

Material MDF

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

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

Fig. 7.1. 10 mm diameter double flute cutter.

Material MULTIPLEX

- cutter 7a with cutting speed v_c = 12500 rpm, feed speed v_f = 1000 mm/min, depth *of* cut$_p$ = 20 mm.
- 8a cutter with cutting speed v_c = 12500 rpm, feed v_f = 2000 mm/min, a_p = 20 mm.
- cutter 9a with cutting speed v_c = 12500 rpm, feed v_f = 3000 mm/min, a_p = 20 mm.

B. With cooling agent

PAL material

- cutter 1b with cutting speed v_c = 12500 rpm, feed speed v_f = 1000 mm/min, a_p = 20 mm.
- cutter 2b with cutting speed v_c = 125000 rpm, feed speed v_f = 2000 mm/min, a_p = 20 mm.
- 3b cutter with cutting speed v_c = 12500 rpm, feed v_f = 3000 mm/min, a_p = 20 mm.

Material MDF

- cutter 4b with cutting speed v_c = 12500 rpm, feed speed v_f = 1000 mm/min, a_p = 20 mm.

- cutter 5b with cutting speed v_c = 12500 rpm, feed speed v_f = 2000 mm/min, a_p = 20 mm.
- cutter 6b with cutting speed v_c = 12500 rpm, feed speed v_f = 3000 mm/min, a_p = 20 mm.

Material MULTIPLEX

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

The cutters are measured before being fed into processing using the ATOS ScanBox BPS electronic scanner.

The samples to be processed, 3 for each material, are 1100 x 320 x 24 mm (Fig. 5.4.).

The cutter processes along a path consisting of forward and backward movements on 10 1000 mm segments and short perpendicular passes to move to the next segment, up to a total travel of 1000 mm.

7.3. Data processing with the mathematical model

The measurement consists of determining the values of the diameter of the cutting edge at points belonging to 10 cross-sections placed at an axial distance of 2 mm from each other, as shown in Fig. 4. Due to the straight direction of the teeth, the diameter measurements are made on the cutting edges of the cutter, keeping the same orientation of the tool around its axis.

After machining, 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 squares method [7, 8].

The graphs in Figures 7.1. to 7.6. show the results of the tool diameter measurements for chipboard (chipboard) in both dry processing (Figures 7.1., 7.3. and 7.5.) and air-cooled processing (Figures 7.2., 7.4. and 7.6.).

Figures 7.7.-7.12. show the results for MDF material. Figures 7.7, 7.9, 7.11, show the graphs for dry processing, while figures 7.8, 7.10 and 7.12 - graphs for air-cooled processing.

Similarly, Figures 7.13. to 7.18. are dedicated to MULTIPLEX material. The dry processing charts are shown in Fig. 7.13., 7.15. and 7.17. The results for air-cooled processing are shown in Figures 7.14, 7.16 and 7.18.

For all graphs, the wear trend in the axial direction has an increasing tendency from the tip towards the tool body. The explanation could be the variable temperature in the axial direction during machining.

Also, a possible explanation could be related to the inhomogeneity of the material at depth, with possibly higher hardness in the case of the outer layers.

For the two situations - uncooled and cooled, the results show lower wear values for cooled compared to cooled machining by about 20%.

In a comparative analysis of the materials, the variation of wear from one material to another shows a slight increase in wear in chipboard - chipboard (average values of 45 µm, 55 µm and 60 µm - without cooling and 40 µm, 43 µm, 36 µm - with cooling), in MDF (average values of 52 µm, 85 µm and 40 µm - without cooling and 40, µm, 35 µm, 40 µm - with cooling) and then in MULTIPLEX (average values of breakage, 57 µm, 86 µm - without cooling and 45 µm, 58 µm and 88 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

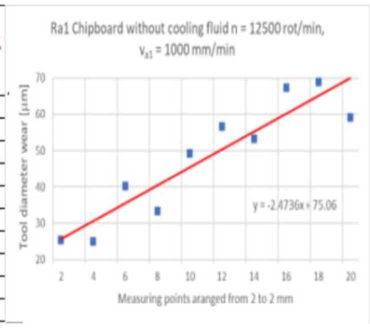


Fig. 7.1. Diameter wear for PAL with 1000 mm/min feed and 12500 rpm without coolant.

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

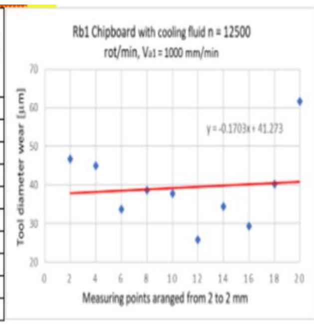


Fig. 7.2. Diameter wear for PAL at 1000 mm/min feed and 12500 rpm with coolant.

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

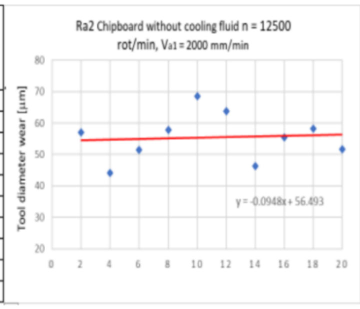


Fig. 7.3. Diameter wear for PAL with 2000 mm/min feed and 12500 rpm without coolant.

Diameter measurement cross sections	Tool diameter 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

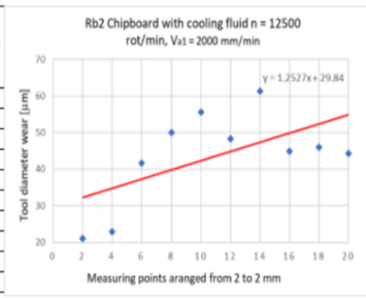


Fig. 7.4. Diameter wear for PAL at 2000 mm/min feed and 12500 rpm with coolant.

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

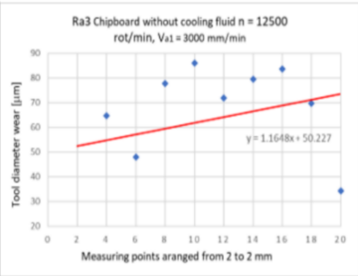


Fig. 7.5. Diameter wear for PAL at 3000 mm/min feed and 12500 rpm without coolant.

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

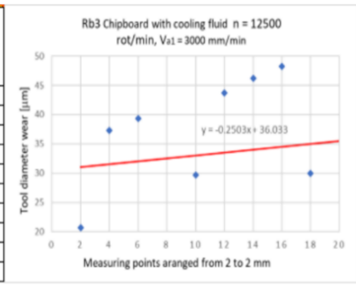


Fig. 7.6. Diameter wear for PAL at 3000 mm/min feed and 12500 rpm with coolant.

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

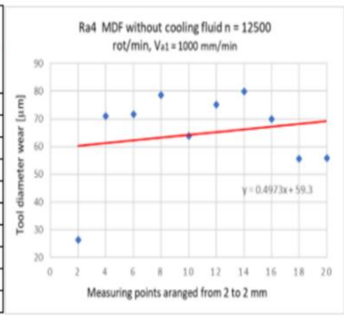


Fig. 7.7. Diameter wear for MDF with 1000 mm/min feed and 12500 rpm without coolant.

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

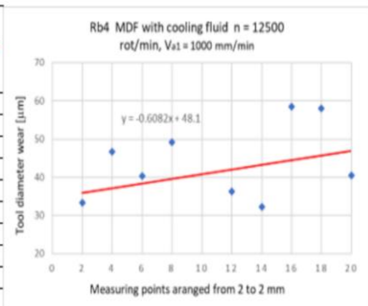


Fig. 7.8. Diameter wear for MDF with 1000 mm/min feed and 12500 rpm with coolant.

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

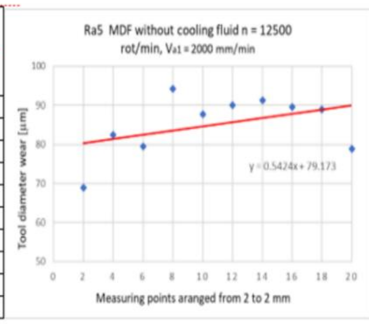


Fig. 7.9. Diameter wear for MDF with 2000 mm/min feed and 12500 rpm without coolant.

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

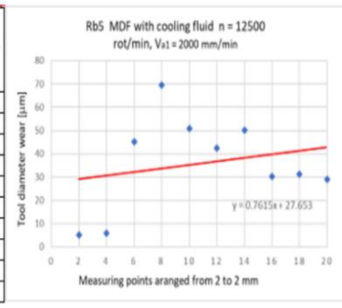


Fig. 7.10. Diameter wear for MDF at 2000 mm/min feed and 12500 rpm with coolant.

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

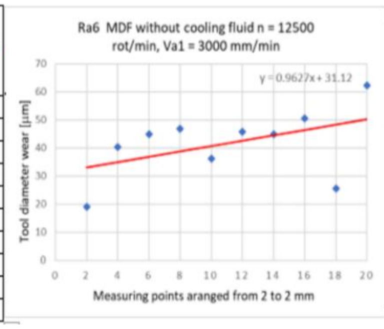


Fig. 7.11. Diameter wear for MDF with 3000 mm/min feed and 12500 rpm without coolant.

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

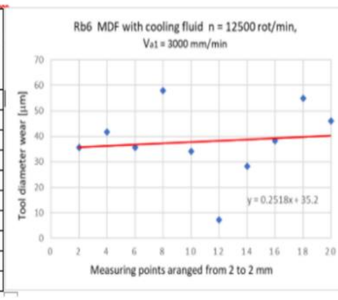


Fig. 7.12. Diameter wear for MDF with 3000 mm/min feed and 12500 rpm with coolant.

Diameter measurement cross sections	Tool diameter wear [µm]
0-2	54,9
2-4	81,6
4-6	682,5
6-8	fractura
8-10	-
10-12	-
12-14	-
14-16	-
16-18	-
18-20	-

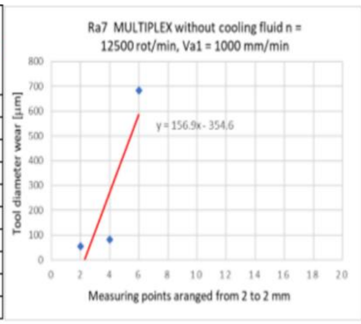


Fig. 7.13. Diameter wear for MULTIPLEX with 1000 mm/min feed and 12500 rpm without coolant.

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

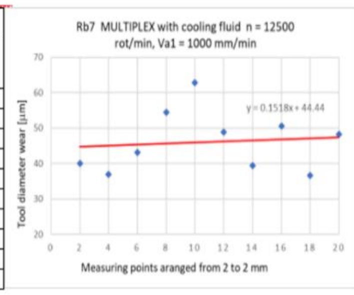


Fig. 7.14. Diameter wear for MULTIPLEX with 1000 mm/min feed and 12500 rpm with coolant.

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

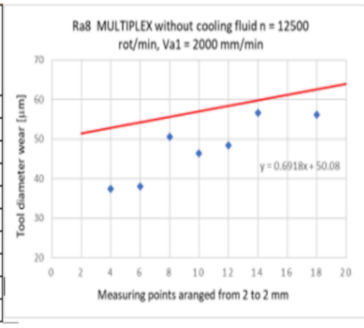


Fig. 7.15. Diameter wear for MULTIPLEX with 2000 mm/min feed and 12500 rpm without coolant.

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

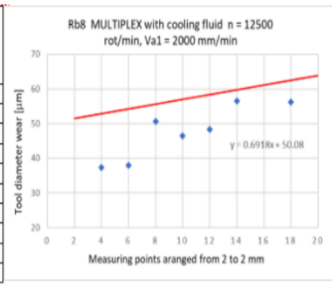


Fig. 7.16. Diameter wear for MULTIPLEX with 2000 mm/min feed and 12500 rpm with coolant.

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

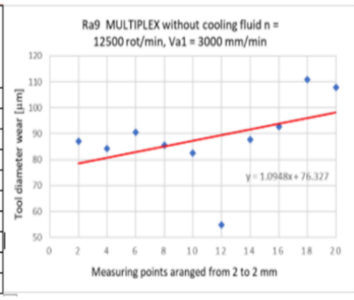


Fig. 7.17. Diameter wear for MULTIPLEX with 2000 mm/min feed and 12500 rpm without coolant.

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

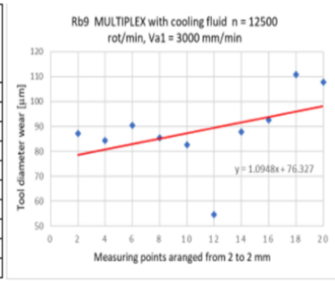


Fig. 7.18. Diameter wear for MULTIPLEX with 2000 mm/min feed and 12500 rpm with coolant.

The measured values were organized and interpreted in a series of tables showing temperatures together with trend lines (linear interpolation).

The following tables and figures show the temperature dependence of the processing length (over 10000 mm) for three types of wood composite materials - chipboard (cut without coolant - fig. 7.19, 7.21 and 7.23, with coolant - fig. 7.20, 7.22 and 7.24), MDF (cutting without coolant - Fig. 7.25, 7.27 and 7.29, with coolant - Fig. 7.26, 7.28 and 7.30) and MULTIPLEX (cutting without coolant - Fig. 7.31, 7.33 and 7.35, with coolant - Fig. 7.32, 7.34 and 7.36).

During dry processing of materials, it is found that the maximum values increase with increasing feed rate. On the other hand, depending on the type of material, the final temperatures (test 10) increase in 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

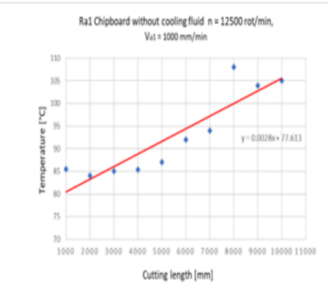


Fig. 7.19 Temperature dependence of the tool as a function of the tool length, without coolant, with cutting mode va1 = 1000 mm/min and n = 12500 rpm for PAL

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

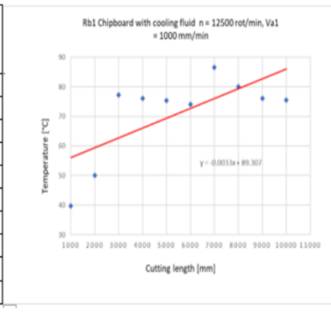


Fig. 7.20 Temperature dependence of the tool as a function of the length of the tool stroke, with coolant, with cutting mode va1 = 1000mm/min and n = 12500 rpm for PAL

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

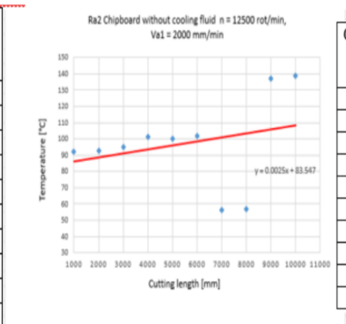


Fig. 7.21 Temperature dependence of the tool as a function of the tool length without coolant with cutting mode va1 = 2000 mm/min and n = 12500 rpm for PAL

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

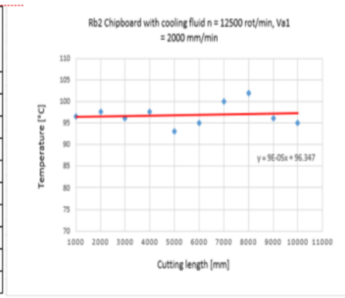


Fig. 7.22 Temperature dependence of the tool as a function of the tool length without coolant with cutting mode va1 = 2000 mm/min and n = 12500 rpm for agglomerated slabs

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

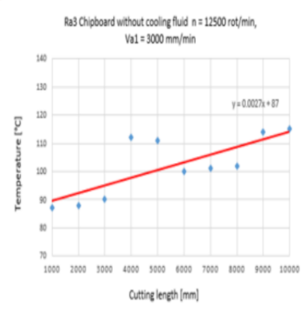


Fig. 7.23 Temperature dependence of the tool as a function of the tool length without coolant with cutting mode va1 = 3000 mm/min and n = 12500 rpm for agglomerated plates.

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

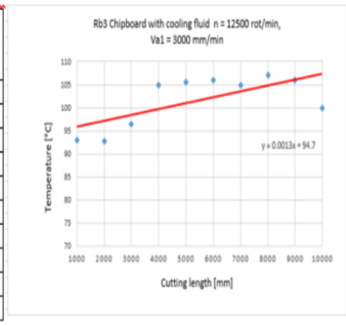


Fig. 7.24 Temperature dependence of the tool as a function of the length of the tool stroke, with coolant, with cutting mode va1 = 3000 mm/min and n = 12500 rpm for agglomerated plates.

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

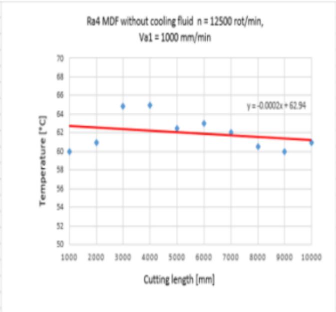


Fig. 7.25 Temperature dependence of the tool as a function of the tool length without coolant with cutting mode va1 = 1000 mm/min and n = 12500 rpm for MDF.

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

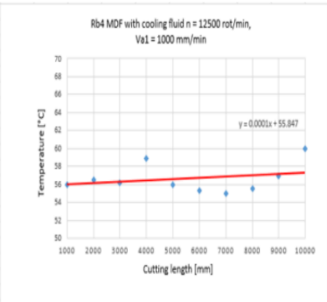


Fig. 7.26 Temperature dependence of the tool as a function of the length of the tool stroke, with coolant, with cutting mode va1 = 1000 mm/min and n = 12500 rpm for MDF.

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

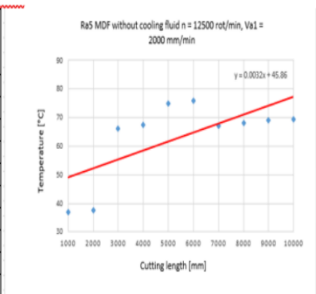


Fig. 7.27 Temperature dependence of the tool as a function of the tool length without coolant with cutting mode va1 = 2000mm/min and n = 12500 rpm for MDF.

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

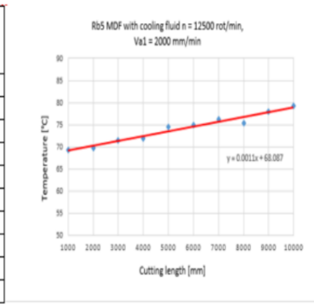


Fig. 7.28 Temperature dependence of the tool as a function of the length of the tool stroke, with coolant, with cutting mode va1 = 2000mm/min and n = 12500 rpm for MDF.

Cutting length [mm]	Temperature [ºC]
1000	80
2000	81,8
3000	65,5
4000	66,9
5000	67
6000	75
7000	77
8000	78
9000	84
10000	85,1

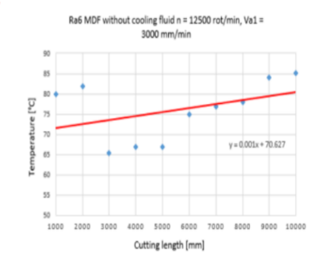


Fig. 7.29 Temperature dependence of the tool as a function of the tool length without coolant with cutting mode va1 = 3000mm/min and n = 12500 rpm for MDF.

Cutting length [mm]	Temperature [ºC]
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

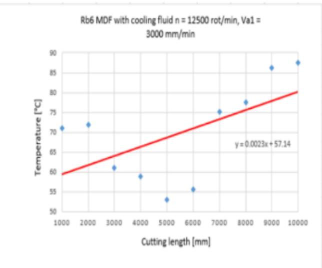


Fig. 7.30 Temperature dependence of the tool as a function of the length of the tool stroke, with coolant, with cutting mode va1 = 3000mm/min and n = 12500 rpm for MDF.

Cutting length [mm]	Temperature [ºC]
1000	108
2000	110
3000	fractură
4000	fractură
5000	-
6000	-
7000	-
8000	-
9000	-
10000	-

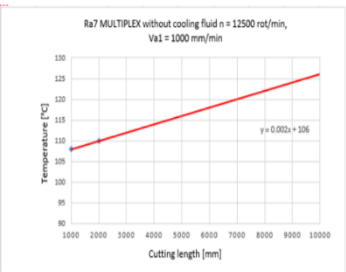


Fig. 7.31 Temperature dependence in the tool depending on the length travelled by the tool, without coolant, with cutting fluid mode va1 = 1000mm/min and n = 12500 rpm for MULTIPLEX.

Cutting length [mm]	Temperature [ºC]
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

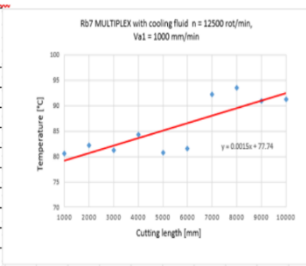
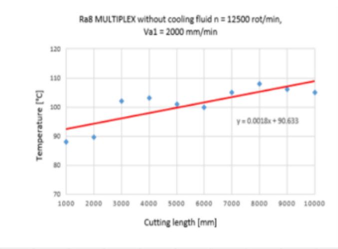


Fig. 7.32. Temperature dependence in the tool depending on the length of the tool, with coolant, with cutting mode va1 = 1000 mm/min and n = 12500 rpm for MULTIPLEX.

Cutting length [mm]	Temperature [ºC]
1000	88
2000	89,5
3000	102
4000	103
5000	101
6000	100
7000	105
8000	108
9000	106
10000	105



Cutting length [mm]	Temperature [ºC]
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

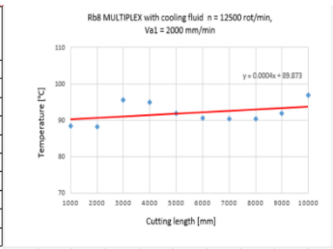


Fig. 7.33 Temperature dependence of the tool as a function of the tool length without coolant with cutting mode va1 = 2000mm/min and n = 12500 rpm for MULTIPLEX.

Fig. 7.34 Temperature dependence of the tool as a function of the length of the tool stroke, with coolant, with cutting mode va1 = 2000 mm/min and n = 12500 rpm 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

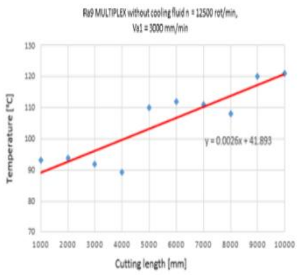


Fig. 7.35 Temperature dependence of the tool as a function of the tool length without coolant with cutting mode va1=3000 mm/min and n = 12500 rpm for MULTIPLEX.

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

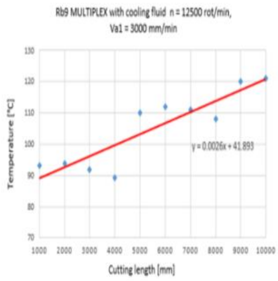


Fig. 7.36 Temperature dependence of the tool as a function of the length of the tool stroke, with coolant, with cutting mode va1= and n = 12500 rpm.

Table 20

Average temperature in processing without coolant

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

Table 21

Average temperature of coolant processing

v_f (mm/mim)	PAL	MDF	MULTIPLEX
1000	75	58	85
2000	92	75	92
3000	102	65	103

As for the average temperatures (test 5), these are shown in Table 20 for processing without coolant and in Table 21 for air-jet processing.

During dry processing, for the three materials there is a tendency for the mean values to increase with feed rate. According to the average temperature values, the hierarchy is as follows: MDF, MULTIPLEX, chipboard.

In the case of air-jet processing, for chipboard and MULTIPLEX there is a tendency for the average to increase with feed rate, while for MDF the variation is not conclusive (possibly due to an uncontrolled variation in measurement conditions). The hierarchy in ascending order of mean temperature of the three materials is - MDF, PALP, MULTIPLEX.

In the case of cooling processing of the three materials, there is a tendency for relative temperature stabilisation regardless of the feed rate.

Conclusions

In this chapter the author has created a mathematical model based on linear interpolation using the least squares method to draw some conclusions on the behaviour of the three wood composite materials analysed: chipboard, MDF and MULTIPLEX.

Analyses were carried out at three different feed rates - 1000, 2000 and 3000 mm/min with or without the use of a cooling fluid (pressurised air). Water was not used as a cooling fluid, as it is well known that wood has a hygroscopic behaviour, swelling under the effect of humidity.

For the three woody materials it was found for chipboard that at feed rates of 1000 mm/min the temperatures obtained when using a coolant were lower than when not using a coolant. At higher feed rates (2000-3000) mm/min there is a uniformity of temperatures (they are in the same range).

In the case of MDF composite material, the situation at feed rates of 1000 mm/min is similar to that for chipboard, with a decrease in temperatures observed when using a coolant. At high feed rates (of 2000 rpm), the temperatures obtained when using a coolant are significantly higher than when not using a coolant. At speeds of 3000 mm/ min, a uniformity of temperatures is observed, with the coolant in this case playing no particular role.

In the case of the MULTIPLEX composite material the experimental investigations failed when using a chipping speed of 1000 mm/min, but from the first three measurements, obtained before the milling cutter broke, it can be concluded that the coolant played an essential role. This trend was also observed when using a feed rate of 2000 rpm, with temperatures becoming more uniform at higher feed rates (3000 rpm).

In terms of milling cutter diameter wear, a decrease can be observed when using coolant, for all three wood composites and for all tool feed speeds.

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Chapter 8. Conclusions

1) Analysing the wear of front end mills, we distinguish the following:

For agglomerated plates, it can be seen from the first graphs (fig. 7.1. and 7.2.) that the wear of the cutter diameter is much more pronounced in the version without coolant than in the version with coolant. The same can be seen in the graphs in figures 7.3. to 7.6., in other words, the slope of the straight line in the case without coolant is greater than in the case with coolant.

For MDF, analysis of the graphs in Figures 7.7.-7.12. shows that the range of values related to tool wear is larger in the version without coolant than in the version with coolant.

For MULTIPLEX we note that in the graph in Fig. 7.13. fracturing of the cutter occurred due to high cutting forces. The slope on the right is very large, which leads to the explanation that it is recommended to change the machining regime. In the case of the graphs in Fig. 7.15. and 7.16., by changing the cutting regime, a more pronounced wear is also observed in the case without coolant compared to the case with coolant.

2) From the general analysis of the tabular data and graphs, it can be said that the present research has shown that, regardless of the cutting regime used, tool wear is more pronounced in the case of "cold" machining, i.e. without coolant, than in the case with coolant (compressed air). Thus, it can be recommended to users in the wood composite processing industry to use a coolant in all machining cases in order to reduce tool wear and thus increase tool durability.

3) To the achievement of the main objective of the doctoral research and development activity, the present PhD thesis brings a number of contributions, such as:

-establishing our own methods of approaching the research method, by finding the most frequently used machining tools as well as the most common semi-finished products used in the furniture industry

-application in the present thesis research of a method of cooling the machining process using compressed air, which has led to a visible reduction in chipping tool wear

-mathematical modelling of the tool wear phenomenon as a function of the chipping regime and the temperature developed in the machining zone.

4) The scientific importance of the present PhD thesis is supported by the contributions made as a result of the experimental research based on an own research methodology as well as the mathematical method of the phenomenon.

5) The practical importance of the present PhD thesis lies in the fact that it has established the link between machining tool wear and chipping regimes in machining situations with and without coolant (compressed air).

6) This PhD thesis is a useful support for students, teachers, companies, specialists in the field of furniture industry as well as for those who are interested in finding new processing methods for composite semi-finished products used in the wood industry.

7) The problem of research and optimization of the machining regimes of wood composite materials requires a continuous research and development activity, analysis, determination and implementation of new scientific breakthroughs such as in the field of diamond tools or tools reinforced with mineral-ceramic carbides.