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COMPOSITE METAL ALLOY-BASED CUTTING TOOL FOR HÖRLLER INDUSTRIAL PAPER CUTTING

FERRAMENTA DE CORTE BASEADA EM LIGA DE METAL COMPOSTA PARA CORTE INDUSTRIAL DE PAPEL TIPO HÖRLLER

HERRAMIENTA DE CORTE A BASE DE ALEACIÓN DE METAL COMPUESTO PARA EL CORTE DE PAPEL INDUSTRIAL HÖRLLER

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ABSTRACT
The Hörller industrial paper cutting requires tools of high precision and durability to meet the needs of the printing and packaging industry. This article covers the development of an innovative cutting tool based on a composite metal alloy, designed to address the specific challenges of this process. The main objective of this study is to design and manufacture a cutting tool that is able to meet the demands of industrial paper cutting type Hörller, providing high efficiency, quality and extended service life. The development process of the cutting tool involved the precise definition of the geometry, the careful selection of the composite alloy material, the application of heat treatment and specialized sharpening techniques. Detailed tests were conducted to evaluate the tool's performance under industrial conditions. The results demonstrate that the cutting tool based on the composite metal alloy provides a remarkable efficiency in the cutting of Hörller-type paper, significantly surpassing conventional alternatives. In addition, its durability has been proven in long periods of industrial operation, minimizing the need for maintenance. This study contributes to the advancement of industrial cutting tool technology, offering a robust and effective solution for Hörller-type paper cutting. The developed tool represents a milestone in the optimization of the cutting process, promoting greater productivity and quality in the printing and packaging industry.

KEYWORDS: Circular Knife. Paper. Paper Industry. Sharpening. Circular Cutting. Metal Alloy and Material.

RESUMO
O corte industrial de papel tipo Hörller demanda ferramentas de alta precisão e durabilidade para atender às necessidades da indústria gráfica e de embalagens. Este artigo aborda o desenvolvimento de uma ferramenta de corte inovadora baseada em uma liga de metal composta, projetada para enfrentar os desafios específicos desse processo. O principal objetivo deste estudo é projetar e fabricar uma ferramenta de corte que seja capaz de atender às demandas do corte industrial de papel tipo Hörller, proporcionando alta eficiência, qualidade e vida útil estendida. O processo de desenvolvimento da ferramenta de corte envolveu a definição precisa da geometria, a seleção criteriosa do material da liga composta, a aplicação de tratamento térmico e técnicas de afiação especializadas. Foram conduzidos testes detalhados para avaliar o desempenho da ferramenta em condições industriais. Os resultados demonstram que a ferramenta de corte baseada na liga de metal composta proporciona uma eficiência notável no corte de papel tipo Hörller, superando significativamente as alternativas convencionais. Além disso, sua durabilidade foi comprovada em longos períodos de operação industrial, minimizando a necessidade de manutenção. Este estudo contribui para o avanço da tecnologia de ferramentas de corte industrial, oferecendo uma solução robusta e eficaz para o corte de papel tipo Hörller. A ferramenta desenvolvida representa um marco na otimização do processo de corte, promovendo maior produtividade e qualidade na indústria gráfica e de embalagens.

PALAVRAS-CHAVE: Faca circular. Papel. Industria de papel. Afiação. Corte circular. Liga de metal e Material.

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RESUMEN

El corte de papel industrial de Hörller requiere herramientas de alta precisión y durabilidad para satisfacer las necesidades de la industria de la impresión y el embalaje. Este artículo cubre el desarrollo de una herramienta de corte innovadora basada en una aleación de metal compuesto, diseñada para abordar los desafíos específicos de este proceso. El objetivo principal de este estudio es diseñar y fabricar una herramienta de corte que sea capaz de satisfacer las demandas de corte de papel industrial tipo Hörller, proporcionando alta eficiencia, calidad y vida útil prolongada. El proceso de desarrollo de la herramienta de corte implicó la definición precisa de la geometría, la cuidadosa selección del material de aleación compuesto, la aplicación de tratamiento térmico y técnicas especializadas de afilado. Se realizaron pruebas detalladas para evaluar el rendimiento de la herramienta en condiciones industriales. Los resultados demuestran que la herramienta de corte basada en la aleación de metal compuesto proporciona una notable eficiencia en el corte de papel tipo Hörller, superando significativamente las alternativas convencionales. Además, su durabilidad ha sido probada en largos periodos de operación industrial, minimizando la necesidad de mantenimiento. Este estudio contribuye al avance de la tecnología de herramientas de corte industrial, ofreciendo una solución robusta y eficaz para el corte de papel tipo Hörller. La herramienta desarrollada representa un hito en la optimización del proceso de corte, promoviendo una mayor productividad y calidad en la industria de la impresión y el embalaje.

PALABRAS CLAVE: Cuchillo circular. Papel. Industria del papel. Afilado. Corte circular. Aleación de metal y material.

INTRODUTION

Efficient material cutting represents a pivotal stage in various industrial processes, and the meticulous selection of the appropriate cutting tool plays a crucial role in achieving optimal outcomes. In the specific context of cutting Hörller paper (also known as paraná paper), it becomes imperative to have a circular knife capable of withstanding the rigorous production conditions in the factory and industrial environment while maintaining its performance when making a significant number of cuts without suffering damage, such as breaks, cracks, or deterioration of the cutting edge.

The conception and development of an efficient circular knife for cutting Hörller paper are of paramount importance for optimizing the production process and ensuring the quality of the final product. However, it is essential to emphasize that this issue remains a gap in academic research and a lack of concise information in specialized literature. Therefore, there is an urgent need to seek innovative and advanced solutions to address the intrinsic challenges of this cutting process.

It is relevant to highlight that the absence of precise and standardized information about the manufacturing of circular knives for cutting Hörller paper poses challenges for the development of effective solutions. This study represents a significant step toward filling this gap and provides clear guidelines for the selection of materials, geometry, and manufacturing processes suitable for circular knives used in this context.

Faced with the aforementioned challenges, the adopted approach consisted of systematic literature reviews and the establishment of strategic contacts with local suppliers to obtain specific knowledge about materials suitable for high-temperature cutting processes. Through these partnerships, a variant of the material already in use was identified, considered more suitable for this specific application. Furthermore, the in-depth analysis of damaged knives available in the market allowed for a detailed study of the material and a comparison with the steel recommended by the supplier (Chang *et al.,* 2009; Mason *et al.,* 2022).

The fundamental purpose of the conducted research lies in the development of the most suitable circular knife for cutting Hörller paper, aiming to meet the requirements of strength, durability, and process efficiency. The justification for conducting this study lies in the scarcity of information available in the literature regarding the manufacturing process of circular knives and the difficulty in finding a knife on the market that fully meets the demands inherent to this industrial process.

BACKGROUND

Overview - Papel Hörller

Initially, it is crucial to clarify the fundamental distinctions between the two types of paper under analysis. Both are widely used in activities such as paper crafts, gift packaging, raw material for the board game market, among other applications. They are both characterized by their high grammage and rigidity, but the main differentiation between them lies in the manufacturing process (Miolo de Agenda, 2023).

Hörller paper (or gray cardboard) is a traditional and exclusive product of the Hörller paper industry. Its production starts with 100% selected raw materials. It is composed of paper scraps acquired from various sources. It is a renewable product that contributes to environmental conservation and has FSC certification (internationally recognized Forest Stewardship Council). Parana paper is an industrial product made from pine wood and water in automated processes or in its natural form, i.e., without alterations in its finish. In its composition, it becomes similar to Hörller cardboard (gray paper), but its manufacturing uses virgin fibers in several layers. Due to the difference in the manufacturing process, Parana paper (Figure 1 – Left side) is more fibrous, porous, and has a less smooth texture, bending more easily, whereas Hörller paper (Figure 1 – Right side) is smoother and more resistant. It has the quality of not bending easily and has a more grayish color that does not interfere with the finishing of the work (Horlle, 2017).

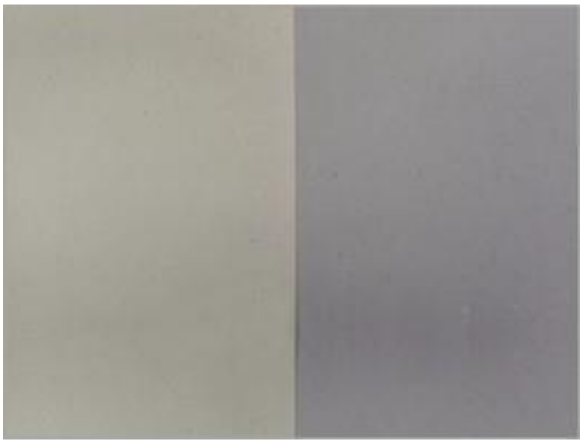

Figure 1. Holler Paper. Source: Authors, (2023).

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Industrial cutting of Hörller type paper

The cutting industry for Parana-type papers involves the manufacturing of specialized machines and equipment for the precise and efficient cutting of this type of paper (Figure 2). These machines are used to cut Parana paper sheets into different sizes and shapes, according to the specific needs of customers and end applications.

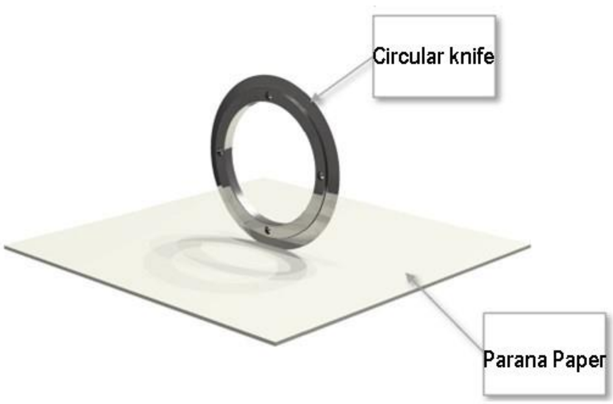

Figure 2. Parana Circular Paper Cutting Knife. Source: Authors, (2023)

The cutting machines for Parana-type papers are designed to handle the thickness and stiffness of this material, ensuring clean and precise cuts. These machines can employ different cutting techniques, such as circular blades, straight blades, special knives, or even laser technologies. Cutting equipment for Parana-type papers is typically designed with advanced automation and control features. They may include automatic feeding systems, programmable size and shape adjustments, fault detection systems, and safety devices to ensure safe and efficient operation. Additionally, these machines can be integrated into other processes, such as printing, finishing, or packaging, to form complete production lines.

Companies specialized in the Parana-type paper cutting industry provide customized solutions according to customer needs, whether for large-scale production or specific cutting requirements. It's important to mention that, in addition to cutting machines, the Parana-type paper cutting industry may also involve the development of specific cutting tools such as knives, blades, or dies that are used in the machines to achieve the desired cuts (Huang *et al.,* 2021).

Overall, the Parana-type paper cutting industry plays a crucial role in the efficient and high-quality production of products that use this type of paper.

Industrial Cutting Fundamentals

The fundamentals of industrial cutting are key principles and concepts that are essential for achieving precise, efficient, and high-quality cuts in industrial processes. Here are some of the important fundamentals related to industrial cutting:

- **Selection of suitable tools**: Choosing the correct cutting tool is crucial to achieve satisfactory results. This includes selecting the blade, knife, milling cutter, saw, or other appropriate tool for the material being cut. Material characteristics such as hardness, thickness, and physical properties must be considered when selecting the cutting tool.
- **Cutting speed**: Proper cutting speed is fundamental to achieving efficient cutting and avoiding tool and material damage. Excessively high speeds can result in excessive tool wear, heating, and loss of precision, while excessively low speeds can lead to irregular cuts and extended processing times.
- **Proper feed rate**: Feed rate refers to the speed at which the cutting tool moves relative to the material being cut. Proper feed rate is important to ensure smooth cuts and prevent issues like overheating. Feed rate can also affect tool life and surface finish quality.
- **Adequate clamping and support**: The material being cut must be properly clamped and supported during the cutting process. This helps prevent vibrations, unwanted movements, and deformations, resulting in more precise cuts. Inadequate clamping can lead to inaccurate, misaligned cuts, or even tool damage.
- **Lubrication and cooling**: In many cases, proper lubrication or cooling is required during industrial cutting processes. This is especially important in metallic materials where heat generation can be high. The use of appropriate cutting fluids helps reduce friction, dissipate heat, and extend tool life.
- **Regular tool maintenance**: Industrial cutting tools should be regularly maintained to ensure optimal performance. This includes sharpening or replacing worn blades or knives, checking and adjusting tool geometry, and inspecting for possible damage. Proper tool maintenance helps ensure consistent and high-quality cuts.

Conventional cutting tools

There are several conventional cutting tools widely used in industrial processes. The main ones to highlight are:

Graphic knife (Figure 3): They are commonly used in guillotines as well as in three-knife trimmers and saddle stitchers. AFIGRAF (2023).

Figure 3. Graphic knife representation. Source: Authors, (2023)

Circular knife (Figure 4): They are used in various sectors such as metallurgy, steel, textile, graphic arts, food, plastic, metal, paper and cardboard, electronics, packaging in general, fabric, etc. They are crucial components in the operation of companies that need to work with heavy materials and require high cutting precision for the production of their products. Santos (2023).

Figure 4. Circular knife representation. Source: Authors, (2023)

Saw: Saws are tools with sharp and spaced teeth, as shown in Figure 5, that cut materials through a back-and-forth motion. They are commonly used to cut wood, metal, and plastic.

Figure 5. Saw representation. Source: Authors, (2023)

Milling Cutter (Figure 6): It is a rotary cutting tool used to remove material from a workpiece through multiple cutting teeth. Milling cutters are widely used in machining to make precise cuts in metallic materials.

Drill Bit (Figure 7): The drill bit is a rotary tool used for drilling materials such as metal, wood, plastic, and masonry. It has a sharp spiral tip that removes material as it rotates.

Figure 6. Milling Cutter Representation. Source: Authors, (2023)

Figure 7. Drill Bit Representation. Source: Authors, (2023)

Lathe (Figure 8): Although best known for shaping and turning parts, the lathe can also be used for cutting materials such as wood or metal using specific cutting tools, such as carbide inserts or manual cutting tools.

Figure 8. Lathe representation. Source: Authors, (2023)

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These are just some of the most common conventional cutting tools used in the industry. The choice of tool depends on the material to be cut, the desired precision, process efficiency, and other specific application factors.

Advances in cutting tool development

In recent years, there have been significant advances in the development of cutting tools to enhance efficiency, precision, and tool life. Here are some recent advancements in this field:

Texturization of Cutting Tool Surfaces: One noteworthy advancement in cutting tool technology involves the texturization of tool surfaces. This technique has gained attention for its ability to improve cutting performance and tool life. Researchers have explored various texturization techniques, including laser-induced surface texturing and other methods. These approaches aim to modify the tool's surface at a micro or nanoscale level, which can lead to reduced friction, improved chip evacuation, and enhanced wear resistance. Texturization has shown promise in extending tool life and enhancing cutting efficiency, particularly in high-speed machining and difficult-to-machine materials.

Advanced Materials: The use of high-strength and hardness materials such as ceramics and carbides has provided increased durability and wear resistance for cutting tools. These materials offer extended tool life, enabling faster and more precise cutting.

Tool Coatings: Tool coatings have been enhanced to reduce friction, wear, and material adhesion during the cutting process. New coatings, such as titanium nitride (TiN), aluminum nitride (AlN), and titanium carbide (TiC), improve tool life and cutting quality (Zhao *et al.,* 2021).

Optimized Geometry: Cutting tool geometry has been improved to enhance performance. New designs, including sharp cutting edges, positive or negative geometry, specific rake angles, and variable edge geometry, result in smoother cuts, reduced vibration, and increased cutting efficiency.

Cooling and Lubrication Technologies: Advances in cooling and lubrication techniques have allowed for the use of more effective and high-performance coolant fluids. These fluids reduce heat generated during cutting, enhance tool performance, and improve surface finish quality.

Monitoring Technologies: The development of monitoring technologies, such as integrated sensors in tools, enables real-time tracking of cutting conditions. This helps detect wear, abnormal vibrations, and cutting issues, allowing for immediate corrective actions and maximizing process efficiency.

Automation and Digital Control: Advancements in automation and digital control systems have led to more precise and efficient cutting machines. The integration of sensors, advanced algorithms, and real-time feedback helps optimize cutting parameters, enhancing quality and productivity.

These advancements have contributed to significant improvements in the cutting tool industry, making cutting processes more efficient, precise, and sustainable. As technology continues to evolve, it is expected that new innovations will emerge, further driving the development of cutting tools in the future (Gürgen; Sofuoğlu, 2020).

Composite Alloys

Composite alloys are advanced materials that combine two or more distinct components to achieve properties superior to those of individual materials. They are formed by incorporating particles, fibers, or other reinforcing materials into a metallic, polymeric, or ceramic matrix.

The main idea behind composite alloys is to combine the desirable characteristics of the reinforcing materials with the matrix to create a material that is stronger, lighter, more wear-resistant, stiffer, or exhibits other specific properties. Reinforcing materials such as carbon fibers, glass fibers, ceramic particles, or metals provide additional mechanical strength, while the matrix acts as a load transfer agent and provides structural cohesion.

There are different types of composite alloys, including:

- **Metal Matrix Composites (MMC)**: These are composites in which a metallic matrix is reinforced with particles, fibers, or other metallic materials. These composites are known for their high strength, stiffness, and fatigue resistance and are widely used in aerospace and automotive applications.
- **Polymer Matrix Composites (PMC)**: These are composites in which a polymer matrix, such as epoxy resin or polyester, is reinforced with fibers, typically carbon, glass, or aramid fibers. These composites have high specific strength, low density, and are widely used in structural applications, such as aerospace, automotive, sports, and naval.
- **Ceramic Matrix Composites (CMC)**: These are composites in which a ceramic matrix is reinforced with ceramic fibers or other materials. These composites have high-temperature resistance, stiffness, and chemical resistance and are used in high-temperature applications such as gas turbines, wear-resistant coatings, and structural ceramic components.

Composites can also be classified based on the orientation of the reinforcing fibers, such as unidirectional, bidirectional, or woven composites. Additionally, advanced manufacturing techniques like compression molding, resin infusion, resin transfer molding, and additive manufacturing are used in the production of composite alloys (Kitagawa; Kubo; Maekawa, 1997).

Composite alloys offer a unique combination of mechanical, thermal, and chemical properties that cannot be achieved by individual materials. These characteristics make composites attractive in a wide range of industrial sectors, where they are applied to enhance the performance and efficiency of products.

Manufacturing Process of Composite Alloy Cutting Tools

The manufacturing process of composite alloy cutting tools follows a similar approach to conventional tool manufacturing, with some additional steps related to composite materials (Whitney, 2012). Here is an overview of the manufacturing process of composite alloy cutting tools:

- **Design**: The process begins with the design of the composite alloy cutting tool. This includes determining the tool's geometry, reinforcement areas, and the appropriate selection of composite materials.
- **Selection of Composite Materials**: Based on the performance requirements of the cutting tool, suitable composite materials are chosen. This involves selecting the matrix (polymeric, metallic, or ceramic) and the reinforcement (carbon fibers, glass fibers, particles, etc.) (Ko; Kwon; Kim, 2004).
- **Material Preparation**: Composite materials are prepared according to the chosen manufacturing process. This may involve preparing the matrix (mixing, heating, melting, etc.) and treating the reinforcement material (cutting, fiber orientation, resin impregnation, etc.).
- **Tool Body Fabrication**: The tool body is fabricated using the prepared composite materials. This can involve techniques such as compression molding, injection molding, manual or automated lamination, resin infusion, and other processes specific to the composite alloy in question.
- **Shaping and Curing**: After the tool body is formed, the composite material is cured to achieve the required strength and dimensional stability. The curing process may involve controlled heat and pressure application, depending on the selected matrix and reinforcement.
- **Final Machining**: The tool body undergoes final machining processes to achieve the desired shape, dimensions, and geometry. This may include the use of CNC machines, grinding, polishing, and other finishing methods.
- **Coating (Optional):** If necessary, the surface of the composite alloy cutting tool can be coated to enhance wear resistance, reduce friction, or provide other desired properties. Coating processes may be similar to those used for conventional tools, such as Physical Vapor Deposition (PVD) or Chemical Vapor Deposition (CVD).
- **Inspection and Quality Control**: Composite alloy cutting tools undergo rigorous testing and inspections to ensure their quality. This may include dimensional analysis, hardness testing, chemical composition analysis, strength testing, and other checks to verify that the tool meets required specifications.
- **Packaging and Distribution**: After completing the manufacturing and inspection process, composite alloy cutting tools are packaged and prepared for distribution to customers following appropriate procedures.

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The manufacturing process of composite alloy cutting tools can vary depending on the materials used, the complexity of the tool's geometry, and specific application requirements (Chuenyindee; Prasetyo; Srisuwan, 2021).

MATERIALS AND METHODS

Materials

A study was conducted at the Conecthus Institute between June 2022 and February 2023 with the purpose of designing and producing a customized circular knife to meet specific equipment requirements. The decision to undertake this project arose from the lack of a suitable option available in the market. Given the limited prior knowledge about carrying out this endeavor, a trial-and-error method was adopted as the central approach throughout the entire process. For this study, the following materials and equipment were required:

- Steel billet (VC 131, 5" x 8mm) – Raw material (Figure 9);
- Lathe machine – Equipment used to transform the billet into a knife;
- Turning tools/inserts for VC 131 steel – Accessories used to assist in the knife's fabrication;
- Metal tempering furnace (Figure 10) – Equipment that alters the mechanical properties of the knife through the rearrangement of its microstructure via heat;
- Container with oil (Figure 11) – What is it used for?
- Grinding machine (Figure 12) – Equipment responsible for sharpening the circular blade;

Figure 9. VC 131 steel billet. Source: Authors, (2023)

Figure 10. Quenching Heat Treatment Furnace. Source: Authors, (2023)

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Figure 11. Representation of a container with oil. Source: Authors, (2023)

Figure 12. Representation of grinding machine. Source: Authors, (2023)

METHODS

Geometry Definition

In this stage, tests were conducted to determine the fundamental parameters of the circular knife, including the outer diameter, thickness, and cutting angle. Initially, a small knife with a 58.5 mm diameter was designed and manufactured, varying the cutting angles between 20° and 60°, with the aim of evaluating cutting quality, as shown in Figure 13.

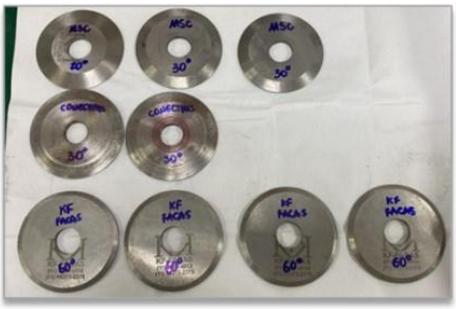

Figure 13. Knives developed for testing. Source: Authors, (2023)

During these experiments, an inversely proportional relationship between the cutting angle and the cutting quality was observed, meaning that the higher the angle, the worse the cutting quality, and

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vice versa, as can be seen in Figure 14, which demonstrates the cutting quality with knives at a 60° angle. It was notably identified that angles of 20° and 30° provided the best cutting quality.

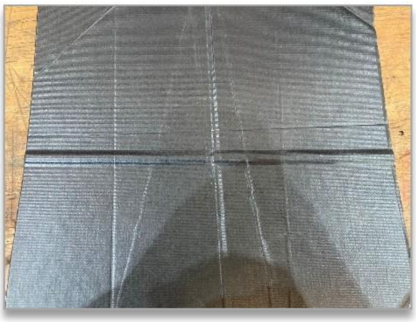

Figure 14. 60° knife test result. Source: Authors, (2023)

Another relevant aspect emerged when analyzing the diameter of the knives used in the tests. It became evident that significant pressure was needed to perform the cut, as observed in Figure 15, even those with the correct angle were generating unsatisfactory results, leaving a "torn" appearance on the paper. Faced with this realization, the decision was made to increase the diameter of the knives, expanding it from 58.5 mm to 117 mm.

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Figure 15. Side view of the test with 20° angle knives. Source: Authors, (2023)

DEFINITION OF MATERIAL

After defining the ideal geometry of the knife, the next step was to choose the most suitable material. The priority was the selection of a metallic alloy that, when combined with its specific chemical components, exhibited mechanical properties suitable for the intended application. During research with steel manufacturers, the recommendation to use tool steel emerged, a material designed especially for cutting a variety of products, widely used in taps, drills, mills, dies, punches, dies, among others.

Based on this information, it was decided to use VC 131 steel (AISI 01) - Table 1. After following the detailed process described in the overview section and setting up the knife on the machine for testing, initial results proved satisfactory. However, after cutting approximately 50 products, a deterioration in the quality of the cut was observed, manifesting as a "torn" appearance. The knife had to be removed to assess the condition of its cutting edge, revealing that it had completely lost its edge, necessitating a new sharpening process. It is worth noting that during the sharpening process, the knife experienced wear on its diameter, resulting in a decrease in cutting force, while the cutting pressure increased, contrary to the original purpose of the knife.

Faced with this challenge, the team sought guidance from a local supplier specialized in knives specifically designed for cutting circuit boards, which was a partner of the institute. Based on their extensive experience, they recommended the use of VC 131 steel as the ideal option for this specific application. Compared to other materials, VC 131 steel offered high dimensional stability and exceptional wear resistance, fully meeting the project's needs.

Before proceeding with the work using the new material, an additional step was incorporated to eliminate any doubts related to the choice of material. Samples of VC 131 steel and VND were collected, as well as a sample of a circular knife from a national reference. To accurately compare the chemical compositions, the EDX-7000 (XRF - X-ray Fluorescence) equipment was employed. During the analysis, it was observed that VC 131 steel contained chemical elements described as "carbide formers" (Table 1), indicating the ability of these elements to create binary salts containing carbon, contributing to greater cutting-edge durability compared to most other materials. When comparing the elements present in VC 131 and VND, it was noted that VND had a reduced amount of carbide-forming elements, explaining the premature loss of the cutting edge in the knife made with this material, which, as shown in Figure 16, demonstrates a whitish appearance along the cutting edge, indicating that it no longer performed clean cutting but rather "torn" cutting.

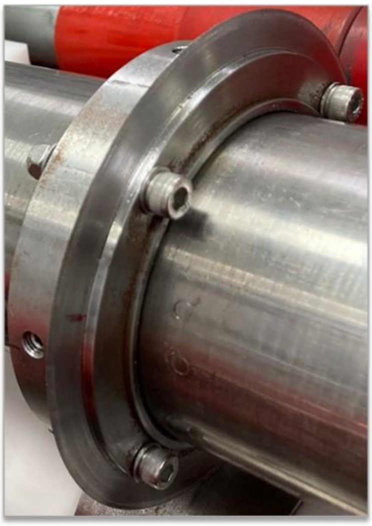

Figure 16. Cordless knife. Source: Authors, (2023)

Table 1. Comparison between the national reference and VC131. Source: Authors, (2023).

Chemical Components		National Reference	VC 131	CND
Iron	Fe	85,65%	86,24%	95,87%
Chrome	Cr	12,18%	12,11%	0,92%
Vanadium	V	0,88%	0,13%	-
Molybdenum	Mo	0,72%	0,23%	0,26%
Calcium	Ca	0,28%	0,25%	0,13%
Nickel	Ni	0,19%	0,24%	2,01%
Copper	Cu	0,10%	0,05%	-
Niobium	Nb	-	-	-
Selenium	Se	-	0,02%	-
Manganese	Mn	-	-	0,74%
Scandium	Sc	-	-	0,06%
Silicon	Si	-	-	-
Tungsten	W	-	0,72%	-

After consulting various manufacturer catalogs, the functions of some chemical elements present in VC 131 Steel were identified, as shown in Table 2

With this information in hand, the team proceeded with the manufacturing of a new knife, now with the correct material and geometry.

Table 2. Functions of the chemical elements that form VC 131 steel. Source: Authors, (2023)

VC 131	Chemical element	Function
86,24%	Iron	-
12,11%	Chrome	Increases corrosion resistance, hardenability, abrasion resistance and forms carbides
0,13%	Vanadium	Increases resistance and forms carbides
0,23%	Molybdenum	Increases hardenability, increases resistance to high temperatures and forms carbides
0,25%	Calcium	-
0,24%	Nickel	Increases impact resistance and forms carbides
0,05%	Copper	-
0,02%	Selenium	-
0,72%	Tungsten	Forms carbides

Heat Treatment and Blade Sharpening

In this phase, it was decided to carry out the heat treatment known as tempering, aiming to enhance the mechanical properties of the knife, making it more rigid and durable. The tempering process followed the subsequent steps:

- **Pre-heating**: The furnace was heated to 700°C to prepare it for treatment.

- **Heating**: The knife was placed in the furnace and heated until it reached a temperature of 930°C. The temperature was maintained for a period of 30 minutes to ensure that the metal reached the ideal temperature for the transformation of the crystalline structure.
- **Cooling**: After heating, the knife was removed from the furnace and rapidly cooled in a cooling medium, in this case, oil. This promoted the formation of a martensitic structure, which is harder and more resistant.
- **Finishing**: To remove the dark layer resulting from the oil cooling, the knife was sanded. It was then subjected to the tempering process, where it was heated to 350°C until it reached a yellowish color. The tempering time varied between 10 and 20 minutes.

This heat treatment process induces changes in the metal's crystalline structure, allowing atoms to rearrange into a stronger structure, resulting in a knife with enhanced mechanical properties.

The final step in knife manufacturing is the grinding process, which requires the expertise of a certified professional. In this procedure, the knife is secured in the lathe, and the grinding machine is positioned so that the grinding wheel is tangent to the cutting angle of the knife. Executing this process requires practical skill, as excessive pressure can compromise the knife's sharpness. It is of utmost importance that the professional can properly control the pressure applied during grinding to achieve a precise and high-quality cutting edge. In Figure 17, you can observe the result of a knife with appropriate geometry, material, heat treatment, and proper grinding.

Certification and practical experience play a crucial role in ensuring that the knife is sharpened correctly, resulting in the desired cutting profile. It is a delicate process that demands meticulous attention to detail and specific skills to achieve the best possible result in knife sharpening.

Figure 17. Knife ready to use. Source: Authors, (2023)

Surface Roughness

As mentioned in the "Material Definition" section, the development process of the circular knife took into account crucial factors such as geometry and material. Another important aspect considered was the surface roughness of the knife. Surface roughness has a direct impact on the knife's effectiveness in cutting operations, influencing the quality of the cut and the knife's durability.

The circular knife was manufactured using VC 131 material, chosen for its high wear resistance and dimensional stability properties. A notable aspect of this process was subjecting the knife to a heat treatment at 350 degrees Celsius. This heat treatment had a significant effect on the hardness of the knife, reducing it from an initial hardness of 250 Brinell to a final hardness of 60 Brinell. This reduction in hardness was carried out to enhance the knife's ability to wear and cut Parana-type paper more efficiently, reducing the risk of breakage or excessive wear.

Furthermore, the surface roughness of the circular knife was meticulously controlled during the manufacturing process. The results of the roughness analysis indicated that the developed knife exhibited exceptionally low surface roughness, with average values in the micro (µm) range. The crest-to-valley height (Rz and Ry) of the knife's surface was strictly maintained within the range of 0.05 to 0.07, contributing to its specific texture, which is suitable for industrial paper cutting.

This extremely low roughness, combined with the heat treatment that adjusted the hardness, plays a fundamental role in ensuring that the knife performs clean and precise cuts without causing damage to the cut materials.

DISCUSSIONS

This study demonstrates the critical importance of proper material selection and processes in the manufacturing of circular knives intended for industrial cutting of Hörller-type paper. Throughout the stages of research and development, a series of findings and conclusions were reached:

- **Knife Geometry and Cutting Angle:** During the geometry definition phase, exhaustive tests were conducted to determine the ideal external diameter, thickness, and cutting angle for the circular knife. The results revealed an inversely proportional relationship between the cutting angle and cutting quality. Angles of 20° and 30° were identified as providing the best cutting quality. Additionally, increasing the knife's diameter from 58.5 mm to 117 mm proved essential in reducing the effort required to make cuts, thereby improving process efficiency.

- **Material Selection:** Selecting the appropriate material was a critical step for the success of the circular knife. Initially, VND steel (AISI 01) was chosen, but after approximately 50 cuts, it became evident that it did not maintain its cutting capacity and required frequent sharpening. Detailed analysis of chemical compositions revealed that VND had a limited amount of carbide-forming elements, contributing to the rapid deterioration of the cutting edge. The switch to VC 131 steel was a significant milestone, as this material offered high dimensional stability and exceptional wear resistance, resolving the knife's performance issues.
  The tempering process was instrumental in enhancing the mechanical properties of the knife, making it harder and more resistant. Heat treatment altered the metal's crystalline structure,

providing a solid foundation for the knife's performance. The final grinding step, performed by certified professionals, was crucial in achieving the desired cutting profile, ensuring that the knife maintained its precision and cutting quality over time.

- **Performance of VC 131 Circular Knife:** The circular knife manufactured with VC 131 steel has proven to be exceptional in terms of performance. This knife was able to cut over 1000 products without showing any signs of wear or cracks. Its durability and operational effectiveness highlight the importance of choosing the right material and following the proper procedures in the manufacturing of circular knives for industrial applications.

- **Contributions to the Industry:** This study offers valuable insights for the industry, emphasizing how careful material selection, precise geometry definition, proper heat treatment, and sharpening processes positively influence the quality and lifespan of circular knives. The findings presented here have the potential to significantly improve the efficiency of industrial paper cutting processes, reducing maintenance costs, and increasing productivity.

CONCLUSION

Based on the research conducted, it can be established that the manufacturing of circular knives is a complex and meticulous process in which the careful selection of materials plays a crucial role. The precise definition of geometry and cutting angle, coupled with the appropriate application of tempering heat treatment, are determining factors in ensuring the hardness and cutting edge's resistance.

The importance of the grinding process performed in the grinder is also emphasized, as it plays an essential role in ensuring the quality and efficiency of the circular knife.

When masterfully manufactured, the circular knife is capable of withstanding the challenges of a manufacturing environment and performing a significant number of cuts without compromising its sharp cutting capacity. This is evident when comparing two distinct knives: one that did not use the ideal material, managing to cut only 50 products before losing its cutting edge, and another made with the appropriate material (VC 131), which cut over 1000 products without affecting the cutting edge, remaining free from cracks or wear.

Such results emphasize the imperative use of high-quality materials and adherence to correct procedures in the production of circular knives. These practices not only ensure product efficiency but also increase its durability and performance. The research provides valuable insights for the industry, demonstrating how careful material selection and precise procedure execution can have a positive impact on the quality and lifespan of circular knives used in industrial processes.

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