FABRICATING A MOLD USING CNC TECHNOLOGY FOR COMPOSITE MATERIAL TENSILE TEST SAMPLES

Chouki Farsi[1,2,*], **Salah Amroune**[1,2], **Mohamed Slamani**[1,2] , **Moussa Zaoui**[1,2], **Amin Houari** [3], **Madani Kouder** [3], **Djeloul Boujemaa**[1]

[1] *Universityof M’sila ;B.P 166 ICHBELIA .M'sila 28000 Algeria.*
[2] *Laboratoire de Matériaux et Mécanique des Structures (LMMS), Université de M’sila.*
[3] *Faculty of Technology, M’hamed Bougara, University, Boumerdes 35000, Algeria.*
E-mail: chouki.farsi@univ-msila.dz

ABSTRACT: *The continuous evolution of composite materials has sparked increasing interest in more precise and reproducible testing methods. The use of Computer Numerical Control (CNC) to create molds for composite material tensile specimens represents a significant advancement in this field. This innovative approach ensures enhanced precision, uniformity in sample fabrication, and efficient adaptation to the specific requirements of composite materials. This article focuses on the CNC mold creation process for composite material tensile specimens, highlighting its advantages and advancements in the field of material testing.*

KEYWORDS: *CATIA, bio-composite, , traction statique, CNC, Gcode.*

1 INTRODUCTION

The creation of Computer Numerical Control (CNC) molds for composite material tensile specimens signifies a pivotal step in testing and analyzing these materials. Composite materials, prized for their unique properties [1-4], demand rigorous and precise assessments of their strength and mechanical behavior. In this context, tensile specimens stand as essential tools for measuring these materials' properties under load.

Traditionally, manufacturing these specimens required manual or semi-automatic techniques, often leading to variations among produced samples [5]. Such variations could affect test outcomes and the reliability of data obtained. With CNC technology, mold creation for producing tensile specimens has become more precise, reproducible, and efficient [6].

The CNC mold creation process begins with Computer-Aided Design (CAD) of the mold itself. CAD software allows for the creation of accurate, detailed three-dimensional models of tensile specimens, accounting for standardized test specifications and materials used. Once the CAD model is established, it is converted into a CNC program, guiding the machine in mold fabrication [7-11].

CNC machines offer exceptional precision in material machining, enabling the creation of molds with exact dimensions compliant with test standards. Materials used for molds vary based on specific requirements of the tested composite material, ranging from metals like aluminum to special polymers capable of withstanding high temperatures or specific environmental conditions [12].

A key advantage of CNC mold creation is repeatability. Each manufactured mold is identical to others, ensuring consistency in producing tensile specimens. This significantly reduces variations among samples, thereby enhancing test result reliability and comparability across different studies [13,14].

Moreover, CNC-manufactured molds facilitate quick adaptation to evolving specimen designs or specific test requirements [15]. Design alterations can be readily incorporated into the CNC program, expediting the manufacturing process and reducing the lead time between design and production [16-18].

Additionally, the novelty lies in the increased flexibility this approach offers. Design adjustments or specific adaptations for composite materials can be easily implemented into the CNC program, allowing rapid adaptation to changing test requirements or advancements in specimen design.

Furthermore, this innovative approach optimizes efficiency by reducing manufacturing lead times and enhancing sample repeatability. The ability to consistently produce high-precision molds contributes to more reliable and comparable tests, thereby reinforcing the validity of results obtained from these complex materials.

In summary, the uniqueness of this approach lies in its capacity to revolutionize mold manufacturing for composite material tensile specimens, providing a more precise, adaptable, and efficient method to meet the growing needs of mechanical testing in the realm of advanced materials.

2 EXPERIMENTAL TECHNIQUES

2.1 Extraction of date palm fiber

The fibers used, extracted from the date palm trees in Hodna M’sila in Algeria, come from a region with over 18.6 million trees across 167,000 hectares. Algeria ranks 4th in date production according to the FAO [19,20]. Various extraction techniques are employed, some mechanical, others chemical or biological, to isolate cellulose fibers. This extraction method involves soaking the palm stems in water for 48 hours, then peeling them and using metal brushes and a scraper to extract fibers measuring from 0.75 meters to 1 meter in length (Fig 1).

In this research, the casting process for sample preparation used a resin called ISO commercial isophthalic polyester (UP) and date palm fibers which are cut to different lengths.

Fig1: FPD uses in this work

2.2. Dimensions of Test samples

The dimensions of test specimens for tensile testing per ISO 3167 vary based on the material being tested. For metals, specimens typically measure around 50 mm in length and 10 mm in width, with a reduced section in the center. The ends might be enlarged for easier fixation in the testing machine. Regarding plastics, the dimensions depend on the type of plastic being tested, but generally, specimens are about 100 mm in length and 10 mm in width, with a specific cross-sectional area. Referring directly to ISO 3167 is crucial to obtain precise details on the specific dimensions of specimens based on the materials being tested, as different material categories may have distinct dimensional requirements (Fig.2).

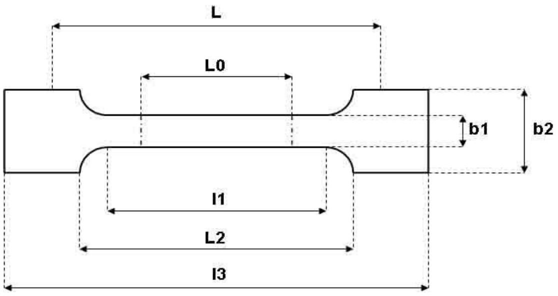


Fig2 : Dimensions of Test Specimens for Tensile Tests According to ISO 3167 Standards

2.3 Mold definition drawing

The mold definition drawing is designed using CATIA V5 software. This technical document extensively describes the specifications of the mold utilized in production, detailing aspects such as dimensions, tolerances, materials used, mold cavities, and other precise information crucial for manufacturing the mold intended for industrial production (Fig 3.).

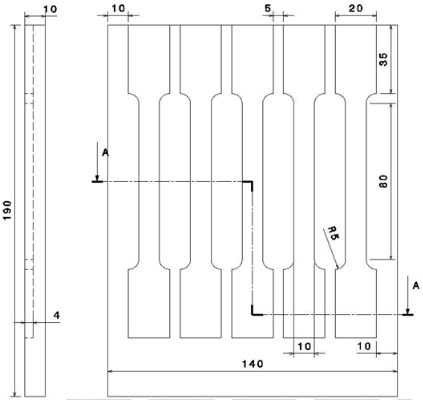


Fig 3 Mold definition drawing

The preparation of the workpiece and mold for Computer-Aided Milling (CAM) involves a methodical, multi-step process (Fig 4.). Initially, the 3D digital model of the workpiece and mold is precisely designed and modeled using Computer-Aided Design (CAD) software such as CATIA, SolidWorks, or AutoCAD. Subsequently, the CAD file is thoroughly analyzed and prepared to ensure its completeness and accuracy for CAM. Adjustments might be necessary to optimize manufacturing. An essential step involves carefully selecting milling tools based on the mold and workpiece materials. These tools, including cutters and machining materials, are carefully chosen to ensure efficient machining. Once the tools are selected, milling parameters are configured in the CAM software. These parameters, such as cutting speed, depth of cut, and feed rate, are tailored to the material specifics and shapes of the workpiece and mold. Next, the CAM program is generated, translating the CAD model into precise instructions for the machine tool, defining the movements and actions required to shape the workpiece and mold. Before commencing milling, meticulous preparation of the machine tool takes place, including tool mounting, machine adjustments, and fixture installation to secure the workpiece and mold during machining. Once the milling process begins, the machine tool cuts and shapes the workpiece and mold according to the CAM program. Finally, a thorough inspection is conducted to ensure compliance with required specifications, including measurements and tests to ensure the final quality of the machined parts. Each step demands meticulous attention to ensure precision and quality in the Computer-Aided Milling process.

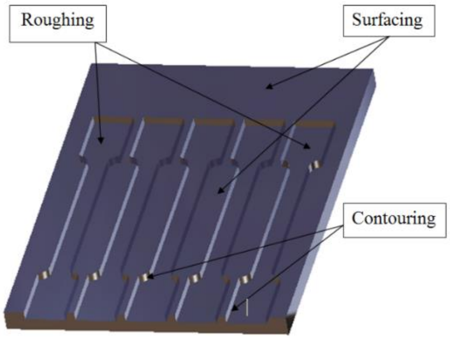


Fig4 : Mold preparation on CATIA

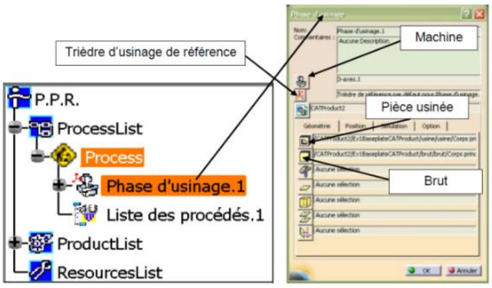


Fig5: Definition of machine, stock and machined part

A machining tool is equipment used to remove starting materials, referred to as raw materials, in order to shape and create finished pieces according to precise specifications. These machines can vary based on their actuation type (such as milling machines, lathes, 3D printers, etc.) and their machining method (like milling, turning, laser cutting, etc.).

The raw material refers to the raw or unworked piece before the machining process. It's the original material form from which a piece will be created. This raw material can be a raw casting, a piece of metal, plastic, or any other raw material intended to be transformed into its final form (Fig 5).

The machined part is the end result of the machining process. It's the manufactured piece that has been worked from the raw material by the machining tool. It aligns with the specific dimensions, shape, and characteristics required by the design or technical specifications. The machined part represents the finished product resulting from the removal of material from the raw material through machining operations such as milling, turning, drilling, etc**.**

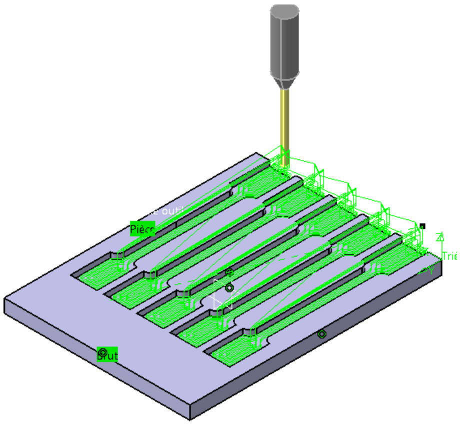
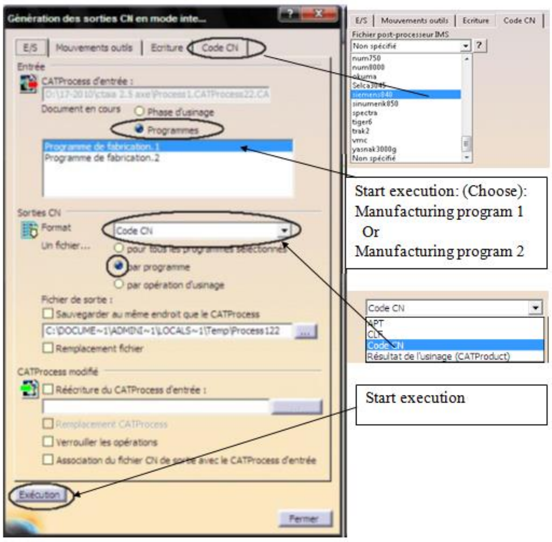


Fig6 : Machining simulation

Machining simulation is a computerized process that virtually predicts and represents the machining process of a part before its physical realization. This simulation replicates typical machining operations like milling, turning, drilling, etc., based on a 3D digital model of the part and the raw material. Executed using specialized software, it incorporates a range of parameters such as machine tool movements, tool paths, cutting speeds, and other key process variables. The benefits of this simulation are manifold: it validates machining feasibility, anticipates potential tool-to-part collisions, rectifies possible errors, and optimizes machining parameters to enhance quality while reducing material waste and associated costs. In summary, machining simulation stands as a crucial step in production preparation, offering a precise and secure view of machining operations before their actual execution (Fig **6) .**



Start execution: (Choose):
Manufacturing program 1
Or
Manufacturing program 2

Start execution

Fig7 : Generation of the CNC program

Generating a CNC program involves developing a detailed set of specific instructions intended for a computer numerical control (CNC) machine tool for the production of a part. This process starts with designing a 3D model of the part to be manufactured using computer-aided design (CAD) software. Then, it involves precisely selecting tools and machining parameters suitable for the materials and specifications of the part. Once these elements are in place, the tool paths that the machine tools will follow to shape the part according to the CAD model are determined (Fig 7). This information is translated into a specific programming language, such as G-code, to create a program understandable by the machine tool.

```
%1000
N1 G54 G64 G40 G90 G17 G94 G49
G80
N2 G53
N3 T2 M6
N4 G0 X112.5 Y-10. S70 M3
N5 Z9.
N6 G1 Z-1. F300.
N7 Y0
N8 X112.499 Y27.929 F1000.
N9 G3 X117.5 Y35. CR=7.5
N10 G1 Y75.
N11 Y115.
   N12 G3 X112.499 Y122.071
            CR=7.5
N13 G1 X112.5 Y147.5
N14 X127.5
N15 X127.501 Y122.071
N16 G3 X122.5 Y115. CR=7.5
N17 G1 Y75.
N18 Y35.
N19 G3 X127.501 Y27.929 CR=7.5
N20 G1 X127.5 Y0
N21 G0 Z.5
N22 G1 Z-2. F300.
  N23 X127.501 Y27.929 F1000.
N24 G2 X122.5 Y35. CR=7.5
N25 G1 Y75.
N26 Y115.
N27 G2 X127.501 Y122.071
CR=7.5
N28 G1 X127.5 Y147.5
N29 X112.5
N30 X112.499 Y122.071
N31 G2 X117.5 Y115. CR=7.5
N32 G1 Y75.
N33 Y35.
N34 G2 X112.499 Y27.929 CR=7.5
N35 G1 X112.5 Y0
N36 G0 Z-.5
N37 G1 Z-3. F300.
N38 X112.499 Y27.929 F1000.
N39 G3 X117.5 Y35. CR=7.5
N40 G1 Y75.
N41 Y115.
N42 G3 X112.499 Y122.071
CR=7.5
N43 G1 X112.5 Y147.5
N44 X127.5
N45 X127.501 Y122.071
N46 G3 X122.5 Y115. CR=7.5
N47 G1 Y75.
N48 Y35.
N49 G3 X127.501 Y27.929 CR=7.5
N50 G1 X127.5 Y0
N51 G0 Z-1.5
N52 G1 Z-4. F300.
N53 X127.501 Y27.929 F1000.
N54 G2 X122.5 Y35. CR=7.5
N55 G1 Y75.
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N6646 X118.008 Y120.986
N6647 X117.851 Y121.19
N6648 X117.35 Y121.777
N6649 X117.173 Y121.964
N6650 X116.614 Y122.497
N6651 X116.419 Y122.665
N6652 X115.808 Y123.137
N6653 X115.597 Y123.284
N6654 X115. Y123.655
N6655 Y125.169
N6656 X116.25
N6657 X117.5
N6658 Y142.5
N6659 X122.5
N6660 Y124.998
N6661 X122.441 Y124.951
N6662 X121.841 Y124.465
N6663 X121.458 Y124.121
N6664 X120.911 Y123.576
N6665 X120.566 Y123.194
N6666 X120.078 Y122.596
N6667 X120. Y122.498
N6668 X119.753 Y122.812
N6669 X119.252 Y123.4
N6670 X118.898 Y123.774
N6671 X118.339 Y124.307
N6672 X117.948 Y124.642
N6673 X117.5 Y124.989
N6674 Y125.169
N6675 Z6. F1.
N6676 G53
N6677 T1 M6
N6678 G0 X0 Y0 S70 M3
N6679 Z0
N6680 G1 Y190. F1000.
N6681 X11.667
N6682 Y0
N6683 X23.333
N6684 Y190.
N6685 X35.
N6686 Y0
N6687 X46.667
N6688 Y190.
N6689 X58.333
N6690 Y0
N6691 X70.
N6692 Y190.
N6693 X81.667
N6694 Y0
N6695 X93.333
N6696 Y190.
N6697 X105.
N6698 Y0
N6699 X116.667
N6700 Y190.
N6701 X128.333
N6702 Y0
N6703 X140.
N6704 Y190.
N6705 M30
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This program is then thoroughly checked to detect any errors or potential collisions between the tool and the part, and adjustments are made if necessary to optimize the machining process. Once validated, this program is transferred to the machine tool to materialize the production, ensuring precise manufacturing in accordance with the initial specifications.

3 RESULTS AND DISCUSSIONS

3.1. Mold machining

After simulating and generating the G-code program through CATIA, the next step is realization. The manufacturing process involves using an EMCO F1 milling machine for molding the mold. This machine, renowned for its precision and versatility, translates the G-code program into mechanical movements to sculpt the piece. The EMCO F1 milling machine is equipped with specific tools tailored to the material and mold specifications, ensuring precise and efficient fabrication. This method ensures a smooth transition from virtual simulation to the physical realization of the mold, delivering dimensional accuracy and fidelity in line with the initial design expectations. By utilizing this specific milling machine, the aim is to achieve a faithful reproduction of the virtually designed model, ensuring the quality and compliance of the finalized mold for its use in subsequent manufacturing processes (Fig 8).

```
FONCTION CNC  INCR. 0.01MM
 N  G     X      Y       Z   F
00 01     00     00 -   50 140
01 01   2400     00     00 140
02 03    500 -  500        140
03 01   8000     00     00 140
04 03    500    500        140
05 01   2400     00     00 140
06 01     00 -1400      00 140
07 01 - 2400     00     00 140
08 03 -  500    500        140
09 01 - 8000     00     00 140
10 03 -  500 -  500        140
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Fig8 : The mold to be machined

The Figure 8 provides an overview of the mold's post-machining state, highlighting significant enhancements in roughness and surface quality, particularly noticeable in the impressions intended for the tensile test specimens. These specific areas exhibit a smoother finish and an improved texture, suggesting a substantial improvement compared to the previous state of the mold surface. This enhancement could potentially have a positive impact on the quality and precision of the specimens produced from this mold, thereby providing more favorable conditions for tensile testing.

3.2. Mechanical properties in tensile tests

Before using the mold, it's crucial to thoroughly clean it using cotton swabs to eliminate any dust or residues. This is especially important to prevent adhesion between the specimens manufactured after molding, thereby facilitating their subsequent extraction. To ease the demolding of the specimens, a small amount of grease was applied to the impressions of the tensile test specimens (Fig 9)

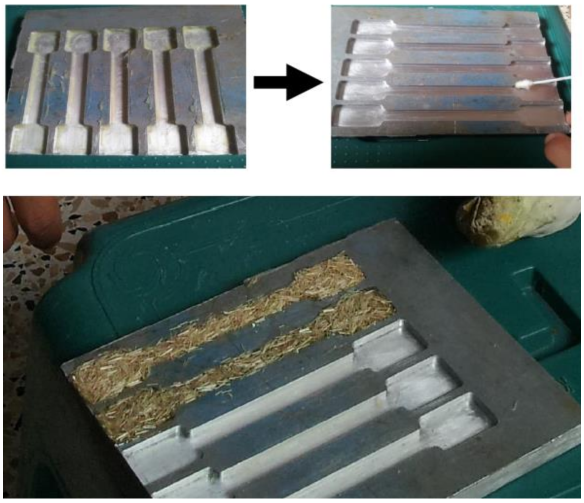

Fig9 : Molding of specimens

Samples reinforced with multidimensional date palm fibers, comprising both long and short fibers, undergo tensile tests at room temperature (22°C). The tensile tests are conducted using a specific machine situated in the Maghreb pipe laboratory, located in the industrial zone of M'sila, Algeria.

Fig10 : The samples tested

Figure 10 depicts the three categories of samples that need to be manufactured: (i) neutral tensile specimens, (ii) tensile specimens reinforced with short fibers (3mm), and (iii) tensile specimens reinforced with long fibers (150mm). In the preparation of composites, two distinct methods are employed based on the dimensions of the fibers used. For the 3mm fibers, a random mixture of these fibers with the resin is carried out in a container, followed by pouring this composite into the mold. Conversely, for the 150mm fibers, the adopted technique is contact molding, a common method in composite fabrication. This process begins by creating layers where the long fibers are longitudinally arranged in the mold. Demolding is only possible after the complete curing of the material, requiring an advanced resin polymerization. To achieve this hardening, the mold is exposed to a temperature of 70°C in an oven, promoting polymerization through hot air heating.

Fig11 : Fixation of the tested specimens

The sample intended for testing is carefully positioned between the specific jaws of the tensile testing machine, ready to undergo a tensile test with a fixed displacement speed of 1 mm/min to assess its mechanical characteristics. In order to evaluate the mechanical behavior of laminates, tensile tests were conducted on specimens composed of pure resin and resin reinforced with plant fibers (Fig 11). The results depict the relationship between the applied load and the displacement of the specimens. It is observed that elongation remains proportional to the applied force until rupture occurs abruptly, indicating a behavior classified as "brittle elastic." Each model was tested using three distinct specimens.

The specifics of the tensile tests on the specimens are as follows:

- Distance between jaws: L0 = 80 mm
- Specimen width: d0 = 10 mm
- Specimen thickness: h0 = 4 mm, resulting in a cross-section S0 = 40 mm²
- Constant displacement speed: Vt = 1 mm/min.

The curves presented below illustrate the relationship between the applied load on the specimens and their displacement during these tests.

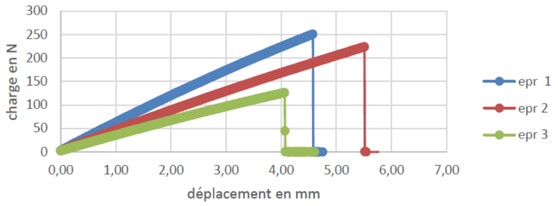

Fig12. Tensile curve of resin specimens

Figure 12 illustrates the stress-strain curve providing an overview of the tensile mechanical parameters for the analyzed material. These values are detailed as follows: the maximum force achieved (F) is 223.88 N, the recorded displacement (ΔL) is 5.75 mm, the tensile strength (σm) is evaluated at 5.597 MPa, the observed strain (ε) is 0.071, the percentage elongation (A%) is 7.1%, and finally, the Young's modulus (E) is estimated at 78.83 MPa. These parameters are crucial for understanding the material's behavior under tensile testing.

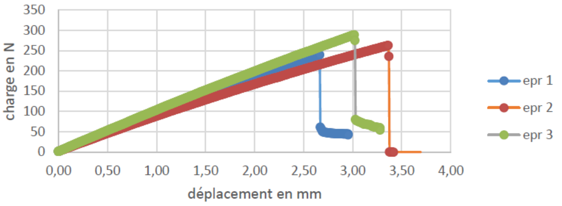

Fig13. Tensile curve of 3mm fiber resin specimens

The stress-strain curve depicted in Figure 13 details the mechanical parameters associated with the material undergoing tensile analysis. Specific values include a maximum force of 235.78 N, a displacement of 3.69 mm, a tensile strength of 5.89 MPa, a strain of 0.046, a percentage elongation of 4.6%, and finally, a Young's modulus of 128.04 MPa. These data provide a precise insight into the material's behavior under tensile testing.

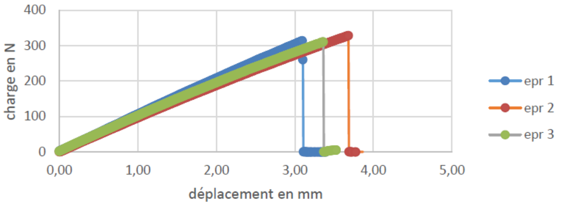

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Fig14. Tensile curve of 150mm fiber resin specimens

Figure 14 displays the stress-strain curve, detailing the mechanical parameters of the material evaluated during tensile analysis. The data includes a maximum force of 311.95 N, a displacement of 3.52 mm, a tensile strength of 7.80 MPa, a strain of 0.044, a percentage elongation of 4.4%, and a Young's modulus of 177.27 MPa. These values provide a detailed perspective on the material's response during tensile testing.

We examined three types of specimens: the first composed of resin alone, the second reinforced with 3 mm fibers, and the third reinforced with 150 mm fibers. The second and third types consist of the same composite material (polyester-date palm fibers).

For the resin specimens, the tensile strength was around 6.597 MPa, with an elongation at break close to 7.1% and a Young's modulus of 78.83 MPa.

Specimens reinforced with 3 mm fibers showed a notable increase in Young's modulus at 128.04 MPa, while the tensile strength reached 5.89 MPa. However, the percentage of elongation at break decreased, settling at 4.6%.

Specimens reinforced with 150 mm fibers exhibited the best performance, achieving a tensile strength of 7.80 MPa and a Young's modulus of 177.27 MPa. However, the percentage of elongation continued to decrease, reaching 4.4%.

The analysis of the tensile results on these three types of specimens highlights the significant impact of the distribution method and fiber length on the mechanical characteristics of the composites. It is evident that the longitudinal distribution method of long fibers offers the best tensile performance for date palm fiber composite materials..

4 CONCLUSION

The incorporation of Computer Numerical Control (CNC) technology into fabricating molds for composite material tensile test samples represents a significant step forward in materials testing. This innovative method offers unmatched accuracy, heightened reproducibility, and impressive adaptability to the specific needs of composite materials.

The precision ensured by CNC results in molds produced with exceptional consistency, reducing variations among test samples. This guarantees more reliable results and facilitates comparison across different studies, thereby enhancing the credibility of data derived from these tests.

Furthermore, the flexibility of CNC enables quick adjustments to accommodate changes in test sample design or specific requirements of composite materials. This adaptability speeds up the manufacturing process, cutting down on timelines and encouraging ongoing innovation in the development of new materials.

In essence, the utilization of CNC for crafting molds used in composite material tensile testing marks a significant leap forward in refining testing methods and characterizing these groundbreaking materials. This pioneering approach cements the reliability of tests, accelerates the pace of development, and widens the application of these materials across diverse industries, paving the way for further advancements in technology and science.

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