People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

University Echahid Hamma Lakdhar-ELOued

FACULTY OF TECHNOLOGY

MECHANICAL ENGINEERING DEPARTMENT

Thesis

PRESENTED FOR GRADUATION FROM MASTER

Specialty: Renewable Energies

Contribution to the study of the mechanical behavior plates under the effect a notches size

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Academic year:2022-2023

بسم الله الرحمن الرحيم

Acknowledgments

First and foremost, we would like to express our gratitude to the Almighty God for granting us the strength and courage to complete this work.

We would like to extend our sincere thanks to our supervisor, Mr. Megdoud Soufiane, for his guidance on the topic. We kindly request you to accept this testimony of our utmost appreciation and profound respect.

We would also like to express our heartfelt gratitude to the entire academic team of the Department of Mechanical Engineering at Echahid Hamma Lakhdar University in El-Oued.

We are particularly grateful to our families for their moral support throughout this work. Thank you for encouraging us and believing in us.

Furthermore, we would like to thank our friends and classmates who encouraged us throughout this project and provided us with significant assistance

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List of Abbreviations

- CMO: Organic Matrix Composite
- CMC: Ceramic Matrix Composites
- CMM: Metal Matrix Composites
- TD: Thermosetting
- PP: Polypropylene
- PE : Polyethylene
- PET: Polyethylene Terephthalate
- PS : Polycarbonate
- PVC: Polyvinyl chloride

Main Notations

- **σ:**istheappliedstress
- **ε:**is the strain, which his the linear elastic modulus
- **S:**is the second-order elastic modulus
- **R:**is the third-order elastic modulus
- **M**:is the mass of the yarn expressed in grams
- **L**:is the length of the yarn expressed in meters.
- **A:**Weight of the sample in grams before calcination.
- **B:** Weight of fibers (g) obtained after calcination.
- **Vf and Vm:** Mass fraction of fibers and matrix in(%).
- **I_z:**Moment of inertia.
- **F:**The deflection in the x-z plane.
- **E_x:**Elastic modulus

Abstract

The study focuses on the mechanical behavior of plates subjected to the presence notches. The objective is to investigate the influence of the notches on the structural response of the plates. The research makes a significant contribution to the understanding of how notches affect the overall strength and stability of the plates.

To achieve this, the study employs experimental methods. The experimental approach involves the fabrication of plate specimens with different notches sizes. This specimens are then subjected to various loading conditions to evaluate their mechanical response. The experimental results provide valuable insights into the behavior of notched plates and highlight the areas of stress concentration and deformation.

Keywords :Composite materials, mechanical behavior, experimental study, notches sizes (hole size), fatigue.

ملخص

تركز هذه الدراسة على السلوك الميكانيكي للوحات تتعرض لوجود نتوءات متفاوتة الاحجام. الهدف هو التحقيق في تأثير النتوءات على الاستجابة الهيكلية للوحات. تقدم هذه الدراسة مساهمة هامة في فهم كيفية تأثير النتوءات على القوة و الاستقرار العام للوحات.

لتحقيق ذلك ، تعتمد الدراسة على الأساليب التجريبية .تتضمن الطريقة التجريبية تصنيع نماذج من اللوحات بتكوينات نتوء مختلفة .يتم تعريض هذه النماذج لظروف تحميل متنوعة لتقييم استجابتها الميكانيكية. توفرالنتائج التجريبية نظرة قيمة على سلوك الوحات ذات النتوءات و تسلط الضوء على مناط قتركز الإجهاد و التشوه.

تقدم الدراسة تحليلاً شاملا للسلوك الميكانيكي للوحات ذات النتوءات المتعددة ، مما يسلط الضوء على التفاعل المعقد بين النتوءات و هيكلتها .

الكلمات المفتاحية :المواد المركبة ، السلوك الميكانيكي ،دراسة تجريبية للصلابة ، أحجام الفجوات (حجم الثقب) ، الاجهاد، التمدد.

Résumé

L'étude se concentre sur le comportement mécanique de plaques soumises à la présence de différent tailles des encoches. L'objectif est d'étudier l'influence des encoches sur la réponse structurelle des plaques. La recherche apporte une contribution significative à la compréhension de l'impact des encoches sur la résistance globale et la stabilité des plaques.

Pour ce faire, l'étude utilise des méthodes expérimentales et numériques. L'approche expérimentale consiste à fabriquer des spécimens de plaques avec différentes configurations d'encoches. Ces spécimens sont ensuite soumis à différentes conditions de chargement pour évaluer leur réponse mécanique.

Les résultants expérimentaux fournissent des informations précieuses sur le comportement des plaques avec des encoches et mettent en évidence les zones de concentration de contrainte et de déformation.

les mots clés : Matériaux composites, comportement mécanique, étude expérimentale, notches sizes (taille de trou), fatigue.

General Introduction :

In the past, the use of composite materials has become widespread. These materials are composed of two or more distinct and different materials. One of them is a reinforcing material, which can be in the form of high-strength fibers such as carbon and glass fibers. The second material is a polymer or resin that gives the final product its desired shape and is called the matrix or matrix material. Composite materials have been present since ancient times, but nowadays, they can be found in various journals and fields around us. They are used in the production of structural components of various sizes and in many sectors, ranging from automobiles to buildings and more. Composite materials have rapidly gained immense popularity due to their mechanical properties, designed from composites reinforced with high-strength carbon or glass fibers, compared to their low volume mass.

This thesis consists of an introduction, a general conclusion, and two main parts: The first part is a literature review that includes two chapters:

Chapter 1: It provides a general overview of organic composite materials, specifically plant fibers, their properties, and their physical and mechanical characteristics.

Chapter 2: This chapter focuses on defining the elastic mechanical behavior of composite materials with reinforcement and studying the mechanical behavior of laminated composite materials.

The experimental part comprises one chapter:

Chapter 3: In this chapter, the practical application of this work is presented, with a focus on selecting the type of reinforcement and resin and assessing their compatibility. It also outlines the necessary methods and steps for preparing laminated composite materials. Additionally, the chapter includes the description of conducting tests and experiments on the material.

Chapter 4 : we presente the results and discussions.

ChapterI:

Generalitieson CompositeMaterials

Introduction :

The study of the mechanical behavior of plates under the effect of a number of notches is of great importance in the field of engineering and materials science. Plates are structures widely used in various applications, ranging from aerospace to construction to the automotive industry. However, the introduction of notches in these plates can significantly influence their structural behavior and mechanical performance.

A deep understanding of the mechanical behavior of notched plates is crucial for the design of safe and reliable structures. It helps to determine the key factors that influence the strength, stiffness, fracture toughness, and service life of the plates. Furthermore, a better understanding of the behavior of notched plates can lead to improvements in manufacturing methods, inspection procedures, and preventive maintenance strategies.

To study the mechanical behavior of notched plates, different approaches can be used, ranging from laboratory experiments to advanced numerical models. Experimental tests allow for directly measuring the performance of notched plates under specific conditions, while numerical modeling offers a more affordable and reproducible approach to predict the behavior of plates in different notch configurations.

Bibliographic references :

The history of composite materials dates back thousands of years. The concept of combining two or more materials to create a new material with enhanced properties has been employed by ancient civilizations in various forms. Today, composite materials play a crucial role in various fields, offering a wide range of properties, including high strength-to-weight ratio, corrosion resistance, thermal stability, and design flexibility. Ongoing research and development continue to push the boundaries of composite materials, enabling innovative solutions in numerous industries.

In 1993, Norman E . Dowling [1] The effect of notch shape on the fracture behavior of plates is an important aspect of understanding the mechanical behavior of these structures. Notches or

cracks act as stress concentrators, leading to increased local stress levels compared to the surrounding material. The shape and dimensions of the notch can significantly influence the stress distribution and the initiation and propagation of cracks, ultimately affecting the fracture behavior of the plate.

The notch shape can impact several key factors related to fracture behavior, including:

Stress Concentration: The shape of the notch determines the stress concentration factor, which is a measure of the localized stress amplification at the notch tip. Different notch shapes will have varying levels of stress concentration, leading to different levels of local stress and potential for crack initiation.

Crack Initiation: The presence of notches can facilitate crack initiation. The shape of the notch can influence the stress state at its tip, affecting the critical stress required for crack initiation. Notch geometry can promote different modes of crack initiation, such as tensile, shear, or mixed-mode.

Crack Propagation: Once a crack is initiated, the shape of the notch can influence the path and direction of crack propagation. Different notch shapes may result in varying stress intensity factors and crack growth directions, leading to different fracture modes, such as ductile or brittle fracture.

Fracture Toughness: The fracture toughness of a material is a measure of its resistance to crack propagation. Notch shape can affect the measured fracture toughness as different notch geometries will produce different levels of stress intensity at the crack tip during fracture toughness testing.

Understanding the effect of notch shape on fracture behavior is crucial for designing and analyzing structures, as it helps predict their failure modes and mechanical performance. Researchers employ experimental testing, numerical simulations, and theoretical models to investigate the influence of notch shape on fracture behavior, contributing to the development of guidelines and design criteria for safe and reliable structures.

By studying the impact of notch shape on fracture behavior, engineers and researchers can optimize structural designs, enhance the durability of materials, and ensure the integrity and safety of various engineering applications, such as aerospace, automotive, civil engineering, and mechanical components.

In 2017 , D. THOMPSON [2] He studied an analysis algorithm to study effort concentration where An analysis to study stress concentration in plates with multiple notches can provide valuable information on their mechanical behavior. Multiple notches in a plate can significantly influence the stress distribution, leading to localized stress concentrations and potential areas of high stress and increased susceptibility to crack initiation and propagation.

The analysis typically involves the following steps:

Geometry and Material Properties: The plate geometry, including the dimensions and locations of the multiple notches, is defined. The material properties of the plate, such as elasticity and strength, are also considered.

Finite Element Analysis (FEA): Finite element analysis is commonly used to simulate the stress distribution in plates with multiple notches. The plate is divided into finite elements, and boundary conditions, such as loads and constraints, are applied.

Mesh Generation: A mesh is generated to discretize the plate into small elements. The mesh density should be appropriately chosen to ensure accurate representation of stress concentrations near the notches.

Material Behavior: The material behavior, including linear or nonlinear elastic properties, plasticity, or damage, is incorporated into the analysis. This allows for the accurate representation of material response under applied loads.

Stress Concentration Analysis: The stress distribution and concentration around each notch are analyzed. Stress concentration factors (SCFs) are calculated, which indicate the amplification of stresses at the notch tip compared to the nominal stress.

Critical Locations: The critical locations, where stress concentrations are the highest, are identified. These areas are prone to crack initiation and can significantly affect the mechanical behavior of the plate.

Fracture Analysis: If required, fracture analysis can be performed to assess the crack initiation and propagation behavior in the plate with multiple notches. Fracture criteria and methods, such as the energy-based approach or stress intensity factor calculations, can be employed.

This information can aid in optimizing designs, mitigating stress concentrations, improving the structural integrity, and minimizing the risk of failure in real-world applications.

In 2018 , JOHNSON [3] He developed an analytical model to predict the stress distribution around multiple cracks in slabs . Analytical models offer simplified mathematical expressions that provide insights into the stress distribution and behavior of the plate, offering a more straightforward and efficient alternative to numerical methods like finite element analysis. Here are the general steps involved in developing such an analytical model:

Plate Geometry and Notch Configuration: Define the geometry of the plate and the configuration of the multiple notches.

Stress Concentration Factors (SCFs): Determine the stress concentration factors associated with each individual notch. SCFs quantify the stress amplification at the notch tip compared to the nominal stress in the plate.

Superposition or Interaction Effects: Consider the interaction effects between adjacent notches. Depending on the proximity and arrangement of the notches, their presence can influence the stress distribution in the plate, affecting the overall stress concentration.

Stress Distribution Calculation: Use appropriate mathematical equations and principles to calculate the stress distribution around each notch and the combined effect of multiple notches. This may involve the superposition of stress fields or other analytical techniques.

Validation and Calibration: Validate the analytical model by comparing its predictions with experimental data or numerical results from finite element analysis. If necessary, calibrate the model parameters to improve its accuracy.

Parametric Analysis: Utilize the analytical model to perform parametric analyses, exploring the effects of varying notch geometries, plate properties, and loading conditions on the stress distribution and mechanical behavior of the plate with multiple notches.

This knowledge can aid in designing more robust structures, optimizing notch configurations, and minimizing the risk of failure in real-world applications. Additionally, analytical models are computationally efficient and provide insights into the underlying mechanics of stress concentration, making them valuable tools in the field of structural analysis and design.

In the same year , G. RODRIGUEZ [4] He studied the numerical simulation of the propagation of cracks in the plates . Numerical simulation of crack propagation in notched plates is an effective approach to gaining a better understanding of the mechanical behavior of these structures. By employing numerical methods such as finite element analysis (FEA), the propagation of cracks and their influence on the structural response can be accurately modeled. Here are the key steps involved in conducting such a simulation:

Plate Geometry and Notch Configuration: Define the geometry of the plate and the configuration of the notches, including their shape, size, and location. Specify the material properties of the plate, such as elasticity and strength.

Mesh Generation: Create a mesh that discretizes the plate into finite elements. The mesh should be refined around the notches and crack front to capture the stress gradients and crack propagation accurately. Various meshing techniques, such as structured or unstructured meshes, can be employed.

Material Behavior: Incorporate the material behavior into the simulation. This may involve considering linear or nonlinear elastic properties, plasticity, or fracture mechanics parameters such as fracture toughness.

Crack Initialization: Introduce an initial crack or notch in the plate according to the desired configuration. The crack can be defined explicitly or by employing cohesive zone modeling or the eX tended Finite Element Method (XFEM).

Loading Conditions: Apply appropriate loading conditions, such as tensile, bending, or mixed - mode loading, to simulate real-world scenarios. The loading can be static or dynamic, depending on the specific analysis objectives.

Crack Propagation Analysis: Use appropriate crack propagation criteria, such as stress intensity factors (SIFs), energy release rates, or critical crack tip opening displacement (CTOD), to assess crack propagation. Incrementally increase the crack size or propagate the crack step-by- step using cohesive elements or XFEM.

Fracture Analysis: Analyze the fracture behavior of the notched plate, including the crack growth path, critical crack length, and mode of failure. Evaluate parameters like crack growth rate and residual strength.

Validation and Calibration: Validate the numerical model by comparing the simulation results with experimental data or established analytical solutions. Calibrate the model parameters if necessary to improve accuracy.

Numerical simulations provide valuable insights into the mechanical behavior of notched plates, allowing for a detailed examination of crack propagation and its impact on structural integrity.

These simulations can aid in optimizing designs, assessing structural performance under different loading conditions, and guiding material selection for notched components.

Additionally, they offer the advantage of flexibility, as various parameters can be easily modified to investigate different scenarios and understand the underlying mechanisms governing crack propagation.

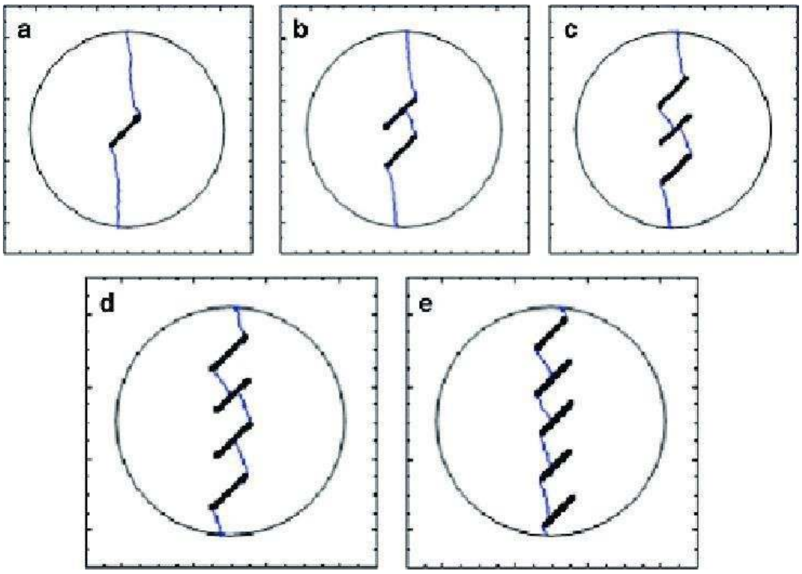


Figure I.1. Numerical simulation of the crack propagation path for pre-cracked[1]

In 2019, A SMITH [5] The stress concentration factor (SCF) in notched plates is a crucial parameter that highlights the influence of the number of notches on the mechanical behavior of the plate. The SCF quantifies the increase in stress at the notch tip compared to the nominal stress in the unnotched region. Here, his Study it for the influence of the number of notches on the SCF and the subsequent effects on the mechanical behavior:

Single Notch: In a single-notched plate, the SCF is primarily determined by the geometry of the notch, such as its shape, size, and depth. The presence of a single notch leads to a localized stress concentration at the notch tip, resulting in an elevated stress level compared to the surrounding material. This higher stress concentration can significantly affect the mechanical behavior, including crack initiation and propagation.

Multiple Notches: The number of notches in a plate further amplifies the stress concentration effect. Each additional notch introduces an additional stress concentration point, leading to higher localized stress levels. The interaction between adjacent notches can also influence the stress distribution, potentially increasing the overall stress concentration in the plate. The SCF associated with each individual notch can be influenced by neighboring notches and their relative positions.

Stress Redistribution: The presence of multiple notches can lead to stress redistribution within the plate. As stress is concentrated at the notch tips, neighboring regions experience reduced stress levels. This stress redistribution can affect the load-bearing capacity and overall strength of the plate, potentially leading to localized deformations and structural failure.

It's important to note that the specific impact of the number of notches on the SCF and mechanical behavior will depend on various factors, including the notch configuration, loading conditions, material properties, and plate geometry. Therefore, comprehensive numerical analyses or experimental investigations are typically conducted to precisely evaluate the influence of the number of notches on the mechanical behavior of notched plates.

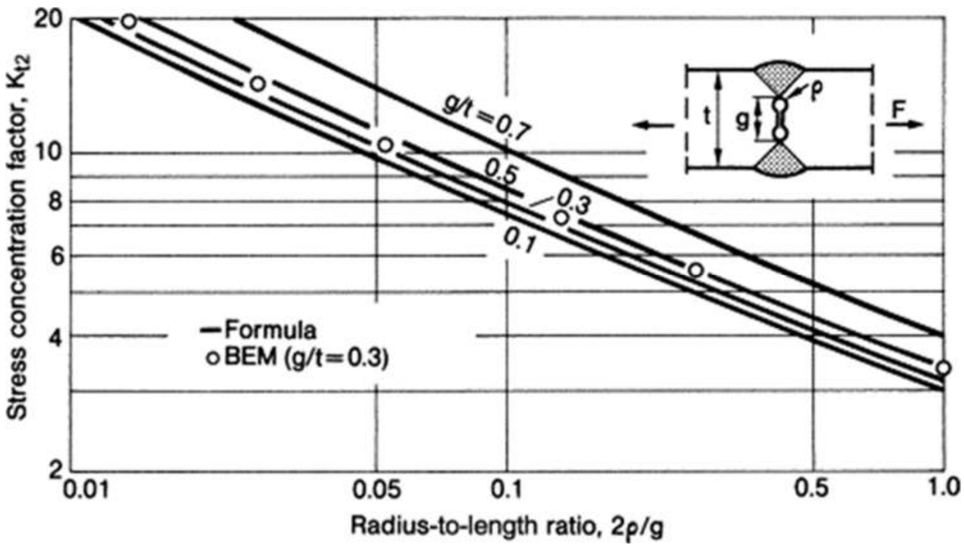


Figure.I.2. Stress concentration factor (SCF)[13]

In the same year , F. MARTINEZ He studied the effect of cutting geometry on the fracture behavior of plates ; where The influence of notch geometry on the fracture behavior of plates is a critical characteristic that holds significant importance in the study of mechanical behavior.

The shape, size, and orientation of a notch can have a profound impact on the stress distribution, crack initiation, propagation, and ultimate failure of the plate.

Understanding the influence of notch geometry on the fracture behavior of plates is essential for designing and analyzing structures. It enables engineers to predict failure modes, optimize designs, and ensure structural integrity and safety. Experimental testing, numerical simulations, and theoretical models are employed to investigate the impact of notch geometry, contributing to the development of design guidelines and criteria for safe and reliable structures.

In summary, the notch geometry plays a crucial role in determining the stress concentration, crack initiation, propagation paths, and fracture behavior of plates. Studying this characteristic is essential for a comprehensive understanding of the mechanical behavior and failure mechanisms of notched structures.

In 2020 , C. WILLIAMS [7] The fatigue behavior of notched plates under cyclic loading is a critical aspect that requires careful consideration in engineering design. Notches in plates can significantly

affect their fatigue performance, leading to accelerated crack initiation and propagation compared to unnotched plates. The following is an overview of a study by C. Williams on the fatigue behavior of toothed plates under cyclic loading:

Stress Concentration: Notches act as stress concentrators, leading to local stress intensification at the notch root. The presence of stress concentrations promotes the initiation and growth of fatigue cracks. The stress concentration factor (SCF) at the notch root is typically higher than in unnotched regions, which increases the likelihood of fatigue failure.

Crack Initiation: Notches provide preferential sites for fatigue crack initiation. The high stresses at the notch root create a favorable environment for crack nucleation. Fatigue cracks may initiate at the notch root due to cyclic loading, even at stress levels below the material's fatigue strength.

Crack Propagation: Once a fatigue crack initiates at the notch root, it tends to propagate under cyclic loading. The geometry of the notch influences the crack propagation behavior, including

the crack growth rate and direction. The presence of notches can accelerate crack growth due to the localized stress concentrations.

Crack Interaction: In notched plates, multiple notches can interact with each other, affecting the crack propagation behavior. Interaction between neighboring cracks can lead to stress redistribution and changes in crack growth paths. The interaction between cracks can accelerate fatigue crack growth compared to a single notch configuration.

Fatigue Life Prediction: Predicting the fatigue life of notched plates is challenging due to complex stress and crack propagation behavior. Various methods, such as stress-based approaches (e.g., stress- life or strain-life methods) and fracture mechanics-based approaches (e.g., Paris law or NASGRO method), are employed to estimate the fatigue life of notched plates. These methods incorporate the effects of notch geometry, stress concentration, and crack growth behavior.

And In the Same year , H . GARCIA [8] Strength analysis of plates with multiple notches under static loading involves assessing the structural integrity and determining the maximum load- carrying capacity of such plates. Here's an overview of the analysis process:

Stress Distribution: The first step is to analyze the stress distribution in the plate with multiple notches. Various analytical methods, such as the finite element method (FEM) or analytical solutions, can be employed to calculate the stress distribution. The presence of notches introduces stress concentration, leading to localized high-stress regions at the notch roots.

Stress Concentration Factor (SCF): The stress concentration factor is a measure of stress amplification at the notch root compared to the nominal stress in the unnotched region. Determining the SCF at each notch is crucial in understanding the stress intensification and identifying critical areas prone to failure.

Failure Criteria: Next, the applied stress is compared to the material's strength properties and failure criteria. Common failure criteria include yield strength, ultimate tensile strength, or fracture toughness, depending on the nature of the material and loading conditions. The stress

state at the notches may influence the choice of the appropriate failure criterion.

Load-Carrying Capacity: The load-carrying capacity of the plate with multiple notches is determined by assessing the critical section(s) and identifying the maximum applied stress. The structural analysis considers the weakest section(s) where failure is most likely to occur due to stress concentrations.

Factor of Safety: To ensure the structural safety, a factor of safety (FoS) is applied by dividing the load-carrying capacity by the expected applied loads. The FoS accounts for uncertainties in material properties, loading conditions, and analysis assumptions.

Design Optimization: If the calculated load-carrying capacity does not meet the desired safety requirements, design optimization techniques can be employed.

Modifying the notch geometry, redistributing the notch locations, or implementing additional reinforcement can improve the plate's strength and performance.

It is important to note that strength analysis of plates with multiple notches requires accurate geometrical and material data, as well as appropriate stress analysis methods. Experimental validation, such as mechanical testing or fracture mechanics testing, can complement the analytical or numerical approaches.

In 2021 , E. DAVIS [9] studied the effect of crack depth on the fracture toughness of slabs ; where The effect of notch depth on the fracture toughness of plates is an important consideration in understanding the structural integrity of materials. Fracture toughness is a measure of a material's resistance to crack propagation and is typically characterized by a parameter called the fracture toughness (KIC).

When it comes to notched plates, the depth of the notch plays a significant role in determining the fracture toughness. Here are some key points regarding the effect of notch depth on fracture toughness:

Stress Concentration: Notches act as stress concentrators, leading to localized stress intensification at the notch root. As the depth of the notch increases, the stress concentration at the notch root also increases. This elevated stress concentration can decrease the fracture toughness of the material.

Crack Tip Constraint: The depth of the notch affects the constraint at the crack tip. Shallow notches result in higher constraint, meaning that the surrounding material restricts the opening of the crack. This increased constraint can enhance the fracture toughness.

Crack Propagation: A deeper notch can lead to more rapid crack propagation due to the increased stress concentration. As the crack propagates from the notch, the material's resistance to crack growth decreases, resulting in reduced fracture toughness.

Notch Acuity: The shape and sharpness of the notch are influenced by its depth. Deeper notches tend to have blunter tips, which can affect the crack initiation and propagation behavior. Blunt notches generally lead to reduced fracture toughness compared to sharper notches.

Material Properties: The influence of notch depth on fracture toughness can vary depending on the material properties. Some materials may exhibit more significant reductions in fracture toughness with increasing notch depth, while others may be less sensitive to notch depth effects.

To assess the fracture toughness of notched plates, experimental testing methods such as the standard fracture toughness tests like the ASTM E399 or the ASTM E1820 are commonly used. These tests involve applying controlled loading to specimens with pre-existing notches to measure their resistance to crack propagation.

Overall, the depth of the notch in plates has a significant influence on fracture toughness, with deeper notches generally resulting in reduced fracture toughness due to increased stress concentration and faster crack propagation.

In 2017 [18] This study investigates the mechanical behavior of composite plates with square holes and its impact on structural integrity. Geometric singularities, such as openings, are essential for mechanical requirements but can weaken the structure due to amplified moment values. The research is divided into experimental testing using the INSTRON bending machine and numerical simulation in FORTRAN. Deflections and bending moments of the composite plates are analysed, and the simulation results are compared with the RDM6 software. The study focuses on understanding moment distribution around square holes under bending loads and conducts a parametric study to explore the effects of hole size and loading type on moment concentration. The findings contribute to optimizing structural designs, ensuring safety, and extending the lifespan of structures with geometric singularities.
In summary, this research delves into the mechanical behavior of composite plates with square holes. By conducting experimental tests and numerical simulations, the study assesses deflections and bending moments. The accuracy of the simulation results is verified by comparing them with those obtained from the RDM6 software. The investigation emphasizes the distribution of moments around square holes under bending loads and explores the influence of parameters such as hole size and loading type on moment concentration. The study's outcomes provide valuable insights for designing structures with geometric singularities, promoting safety, and enhancing their longevity.

Conclusion bibliography :

In conclusion, the bibliography search on the topic "Contribution to the study of the mechanical behavior plates under the effect of a number of notches" yielded a range of articles that address various aspects of plate behavior under different conditions. The articles cover topics such as functionally graded material plates, sandwich plates on elastic foundation, BFRP-steel composite plates, and initially curved micro plates under electrostatic actuation.

The studies employ different methods, including finite element analysis and hyperbolic shear and normal deformation plate theory, to analyze the mechanical behavior of the plates. These approaches allow for a comprehensive understanding of the response of plates under the influence of notches.

I.1 General definition of composites:

A composite material consists of combining two or more materials of different natures that complement each other and result in a heterogeneous material. The overall performance exceeds that of the components taken separately [15].

The main advantage of using composite materials comes from their significant advantages over traditional materials.

Offers numerous functional advantages.:

• Lightness.

• High resistance to fatigue.

• Freedom of forms.

• Reduced maintenance.

• Low aging under the action of humidity, heat, corrosion (except aluminum carbon).

• Insensitive to chemicals except paint strippers which attack resins.

• Good electrical insulation.

Their low utilization rate comes from their cost

There are two types of composites : Mass market composites and high performance composites.

- **Large distribution:**

Widely used composite materials offer essential advantages, which include:

Cost optimization through reduced production costs, achieved through the use of polyester and fiberglass (either long or short fibers in the form of mat or fabric), as well as the simplicity of the manufacturing process (contact molding, SMC, and injection).

- **High performance :**

High-performance composite materials are used in the aerospace industry where there is a need for high performance due to high added value. The reinforcements used in these composites are typically long fibers, and the reinforcement ratio is higher than 50%. These composites are manufactured using the following procedures[15]:

• Autoclave draping, filament winding, RTM.

• Many processes still manual.

• CMM, CMC.

I.2 Composition of a composite material :

A composite material is composed as follows : **matrix or resin Fillers and additives reinforcement.**

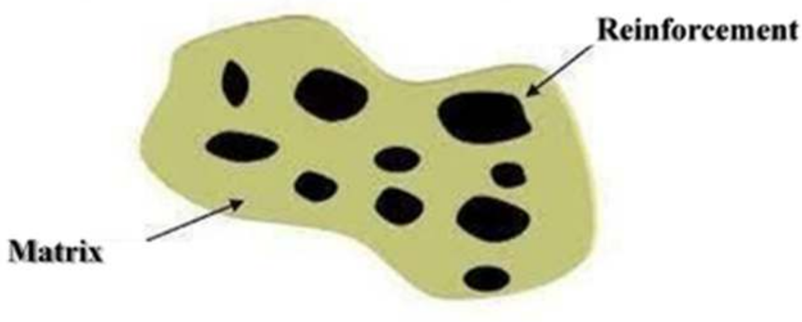


Figure I.3: Schematic representation of a composite material[15]

I.2.1 The matrix :

The matrix is the component that surrounds and holds the fibers or reinforcements in a composite material. It can be made of polymer resins, metals, ceramics, or other materials. The matrix provides cohesion, stress resistance, and load transmission between the reinforcements, which contributes to the mechanical and structural properties of the composite material[12].

There are 3 main categories of matrices:

- **CMO or organic matrix composites.**

These are the most common materials, including thermoplastics and thermosetting polymers. Organic matrix composites are in turn divided into two categories :

  - Composite materials with widespread use: these are composites with lower performance and more affordable costs. They are used in over 95% of cases, particularly in large-scale production.
  - High-performance composites: these are materials that exhibit superior mechanical properties and therefore represent a higher cost. They are often used in the aerospace and construction industries.

- **CMC or ceramic matrix composites such as aluminum, titanium or magnesium.**
- **CMM or composites with a metal matrix such as carbon or silicon carbide**

I.2.2 The reinforcements :

The reinforcement is the skeleton of the composite material and provides the majority of its mechanical properties. Generally, reinforcements are fibers such as fiberglass (which is the most common), carbon fiber, aramid fiber, or even plant-based fibers (which are renewable). The reinforcement can also take the form of particles. Reinforcements make the material even more high-performing [15].

The classification of different types of reinforcements is given in Figure 04

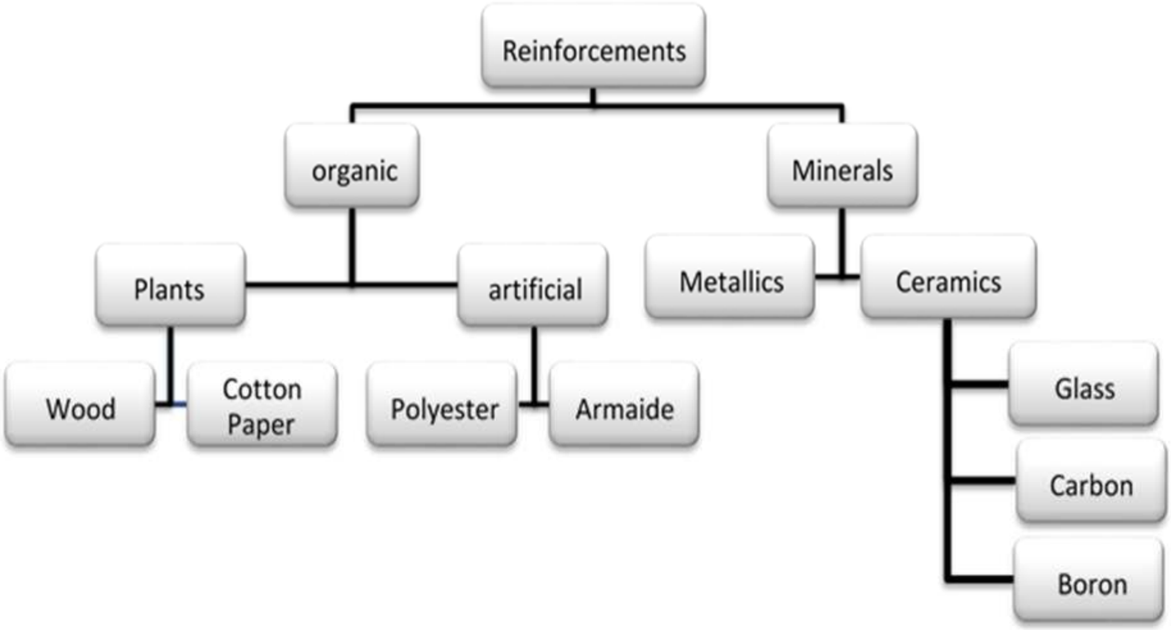


Figure I.4. Classification of different types of reinforcements. [15]

I.2.2.1 Different types of reinforcements :

I.2.2.1.1 Fiber glass :

They are widely used as reinforcement in composite materials. They are made from continuous glass fibers or chopped glass fibers. Fiberglass offers good mechanical strength, low thermal and electrical conductivity, as well as resistance to corrosion [1].

Figure I.5. Glass roving

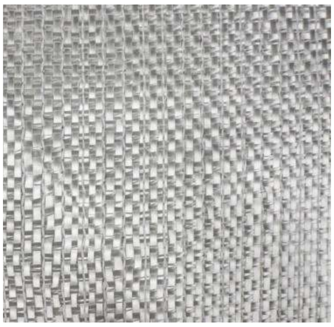


Figure I.6. Glass mat

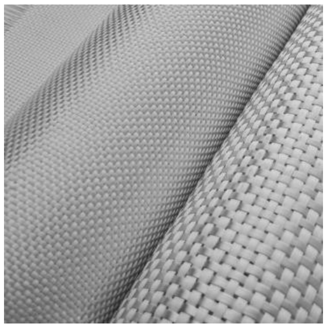


Figure I.7. Glass fabric

I.2.2.1.2 **Carbon fibers :**

They are very lightweight and exhibit excellent mechanical strength and high rigidity. They are used in applications that require high performance, such as aerospace, racing cars, and sporting equipment [1].

I.2.2.1.3 **Aramid fibers :**

Aramid fibers, such as Kevlar, offer exceptional tensile strength, as well as high resistance to impact and penetration. They are commonly used in applications that require ballistic protection, such as bulletproof vests [1].

I.2.2.1.4 **Natural fibers :**

Natural fibers such as linen, hemp, and jute are also used as reinforcements in composite materials. They offer ecological advantages such as low carbon footprint, biodegradability, and ease of manufacturing [1].

These different types of reinforcements offer specific characteristics in terms of strength, stiffness, weight, and thermal properties. The choice of reinforcement depends on the specific application and the desired properties for the composite material.

I.2.2.2 Forms of reinforcements :

I.2.2.2.1 **Laminates based on unidirectional fabrics :**

Laminates are composed of successive layers (sometimes called plies) of reinforcements (such as fibers, fabrics, mats, etc.) impregnated with resins. A material composed of an ordered set of layers of given orientation and thickness, made up of various materials, is also called a laminate. A layer of a laminate is often referred to as a lamina.

The type of laminate is generally defined by its stacking sequence, which provides a concise description of the orientation of the various layers in a laminate [2]. The advantage of composite laminates is the ability to create materials with optimally oriented mechanical properties to better withstand structural loads.

I.2.2.2.2 **The sandwiches:**

Sandwich structures are composite material structures that consist of three main layers: two rigid external layers called skins, and a lightweight and strong central layer called the core. The materials used for the skins and core can vary depending on the specific needs of the application.

The skins of sandwiches can be made of materials such as metal, fiber-reinforced plastic, carbon fiber composite, or fiberglass composite. They provide the structural strength and external protection of the composite structure.

The core of the sandwich can be made of different materials, such as polyurethane foam, polystyrene foam, aluminum honeycomb, or fiberglass honeycomb. The core is lightweight and has low density, which allows for reducing the overall weight of the structure while maintaining adequate strength.

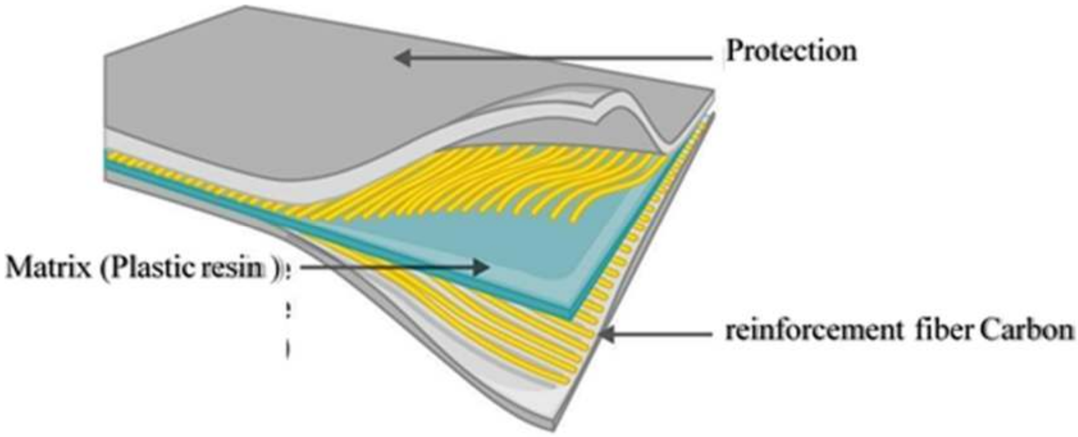


Figure I.8. Multilayer, an example of a composite material

I.2.2.3 Types of woven laminates :

Canvas or taffeta :

Each warp thread passes over and then under each weft thread, and vice versa. The resulting fabric has good flatness and relative rigidity but is not very deformable for processing. The numerous successive inter lacings generate significant take-up and reduce the mechanical properties.

Serge :

Each warp thread floats above several weft threads and each weft thread floats above several warp threads. This creates a more elastic taffeta fabric with a good number of threads.

Satin :

Each warp thread floats above several weft threads and vice versa. These fabrics have different appearances on each side. They are quite flexible and suitable for shaping parts with complex surfaces. This type of fabric has a high specific mass.

I.2.3 **The different matrices :**

There are six types of matrices.

I.2.3.1 Thermosetting resins:

Thermosetting resins (TD) are generally associated with long fibers. Thermosetting polymers have a three-dimensional network structure; during polymerization, this network cross links (double bond polymerization) and hardens definitively upon heating according to the desired shape. The transformation is irreversible[**6**] . The thermosetting resins currently mainly used are :

- **Polyester resin :**

Polyesters are the most commonly used resins in widespread applications. They are in the form of a polyacid plus polyalcohol solution that becomes rigid under the action of a catalyst and heat.

Unsaturated polyester resins are far ahead in the implementation of composite materials [6]. Their development is the result of:

- Their low production cost
- Their diversity offering multiple possibilities,
- Their adaptation to easy-to-implement and automate manufacturing processes. This results in constantly growing industrial development .

Depending on their modulus of elasticity, polyester resins are classified into:

- Flexible resins.
- Semi-rigid resins.
- Rigid resins.

The resins commonly used in the manufacturing of composite materials are of the rigid type , For these cured resins, we will consider the following characteristics:

Table I-1. Main mechanical characteristics of polyester resins.

Volumic mass(1200kg/m3)	1200
Modulus of elasticity in tension(GPa)	2,8à3,5
Modulus of elasticity in bending(GPa)	3à4,5
Tensile stress at break(MPa)	50à80
Stress at break in bending(MPa)	90à130°
Elongation at break in tension	2à 5%
Elongation at break in bending	7à 9%
Compressive strength (MPa)	90à200
Shear strength(MPa)	10à20
Deflection temperature under load(1,8MPa)	60à 100°C

Among the advantages and disadvantages of unsaturated polyesters, we will focus on the following (Table.2):

Table I-2. The advantages and disadvantages of polyesters

Advantages	Disadvantages
-Good rigidity resulting from a relatively high Modulus of elasticity	-Poor temperature resistance: lower than 120°Cincontinuousservice
-Good dimensional stability	-Sensitivity to cracking, mainly in the case of Impacts
-Good wetting ability of fibers and fabrics	-Significantshrinkageofabout8to10%
-Ease of processing	-Poor behavior with steam and boiling water with a risk of hydrolysis, hence the need to cover polyester resin composite materials with a layer of gel coat to make them waterproof
-Good chemical resistance	-Degradation due to exposure to ultraviolet Light
-Low production cost	-Flammability
-Good chemical resistance to hydrocarbons (gasoline, fuel, etc.) at room temperature.	-Limited pot life

- **Epoxy resins:**

The most commonly used resins after unsaturated polyesters are epoxy resins. However, they only represent about 5% of the composite market due to their high cost (around five times that of polyester resins). They are preferentially used for high-performance composites [**6**].

Table I-3. Advantages and Disadvantages of Epoxy Resins.

The advantages	The disadvantages
-good mechanical properties (in tension, flexion, compression, impact, creep, etc.)superior to those of polyesters -good high-temperature resistance: up to150°Cto190°Ccontinuously -excellent chemical resistance -low molding shrinkage(from0.5%to1%) -very good reinforcement wetting -excellent adhesion to metallic materials	-High cost. -Sensitivity to moisture and UV . - Ageing under temperature. -Sensitivity to shocks. -Polymerization time.

- **Phenolic resin :**

Phenolic resins are the oldest of the thermosetting resins. They have excellent dimensional stability, good heat resistance (which is why they are used in railways), good chemical resistance, good mechanical properties, and low cost

Table I-4. Advantages and disadvantages of phenolic resins

The advantages	The disadvantages
- Excellent dimensional stability - Good resistance to heat and creep - Good chemical resistance - Low shrinkage - Good mechanical properties - Low cost	- Processing under pressure, therefore at low speeds - The dark colors of the resins - not suitable for food applications.

- **Polyamide resin :**

Polyamide resin is produced by the reaction of dimer acid and polyamine. It is mainly used to produce various types of gravure and flexible printing ink and paper ink. It is suitable for use in printing materials such as PE, PVC, PP, terylene paper, cellophane, and so on. Depending on the product, the printing ink has a high gloss, low freezing point, excellent adhesion, and good solvent resistance, and is compatible with nitrocellulose.

I.2.3.2 Thermoplastic resins:

Thermoplastic resins are a type of polymers that soften and melt when heated, and harden again when cooled. Unlike thermosetting resins that harden irreversibly when heated, thermoplastic resins can be melted and reshaped multiple times without undergoing significant chemical changes [12].

Here are some common examples of thermoplastic resins:

1) Polyethylene (PE): This is a commonly used thermoplastic resin that exhibits good resistance to corrosion, low density, and high flexibility. It is found in plastic bags, bottles, tubes, and films.

2) Polypropylene (PP) : This thermoplastic resin is appreciated for its heat resistance, stiffness, and chemical resistance. It is used in various applications including packaging, textiles, automotive components, and household appliances.

3) Polyvinyl chloride (PVC) : This is a versatile thermoplastic resin used in the production of pipes, profiles, flooring, windows, and many other products. PVC can be rigid or flexible, depending on the additives used.

4) Polycarbonate (PS) : This resin is known for its lightness, rigidity, and transparency. It is used in packaging, disposable cups, electronic device casings, and toys.

5) Polyethylene terephthalate (PET) : This is a thermoplastic resin mainly used in plastic bottles for beverages and food packaging. Thermoplastic resins offer advantages such as ease of processing, recyclability, and a wide range of mechanical properties.

Their use is widespread in many industrial sectors, including packaging, automotive, electronics, and construction.

I.3 The reasons for using composites:

The use of composites has several advantages that explain their growing popularity in many industrial fields. Here are some of the key reasons why composites are widely used:

A. **Resistance and lightness**: Composites offer a unique combination of high strength and lightness. They are often lighter than traditional materials such as metal, while still being able to withstand high loads. This makes them ideal for applications where weight reduction is important, such as in the aerospace and automotive industries, which can lead to fuel savings and better performance.

B. **Resistance to corrosion and chemicals** : Composites are inherently resistant to corrosion, unlike many metals. They do not require additional protective coatings, which reduces long-term maintenance costs. Additionally, composites are also resistant to many aggressive chemicals, making them suitable for chemically corrosive environments.

C. **Durability and longevity** : Composites are known for their durability and longevity. They have excellent fatigue resistance, which means they can withstand repeated cycles of loading and deformation without breaking [4]. They are also resistant to weathering, UV degradation, and extreme environmental conditions, making them durable materials in varying conditions.

D. **Design Flexibility** : Composites offer great design flexibility, allowing for the creation of complex shapes and custom parts. They can be molded into different shapes and sizes, offering creative design freedom. This opens up possibilities for performance optimization, reduction in the number of parts, and integration of additional functionalities.

E. **Electrical insulation** : Composites exhibit high electrical insulation properties, making them useful in electrical and electronic applications. They can be used to insulate wires, cables, and electrical components, providing protection against unwanted electrical currents.

F. **Absorption of vibrations and noise reduction** : Composites have the ability to absorb vibrations and reduce noise, which can be advantageous in applications requiring vibration damping and noise reduction.

These advantages make composites versatile and sought-after materials in many fields, such as aerospace, automotive, construction, sports, wind energy, and many others.

I.4 Pressure-based molding :

I.4.1 Simultaneous projection molding :

Simultaneous injection molding, also known as simultaneous injection or injection- compression molding, is a composite manufacturing process that enables the production of complex parts from thermosetting resins reinforced with fibers.

The process of simultaneous injection molding involves the simultaneous injection of the thermosetting resin and fiber reinforcements into a closed mold. The mold is typically heated to facilitate the polymerization of the resin and the curing of the fiber reinforcements [1].

Here are the main steps of the simultaneous projection molding process:

- Mold preparation : The mold is prepared by applying a release agent and heating it to the appropriate temperature.

- Preparation of fiber reinforcements : The fiber reinforcements, such as fabrics, mats, or preforms, are cut or prepared to the desired shape and size for the part.

- Simultaneous injection : The thermosetting resin and fiber reinforcements are introduced simultaneously into the mold using an injection system. The resin is typically pre-mixed with additives such as hardeners, reinforcing agents, or fillers.

- Compression : Once the resin and fiber reinforcements are injected into the mold, compression is applied to evenly distribute the material in the mold and eliminate voids or air bubbles.

- Polymerization and curing : The mold is held at a specific temperature to allow the resin to polymerize and the fiber reinforcements to cure. This process can be accelerated using an external heat source or a heating system integrated into the mold.

- Cooling and demolding : Once polymerization and curing are complete, the part is cooled in the mold. Once cooled, the part is demolded from the mold, ready for finishing and potentially subjected to post-processing operations such as machining or coating.

Simultaneous projection molding allows for the production of parts with excellent mechanical strength, high dimensional accuracy, and complex geometries.

It is used in various industries, including aerospace, automotive, sports, and leisure, where lightweight, rigid, and resistant parts are required.

I.4.2 Contact Molding :

The principle of Contact Molding consists of manually placing reinforcements (in the form of mat or fabric) impregnated with a thermosetting matrix into a mold. Parts of various shapes can be produced at a very low rate [1].

I.5 Architecture of composite materials :

The various processes used demonstrate the predominance of a design approach for composite materials :

By surfaces : plates or shells.

By layering successive layers :this concept justifies the importance that will be given later to the study of composite materials considered in the form of plates or shells, made up of different (or non-) layers, shells can be modeled as a set of plates, and their studies will be deduced from the studies of plates[**16**].

Thus, we highlight the importance of the general architectures of composite materials for their design and manufacturing methods, and we will subsequently develop these different architectures.

Stratified : The laminates are composed of successive layers of reinforcements, often called plies, impregnated with resin.

- Each layer is designated by a number indicating the value in degrees of the angle that the fiber direction makes with the reference axis.
- Unidirectional layers have good mechanical performance in the fiber direction.
- Mats are not very resistant to tension and should be reserved for compression zones.
- Interlayer hybrids are composed of a sequence of layers, each with different properties.

Sandwiches : Sandwich structures occupy a large niche in composite part construction and appear in virtually all fields of application[1].

Other Architectures : The other architectures of composites can be schematically classified into:

Reinforced plastics : Made up of a matrix or resin in which short fibers, solid or hollow beads, metallic or graphite powders are introduced, these reinforcements increase the elastic modulus by two to five times. They are volume composites.

ChapterII:

Mechanical Behavior Of Composite Materials

Introduction :

The second chapter of this research focuses on the study of the mechanical behavior of plates with notches. It examines the effect of different notch configurations on the strength, stiffness, and failure of the plates. Experimental tests, numerical simulations, and theoretical analyses are used to obtain a deep understanding of the mechanical response of notched plates. The results of this study will contribute to the design and analysis of more reliable and safer structures, by providing valuable information for optimizing the performance of notched plates.

II.1 Elastic behavior of materials :

The elastic behavior of materials refers to the ability of a material to return to its original shape and dimensions after being subjected to stress or deformation. In other words, when the material is subjected to a force, it undergoes a temporary deformation, but returns to its original shape and size once the force is removed [5].

The elastic behavior is governed by Hooke's law

II.1.1 Generalized Hooke's Law :

The Generalized Hooke's Law is an extension of Hooke's law that takes into account the nonlinear behavior of materials [8]. Unlike the linear Hooke's law, which applies only to elastic deformations, the Generalized Hooke's Law is used to model the behaviors of materials that do not respond linearly to loads or stresses

The linear elasticity relationship can be expressed in the following form:

$$\sigma = C\,\varepsilon \quad \text{……………………}(\text{II}.1)$$

Or in the following matrix form:

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \sigma_4\\ \sigma_5\\ \sigma_6\end{bmatrix}=\begin{bmatrix}C_{11} & C_{12} & C_{13} & 0 & 0 & C_{16}\\ C_{21} & C_{22} & C_{23} & 0 & 0 & C_{26}\\ C_{31} & C_{32} & C_{33} & 0 & 0 & C_{36}\\ 0 & 0 & 0 & C_{44} & C_{45} & 0\\ 0 & 0 & 0 & C_{54} & C_{55} & 0\\ C_{61} & C_{62} & C_{63} & 0 & 0 & C_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \varepsilon_4\\ \varepsilon_5\\ \varepsilon_6\end{bmatrix} \quad (.2)$$

The Generalized Hooke's Law is mathematically expressed by the equation :

$$\sigma = C\varepsilon + S\varepsilon^2 + R\varepsilon t + \quad (\text{II}.2)$$

with :

σ : is the applied stress

ε : is the strain, which is the linear elastic modulus

S : is the second-order elastic modulus

R : is the third-order elastic modulus

And so on for higher orders. The non-linear elastic moduli S, R, etc. represent the strain coefficients that describe the non-linear response of the material.

The generalized Hooke's law is an extension of the linear Hooke's law that allows for modeling the non-linear behaviors of materials. It is useful for predicting deformations and stresses in real-world situations, such as plasticity, visco elasticity, and fatigue. The generalized Hooke's law is important for the design of precise and durable structures.

II.1.2 **Stiffness matrix :**

The stiffness matrix is a mathematical matrix used in structural mechanics to describe the elastic properties of a material or structure. It is obtained by applying the equations of linear Hooke's law to an element of structure and describes the relationship between the forces applied to a material or structure and the resulting deformations. The stiffness matrix is used to calculate the deformations and stresses in a material or structure subject to loads, and to design structures capable of supporting specific loads[7].

In the generalized Hooke's law, the stiffness matrix C is symmetric. This means that the linear behavior of a material can be described using 21 independent coefficients in the general case. The flexibility or compliance matrix Sij can be written as the inverse of the stiffness matrix C.

$$\boldsymbol{\varepsilon = S\,\sigma} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \ (\text{II}.3)$$

II.1.3 **Compliance matrix :**

The flexibility matrix is a mathematical matrix that describes the elastic properties of a material or structure, but from a different perspective than the stiffness matrix. While the stiffness matrix describes the relationship between stresses and strains in a material or structure, the flexibility matrix describes the relationship between forces and strains[11].

The flexibility matrix is the inverse of the stiffness matrix and is obtained by taking the inverse of the latter. Like the stiffness matrix, the flexibility matrix is symmetric and square, and its size depends on the number of degrees of freedom of the structural element.

The elasticity relationship (II.1) can be expressed in the inverse form as shown below [17]:

$$\varepsilon = S\sigma \quad \text{………………} \quad (II.4)$$

This is achieved by introducing the inverse matrix of the stiffness matrix. The matrix S is referred to as the compliance or flexibility matrix and is generally expressed in the following manner [17]:

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \\ \sigma_6 \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & C_{16} \\ C_{21} & C_{22} & C_{23} & 0 & 0 & C_{26} \\ C_{31} & C_{32} & C_{33} & 0 & 0 & C_{36} \\ 0 & 0 & 0 & C_{44} & C_{45} & 0 \\ 0 & 0 & 0 & C_{54} & C_{55} & 0 \\ C_{61} & C_{62} & C_{63} & 0 & 0 & C_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \end{bmatrix}$$

With: The coefficients Sij are called the compliance constants or flexibility constants.

$$S = C^{-1} \quad \text{…………………} (II.5)$$

A material that depends on 21 independent constants is called an anisotropic material. It is a material that does not possess any symmetry property [17].

II.1.4 **Different materials :**

There are different types of materials used in the manufacture of products and structures. The main types of materials include metals, polymers, ceramics, composites, semiconductors, and natural materials. Each of these materials has specific physical and mechanical properties, which make them more suitable for certain applications than others [12]. Engineers and scientists study these properties to design products and structures that meet specific performance requirements.

II.1.4.1 Monoclinic materials :

Monoclinic materials are crystalline materials with a monoclinic symmetry, characterized by two perpendicular axes of rotation and a third inclined axis relative to these two axes. These materials are often used in applications where high mechanical strength is required, such as cutting tools, gears, bearings, and turbines, as well as packaging materials for their compression resistance. The mechanical properties of monoclinic materials depend on their crystal structure, composition, and fabrication method, allowing engineers and scientists to develop new monoclinic materials for specific applications[17].

In the case of a material with a symmetry plane, specifically monoclinic symmetry, certain constants become zero, allowing the behavior to be described using only 13 independent constants [17].

$$: \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \\ \sigma_6 \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & C_{16} \\ C_{21} & C_{22} & C_{23} & 0 & 0 & C_{26} \\ C_{31} & C_{32} & C_{33} & 0 & 0 & C_{36} \\ 0 & 0 & 0 & C_{44} & C_{45} & 0 \\ 0 & 0 & 0 & C_{54} & C_{55} & 0 \\ C_{61} & C_{62} & C_{63} & 0 & 0 & C_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \end{bmatrix}$$

II.1.4.2 Orthotropic materials :

Orthotropic materials are materials whose physical properties vary along three orthogonal axes. They are often used in applications requiring high strength and stiffness in a particular direction, such as carbon fiber composites and wood. The mechanical properties of orthotropic materials are characterized by different elasticity coefficients in the three orthogonal directions, as well as different Poisson's ratios. Engineers and scientists study these properties to design structures and products that meet specific performance requirements[17].

A material is said to be orthotropic for a given property if that property remains invariant under directional changes achieved through symmetry relative to two orthogonal planes. It is observed that symmetry with respect to the third orthogonal plane is automatically achieved. This mode of behavior is relatively well realized in unidirectional composites [17].

The number of independent coefficients reduces to 9. The behavior law can then be written as follows:

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \sigma_4\\ \sigma_5\\ \sigma_6\end{bmatrix}=\begin{bmatrix}C_{11} & C_{12} & C_{12} & 0 & 0 & 0\\ & C_{11} & C_{12} & 0 & 0 & 0\\ & & C_{11} & 0 & 0 & 0\\ & & & C_{44} & 0 & 0\\ & sym & & & C_{44} & 0\\ & & & & & C_{44}\end{bmatrix}\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \varepsilon_4\\ \varepsilon_5\\ \varepsilon_6\end{bmatrix}$$

$$\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \varepsilon_4\\ \varepsilon_5\\ \varepsilon_6\end{bmatrix}=\begin{bmatrix}S_{11} & S_{12} & S_{13} & 0 & 0 & 0\\ & S_{22} & S_{23} & 0 & 0 & 0\\ & & S_{33} & 0 & 0 & 0\\ & & & S_{44} & 0 & 0\\ & sym & & & S_{55} & 0\\ & & & & & S_{66}\end{bmatrix}\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \sigma_4\\ \sigma_5\\ \sigma_6\end{bmatrix}$$

And also:

$$\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \varepsilon_4\\ \varepsilon_5\\ \varepsilon_6\end{bmatrix}=\begin{bmatrix}\frac{1}{E_{11}} & \frac{-\nu_{21}}{E_{21}} & \frac{-\nu_{31}}{E_{31}} & 0 & 0 & 0\\ \frac{-\nu_{12}}{E_{12}} & \frac{1}{E_{22}} & \frac{-\nu_{32}}{E_{23}} & 0 & 0 & 0\\ \frac{-\nu_{13}}{E_{13}} & \frac{-\nu_{23}}{E_{23}} & \frac{1}{E_{33}} & 0 & 0 & 0\\ 0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0\\ 0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0\\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{12}}\end{bmatrix}\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \sigma_4\\ \sigma_5\\ \sigma_6\end{bmatrix}$$

By introducing the elastic characteristics:

$E1, E2, E3$: Young's moduli.

$G12, 13, G23$:Shear moduli.

$v12, 13, v23$: Poisson's ratios (contraction).

The relationship (2.8)can be written as follows:
The symmetry of the compliance matrix [S] imposes the following relationships :

$$\frac{v_{21}}{E_2} = \frac{v_{12}}{E_1} \text{ ………… (I.11)}$$

$$\frac{v_{31}}{E_3} = \frac{v_{13}}{E_1} \text{ ………… (I.12)}$$

$$\frac{v_{33}}{E_2} = \frac{v_{32}}{E_3} \text{ ………… (I.13)}$$

II.1.4.3 Isotropic materials :

Isotropic materials have the same physical properties in all directions. Common examples include pure metals, certain polymers, and ceramics. The mechanical properties of isotropic materials are characterized by simple parameters such as Young's modulus, Poisson's ratio, and thermal expansion coefficient. Isotropic materials are often used in applications requiring uniform performance in all directions, such as mechanical parts, building structures, vehicles, and electronic equipment. Knowledge of the mechanical and thermal properties of isotropic materials is therefore essential for the design and manufacture of efficient and durable products[17].

In this scenario, the material exhibits isotropy, where all directions and points possess identical mechanical properties. As a result, the number of independent coefficients decreases to 2, and the behavior law can be expressed as [17].

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \sigma_4 \\ \sigma_5 \\ \sigma_6 \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{12} & 0 & 0 & 0 \\ & C_{11} & C_{12} & 0 & 0 & 0 \\ & & C_{11} & 0 & 0 & 0 \\ & & & \frac{C_{11}-C_{12}}{2} & 0 & 0 \\ & sym & & & \frac{C_{11}-C_{12}}{2} & 0 \\ & & & & & \frac{C_{11}-C_{12}}{2} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \end{bmatrix}$$

II.1.4.4 Transverse isotropic materials :

Transversely isotropic materials have isotropic physical properties in a specific transverse direction, but are anisotropic in all other directions. Common examples of transversely isotropic materials include glass and carbon fiber composites. The mechanical properties of transversely isotropic materials are more complex than isotropic materials due to their asymmetry. Elasticity coefficients in the transverse direction and transverse Poisson ratios are often different from those in other directions, which can affect the material's behavior under different types of loads or stresses. Transversely isotropic materials are often used in applications requiring high strength in a particular direction, such as the production of lightweight and strong parts for airplanes, race cars, boats, and sports equipment. Knowledge of the mechanical properties of transversely isotropic materials is therefore important for the design and manufacture of effective and safe products [17].

II.1.4.5 Quasi-isotropic transverse materials :

Quasi-isotropic materials are materials that have uniform physical properties in all directions except for a particular direction called the transverse direction. These materials are used in applications where strong resistance to transverse stresses is required, such as composites and aerospace structures. In summary, quasi-isotropic transverse materials are suitable for resisting transverse loads and reducing the risk of failure due to shear stresses [10].

II.1.4.6 Quasi-isotropic materials :

Have uniform physical properties in all directions. They are used in applications where high strength and uniform physical properties are required, such as composites and machine structures. Quasi isotropic materials are also used in applications requiring dimensional stability and fatigue resistance. In summary, these materials are suitable for applications where consistency of physical properties is paramount [10].

II.2 Mechanical characteristics of the reinforcement-matrix mixture:

The mechanical characteristics of the reinforcement-matrix mixture depend on several factors, including the individual properties of the reinforcement and matrix, their interaction, and the applied loading mode. The main mechanical characteristics of the composite include tensile strength, compressive strength, flexural strength, shear strength, and fatigue strength. The strength under each type of load depends mainly on the properties of the reinforcement and matrix.

II.2.1 **Elastic modulus and Poisson's ratio of the woven fabric ply :**

The woven fabric ply is a composite material consisting of several layers of interlocking fabrics. The elastic moduli of the woven fabric ply depend on the individual properties of the reinforcement

and matrix as well as their volume fractions in the composite. The transverse elastic modulus is usually lower than the axial elastic modulus due to the presence of the matrix, which has a weaker strength than the fibers. The Poisson's ratio of the woven fabric ply also depends on the properties of the matrix and fibers, but is typically higher in the transverse direction due to the higher fiber density in this direction. The weave geometry can also influence the Poisson's ratio [17].

ChapterIII:

Experimental study on perforated plates

Introduction :

Experimental study on perforated plates is a scientific approach aimed at analyzing the mechanical properties of this type of structure. Perforated plates are used in many industrial applications, including aerospace, automotive, and construction.

The objective of this study is to analyze the influence of hole geometry on the mechanical properties of the plate, such as rupture strength, deformation, and stiffness. This analysis will help to better understand the behavior of perforated plates and optimize their design based on the specific constraints of each application.

In this study, we will use mechanical testing techniques to characterize the properties of perforated plates. We will also perform numerical analysis to verify the experimental results and evaluate existing theoretical models. The results obtained will allow us to formulate recommendations for the design and manufacture of perforated plates in different industrial contexts.

III.1 Preparation and fabrication :

In order to obtain reliable and high-quality results, we have carefully prepared the materials used and treated them to achieve the desired objectives.

III.1.1 Materials :

Fabric (satin) : Each warp yarn passes over and under each weft yarn, and vice versa. The fabric has good flatness and relative rigidity, but is not very deformable for processing. The numerous successive intersections generate significant yarn crimping and reduce mechanical properties.

A fabric deforms easily because the warp and weft yarns slide against each other. This phenomenon is easier to achieve with a reduced number of intersections.

Figure III.1. Fabric fiber

The polyester resin : It is a thermosetting synthetic resin used in the manufacturing of composite parts, repairing boats and car bodies, and making flooring coatings. It is produced from a mixture of unsaturated polyesters, styrene monomers, and a catalyst.

FigureIII.2.polyester resin

III.1.2 **Equipment :**

- **Hardener** : A catalyst is a chemical substance added to the resin to trigger the polymerization reaction that transforms it into a solid and hard mass.
- **Catalyst (Releaser)**: used to facilitate demolding.
- **Scissors** : used to cut the fabric.
- **Black and white paint** : used to mark the test specimens.
- **Stainless steel mold** : used for molding.
- **Degassing tool** : used to remove air bubbles.
- **Drill** : machine tool used to drill the samples.

III.1.3 **The basic steps of lamination :**

- We have prepared reinforcements.
- We carefully cut the fiber fabric to avoid tearing or damaging it
- We used polyester resin, which is readily available in online stores. We carefully followed the manufacturer's instructions to prepare the resin. This involved mixing two components: the resin itself and the hardener, following the recommended proportions
  - We incorporate 2% of the catalyst

FigureIII.3.Catalyst (Releaser)

-We mix the polyester resin and the liquid hardener, where we combine 400 grams of polyester resin with 16 grams of hardener and carefully mix them.

Figure III.4. Adding the resin

Figure III.5. 400 grams of resin

Figure III.6.16 grams of hardener

- We spread the resin on the mold and on the part we want to laminate

Figure III.7. The resin with the mold

-We apply a release agent on the mold plate to facilitate the release of the panel, then we apply a layer of resin on the mold plate using a roller. Then, we place the fabric plies one after another, carefully impregnating each ply with resin until it becomes transparent

Figure III.8.a release agent on the mold plate

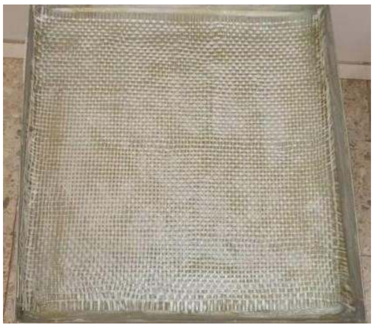


Figure III.9. Placing the fabric layers

Figure III.10. Impregnating the fabric layers with resin

III.1.4 **Preparation of specimens :**

According to ASTM 5045 standards, we employed a diamond blade to cut sheets of polyester resin reinforced with fabric fibers. We performed the cutting process to prepare rectangular samples for bending tests.

We used a shaping cutting machine (III.11) under the following cutting conditions:

- Diamond disc.
- Slow manual feed.
- Cutting speed of 3000 revolutions per minute.
- Dry cutting (without lubrication).

III.1.4.1 Drilling type :

III.1.4.1.1 **Material removal drilling :**

Drilling is one of the oldest material removal machining processes, easy to use but difficult to master. Among the difficulties specific to drilling composites, we can mention:

- Significant and progressive change in cutting speed (Vc) along the cutting edge.
- Evolution of tool geometry with radius.
- Three-dimensional oblique cutting.
- Machining in a confined space that prevents chip and heat evacuation from the cutting zone. The operation of drilling circular holes in the center of composite specimens using a cutting machine, commonly referred to as a drill press, involves the use of various diameter cutting tools (drill bits).

After cutting the samples, we proceed with drilling holes:

Cylindrical holes are drilled using high-speed steel drill bits of different diameters: Ø5, Ø7, Ø10,Ø12.

III.1.5 **Defects in drilling of composite materials :**

Today, we conducted a significant number of drilled holes in composite materials using a two- flute twist drill. We conducted multiple studies to identify the defects that occur in the composite material during drilling with a twist drill.

We have continued to develop geometric shapes for other tools that are more suitable for manufacturing composite materials, yielding varying degrees of satisfactory results.

We categorized the encountered drilling defects into two groups:

- Defects related to the geometric characteristics of the hole, applicable regardless of the material nature:

- Circular shape.
- Diameter: varying across the series of holes.
- Surface roughness.

Defects related to the structure of the composite material:

- Defects on the emerging side:

- Edge chipping (resin fracture on the outer side).
- Burr (fiber delamination on the exit surface).
- Hole wall cracking.

Additionally, execution parameters, material structure, and drill engineering also influence the nature of the defects resulting from the process.

While high-speed steel drills may be adequate, quality can be improved by using carbide drills.

We recommend holding the rear part of the work piece and slowing down the feed before breakthrough to avoid delamination of the top layers. For drilling woven sheets, we have improved the cutting quality, particularly by eliminating burrs, if the drill has a centering tip and a reduced cutting edge to reduce friction on the hole edge.

III.1.6 **Machining the square form :**

We manufacture the square shape after the drilling process using manual milling :

Figure III.11. Composite specimens

III.1.7 **Speckled :**

We use surface mottling of natural origin (such as textures) or artificial origin (black or white spray coating, chemical etching, etc.) to provide sufficient levels of gray shading to ensure the success of the bonding process.

III.1.8 **Preparation of fabric fiber specimens :**

III.1.8.1 Fiber characterization :

Woven fabrics are reinforcement materials that are in the form of textile weaves (as per the NF G07-154 standard). They are usually bidirectional, meaning they have two primary directions of strength. However, in certain cases, they can be considered quasi-unidirectional, where their

strength is predominantly oriented in one direction. A woven fabric consists of warp yarns, which run in the direction of winding on the support, and weft yarns, which are arranged perpendicular to the warp yarns.

To determine the mechanical properties and behavior of the fibers used in these woven fabrics, samples of each type of reinforcement are subjected to flexural testing. Flexural testing involves applying a bending force to the samples using a universal testing machine. This test helps evaluate the flexural strength, stiffness, and other mechanical properties of the fibers and the overall performance of the woven fabric as a reinforcement material.

III.1.8.2 Mechanical characterization of yarn :

Yarn count :

The yarn is characterized by a linear mass known as the "yarn count." Two types of yarn count can be calculated: the conditioned yarn count and the dehydrated yarn count, which represents the commercial linear mass. The conditioned yarn count is determined by measuring the weight and length of a yarn in the textile conditioning atmosphere. The dehydrated yarn count is determined by weighing a specific length of yarn after drying it in an oven under specified conditions [NFG04].

The unit system used is the "tex," and the equation that gives the value of the linear mass of a yarn is as follows:

Yarn count = M (g) x 1000 / L (m) ……. (Ⅲ.1)

Or:

M: is the mass of the yarn expressed in grams L: is the length of the yarn expressed in meters.

Tensile test on yarn :

This test is used to determine the force and elongation of yarns subjected to tension until failure. The curve contains more information than just the tensile strength of the sample. The main characteristics that can be derived from the force-elongation curve are:

- Yield Point: The curve often exhibits a point of decreasing slope. This point is the "yield point" or "yield strength." Below the yield point, the extension of the material is considered elastic, and the specimen returns to its original length when the force is removed. Above the yield point, a portion of the extension is non-recoverable, and the specimen retains some elongation at the end of the test.
- Modulus of Elasticity: The slope of the initial linear portion of the curve up to the yield point is known as the initial modulus (Young's modulus). There are several possible modulus values that can be measured.
  This value is obtained from the slope of the steepest linear region of the curve.

III.2 Determining the fiber content :

Thermogravimetric analysis (TGA) is a technique used to determine the fiber content in the studied composite material. We obtained two samples from the specimen after the flexural test. The sample was weighed using a digital scale with an accuracy of

0.001 grams. Then, the sample was heated in an oven at a typical temperature of 750 degrees Celsius for two hours to ensure complete resin pyrolysis. The remaining fibers were then cooled and weighed.

The rates of fabric fibers and resin are determined using the following formulas:

$Vf = (B/A)*100\%$ .... (Ⅲ.2) $Vm = 100\% - Vf$………….. (Ⅲ.3)

A : Weight of the sample in grams before calcination.

B : Weight of fibers (g) obtained after calcination.

Vf and Vm : Mass fraction of fibers and matrix in (%).

Table III 1.Determination of the polyester/fabric material ratio.

N°	A(g)	B(g)	V_m %	V_f%
1	1,309	0,702	53,62	46,37
2	0,33	0,17	50,98	49,02

III.3 Determination of Young's modulus :

III.3.1 **Experimental method :**

Firstly, we conducted a tensile test on two specimens, the first one made of polyester resin and the

second one made of fabric fiber, as well as a flexural test on a composite specimen to determine the Young's modulus.

III.3.2 **Analytical method :**

If the rule of mixtures for Young's modulus (longitudinal elasticity modulus) yields good results, the formulas for transverse characteristics are much more approximate. It should be noted that the properties of the material in terms of stiffness and especially strength depend on the manufacturing method.

Therefore, to determine the material's characteristics, tests should always be conducted on specimens that are fabricated in the same manner as the final structure.

The rule of mixtures: $E_{éq}=E_f*V_f+E_m*V_m$..................... (III.4)

$Ef = \frac{Em \times Vm - Eéq}{Vf}$ or $Em = \frac{Ef \times Vf - Eéq}{Vm}$ …….. (III.5)

III.4 Determination of the Poisson's Ratio:

During the test, the elongation of the specimen occurs in the direction of tension, which is along the length L. This elongation results in an increase in volume if the deformation is elastic.

Therefore, there is a partial compensation for this volume increase through lateral contraction of the specimen in the width direction b, which can be understood as perpendicular to the axis of tension [15].

The relative deformation in the y and z directions is expressed as follows:

$$Sy = \frac{\Delta y}{y0} \quad \text{or} \quad Sz = \frac{\Delta z}{z0} \text{...... (III.6)}$$

Therefore, the Poisson's ratio is defined as the ratio of the transverse relative deformation to the longitudinal relative deformation.

So $$\Delta = \frac{\Delta V}{V0} = \frac{V - V0}{V0} \text{........................ (III.7)}$$

$$V0 = X0 \times Y0 \times Z0 \text{.............(III.8)}$$

And $$\Delta = \frac{x \times y \times z - x0 \times y0 \times z0}{x0 \times y0 \times z0} \text{..............(III.9)}$$

We neglect terms that are infinitely small or of order 2, thus we have:

$$V = x0\left(1 + \frac{\Delta x}{x0}\right) y0\left(1 + \frac{\Delta y}{y0}\right) z0\left(1 + \frac{\Delta z}{z0}\right) \text{................. (III.10)}$$

By substituting equations (III.8) and (III.9) into equation (III.11)

$$\Delta = \frac{\Delta x}{x0} + \frac{\Delta y}{y0} + \frac{\Delta z}{z0}; \quad \frac{\Delta x}{x0} = Sx \quad \text{And} \quad \frac{\Delta y}{y0} = Sv \quad \frac{\Delta z}{z0} = Sz$$

And $$V = -\frac{Sy}{Sx} = -\frac{Sz}{Sx} \qquad \text{(III.11)}$$

Either $$\Delta = Sx(1 - 2v)$$

III.4.1 **Tensile Testing and Deformation Measurement Video :**

Tensile tests for small deformations are conducted using the INSTRON TYPE 5969 tensile testing machine equipped with a non-contact deformation measurement system known as video extensometer .

The principle of this system relies on using an LVDT camera mounted on a PC and positioned on a stand. Real-time image processing software allows for the analysis of the image. This method enables the application of axial deformation and deformation rate and provides real-time measurement of transverse deformations through surface markings on the test specimen .

In our case, the four-point method was employed, where two tasks are aligned along axis 1 and the other two along the transverse direction. Deformations and stresses are estimated during loading in the useful portion that represents an elementary volume, ensuring that the necking effect is contained. The tasks are positioned on the specimen's surface.

The geometric analysis of these tasks involves determining the position of their centroids and recording the variation in their relative distances. The image processing software estimates the axial

and transverse deformations along axis 2 during the test and simultaneously records the applied force to determine the axial stress. This allows for the estimation of axial deformation (in the direction of axis 1, tension direction) as well as transverse deformations (in directions 2 and 3) and subsequently the volumetric deformation and stress.

III.4.2 **Before deformation :**

The estimation of axial deformation ε11 and transverse deformation is performed using a polynomial interpolation carried out within the useful zone by Gsell .It provides the following:

$$Q33 = \frac{F}{S0 \times h^2 S11} \qquad And \qquad V = -\frac{S33}{S11} \;\ldots\ldots\ldots\ldots \quad (\text{III}.12)$$

$$S11 = \ln\frac{AB}{A0B0} \qquad And \qquad S22 = \ln\frac{CD}{C0D0} \;\ldots\ldots\ldots \quad (\text{III}.13)$$

ChapterIV:

Results And Discussions

IV.1 Representation of experimental results:

The first task is to determine the Young's modulus of the basic elements constituting the composite material. This study, prepared by [18], deals with the example of flexion of composite plates with and without notches, with the following dimensions: width (b) = 25.7 mm, length (L) = 100 mm, thickness (h) = 1.56 mm.

Furthermore, to avoid the influence of transverse shear on the plate's behavior, the aspect ratio between length and thickness should be around 65. In order to evaluate the maximum vertical displacement (W_max), moments, and stresses

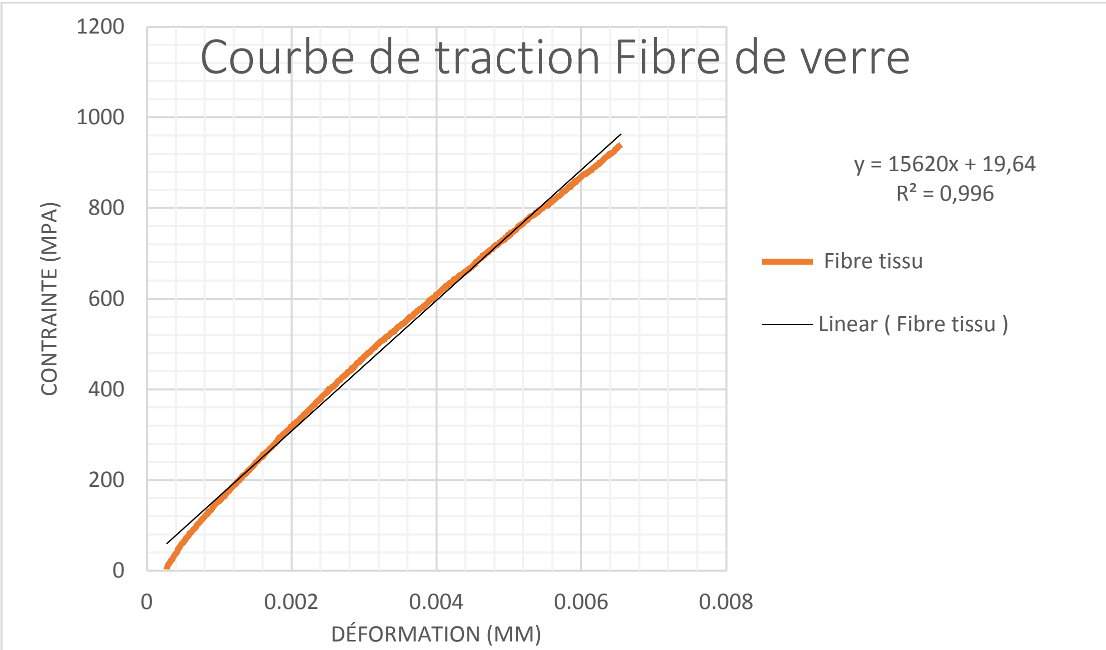


Figure IV.1. Fabric fiber tensile curve [18]

This curve represents the linear stress-strain relationship for the woven fiber in the small deformation range. The Young's modulus was found to be 15.62 GPa.

For the resin is difficult to determine the Young's modulus by the tensile test:

Pour la résine est difficile de déterminer le module de Young par l'essai de traction :

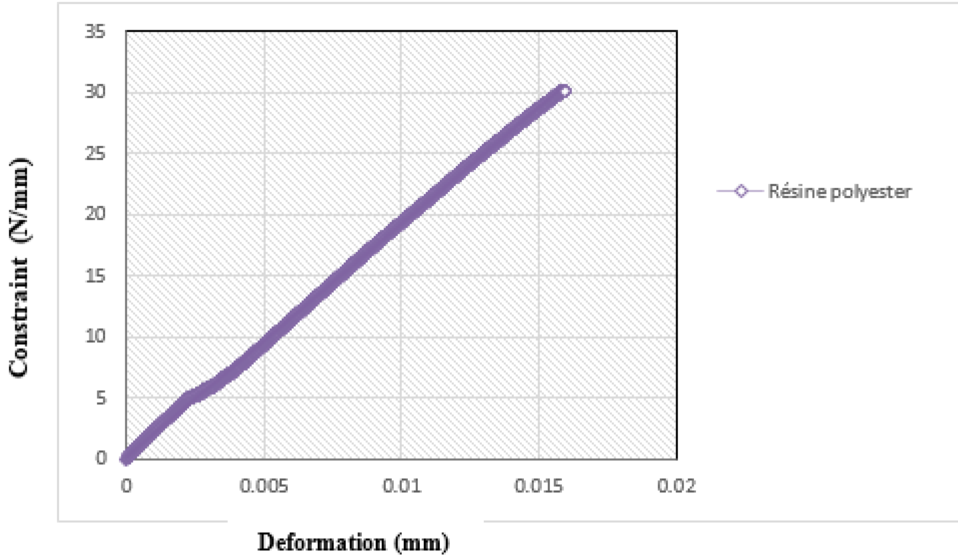


Figure IV.2.3-point bending curve in polyester resin [18]

Due to its brittle behavior, there is also the influence of fixtures on the specimen during testing. For this reason, a flexural test is used, which yields a Young's modulus value of 1.90 GPa.

Finally, a three-point bending test was carried out on the composite material:

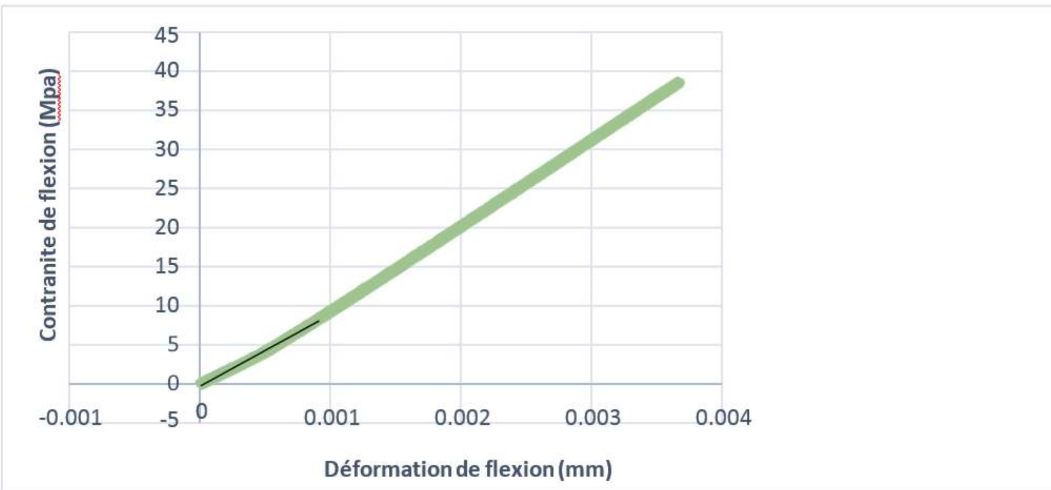


Figure IV.3.3-point bending curve composite specimen without hole [18]

According to the recorded curve, the equation of the linear portion gives us a Young's modulus value of 9.15 GPa.

The Poisson's ratio, based on the results obtained from the tensile test video on the composite, is determined by plotting the longitudinal and transverse strain curves, from which the value of the Poisson's ratio is derived.

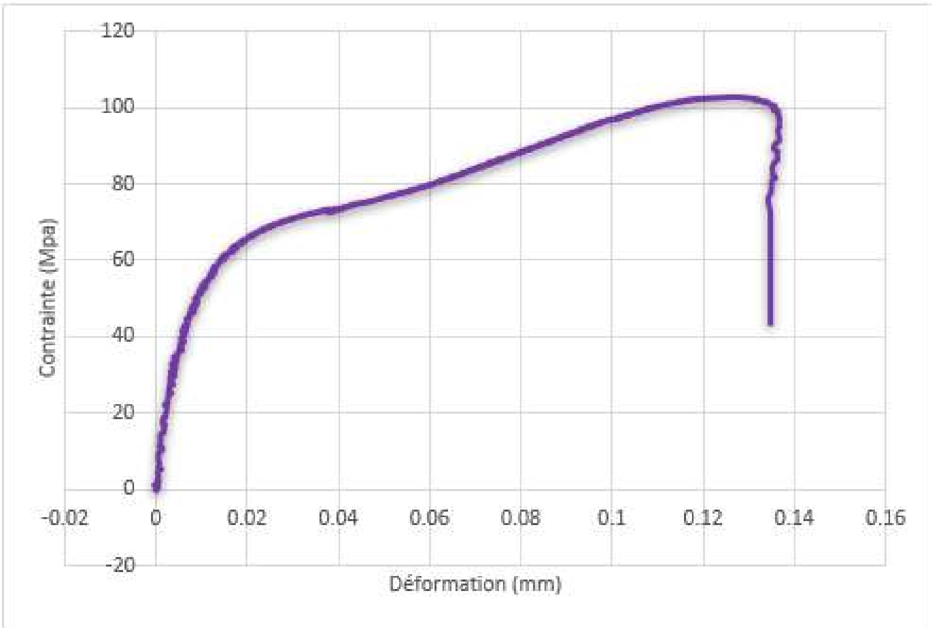


Figure IV.4. Longitudinal deformation curve of the material polyester/fabric of orientations of [0/90°] [18]

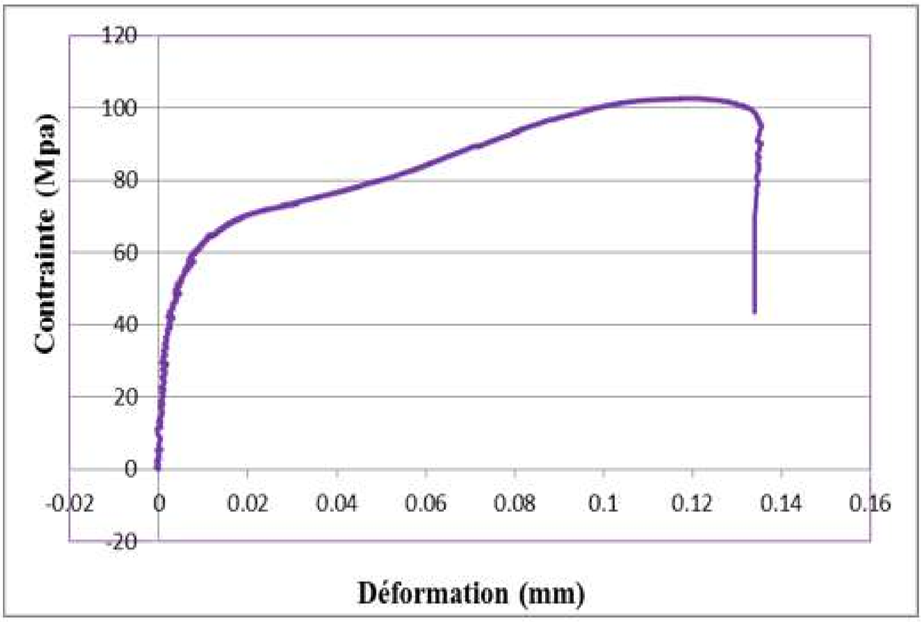


Figure IV.5. Cross-strain curve of polyester/fabric material with orientations of [0/90°] [18]

In this chapter, we will present all the results obtained experimentally.

The mechanical characteristics of the composite are represented in the following table.

Table IV-1. Mechanical characteristics of the materials used

Materials	young's modulus	Poisson's ratio
Fabric fiber	15.620	/
Polyester resin	1.905	/
Composite	9150	0.33

The results of the notch less specimens obtained during the 3-point bending test are as follows:

Table IV-2. Experimental results of notchless specimens**.**

	The thickness h(mm)	Load (N)	Deflection(mm)	Stress(N/mm)
Test tube without notches	1.60	3.0070	0.8934	5.6537

In the field of materials engineering and stress analysis, it is well known that the presence of notches or cracks in a material can have a significant impact on its deformation and rupture resistance. Specifically, in composite materials, notches can serve as initiation sites for crack propagation, which can lead to early material failure under load.

The d/b ratio in the table represents the ratio of the notch length (d) to a certain characteristic dimension of the material (b). An increase in this ratio indicates an increase in the size of the notch relative to the material dimension.

• d/b ratio: This is the ratio of the notch size (d) to the plate size (b). A larger ratio means a larger notch compared to the plate.

• Deflection (mm): This could represent the deflection or sagging of the plate in millimeters. It measures the degree to which the plate bends or deforms under applied load.

• Stress (N/mm^2): This represents the applied stress on the plate, measured in newtons per square millimeter (N/mm^2), also known as mega pascals (MPa). It indicates the intensity of the force exerted on the material.

• Deformation: This value represents the deformation of the plate, which refers to the extent of distortion or change in shape of the plate under stress.

The Newton interpolation method with divided differences (MDD)

The Newton interpolation method with divided differences (MDD) is an important tool in engineering and physics, particularly in the analysis of mechanical behavior based on experimental results. Here are some reasons why this method is useful:

1. Function approximation :

In many cases, experiments in physics and engineering provide discrete data, and it may be necessary to estimate the behavior of the variable of interest between these data points. The Newton method allows for generating a polynomial that passes through all the data points and can be used to estimate values between these points.

2. Flexibility :

The Newton method is flexible in that it can work with any number of data points. Additionally, if additional data becomes available, it can be easily incorporated into the model without requiring a complete recalculation.

3. Estimation of derivatives and integrals :

Once the interpolation polynomial has been determined, it can be used to estimate derivatives and integrals of the function, which can be useful in understanding the mechanical behavior of the system.

Regarding the analysis of mechanical behavior, the Newton interpolation method could be used to model stress-strain curves based on experimental data, estimate the behavior of materials under different loads, or model the motion of a mechanical system based on measured position and velocity data, among other applications.

However, it is important to note that all interpolation methods, including Newton's method, have their limitations. They assume that the behavior between data points can be well approximated by a polynomial, which is not always the case. Additionally, while interpolation can provide good results near the data points, it can yield less accurate or even erroneous results when extrapolated to points far from the original data.

Therefore, caution should be exercised when using interpolation for estimating derivatives, integrals, or behavior beyond the range of the available data, and alternative methods or additional information should be considered to ensure the accuracy and reliability of the results.

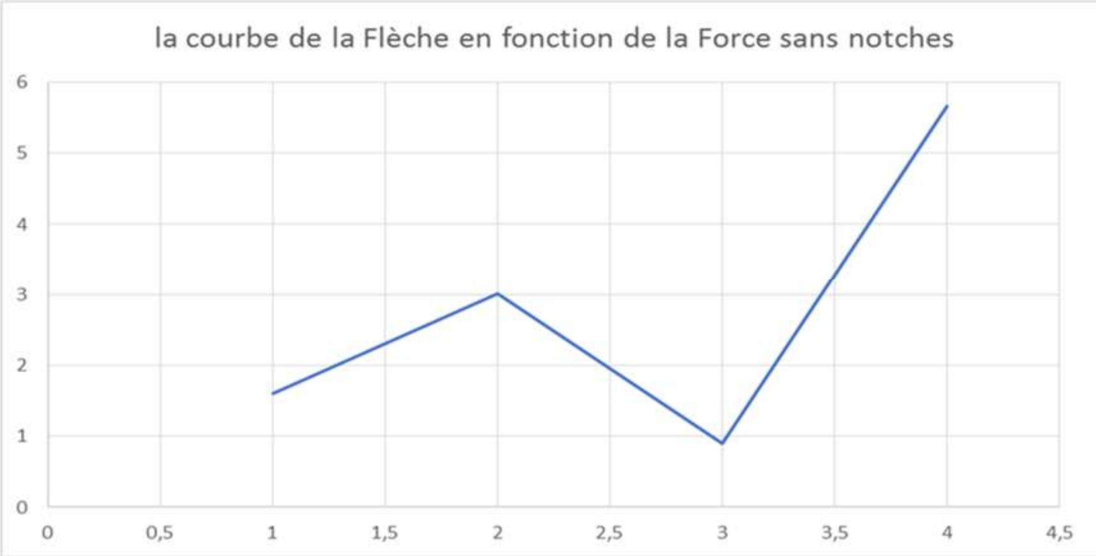


Figure IV.6.The curve of the deflection as a function of force without notches

Through examining the arrow's curve without any gaps, we observe an increase in the arrow's force reaching point 3.

Then, we notice a gradual decrease in the curve of the arrow's force to the lowest point, followed by an increase in the curve of the arrow's force to the highest point.

The values of deflection for the four types of specimens with different openings obtained during the 3-point bending test are as follows:

Table IV -3. Experimental results of perforated specimens.

	Rapport(d/b)	The thickness h(mm)	Load(N)	Deflection(mm)
TestspecimenNo.1	0.2	2.01	3,02197	0.40569
TestspecimenNo.2	0.3	1.76	3,02089	0.67144
Test specimen No. 3	0.4	1.84	3,01908	0.69560
TestspecimenNo.4	0.5	1.92	3,02637	0.68609

1-Deflection curve as a function of force with slits for (d/b = 0.2) :

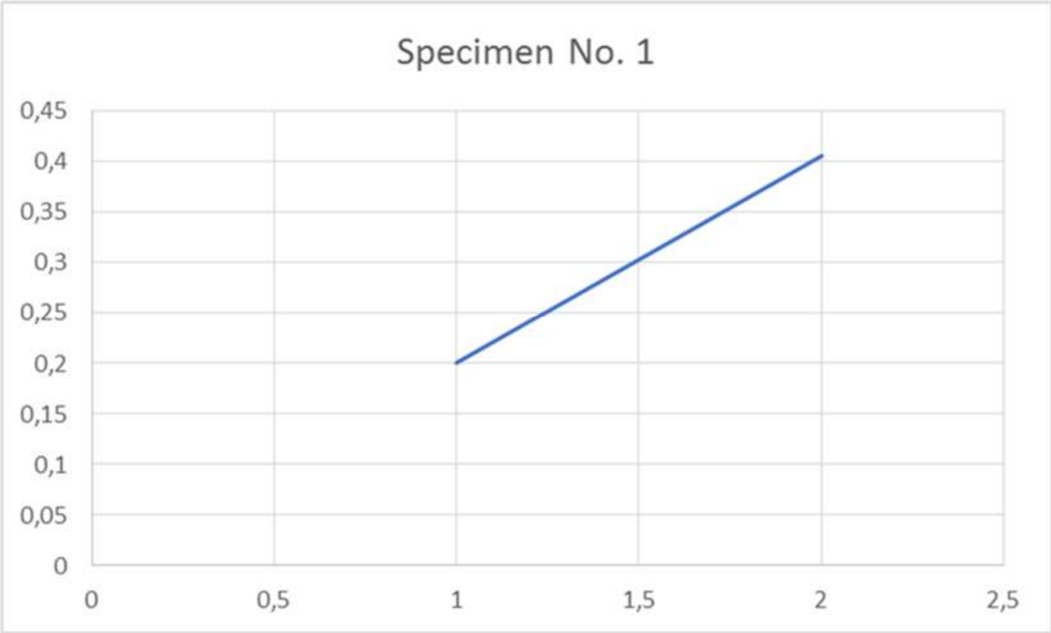


Figure IV.7 the curve of the arrow as a function of the force with notches for $(d/b = 0.2)$.

2-Deflection curve as a function of force with notches for (d/b=0.3) :

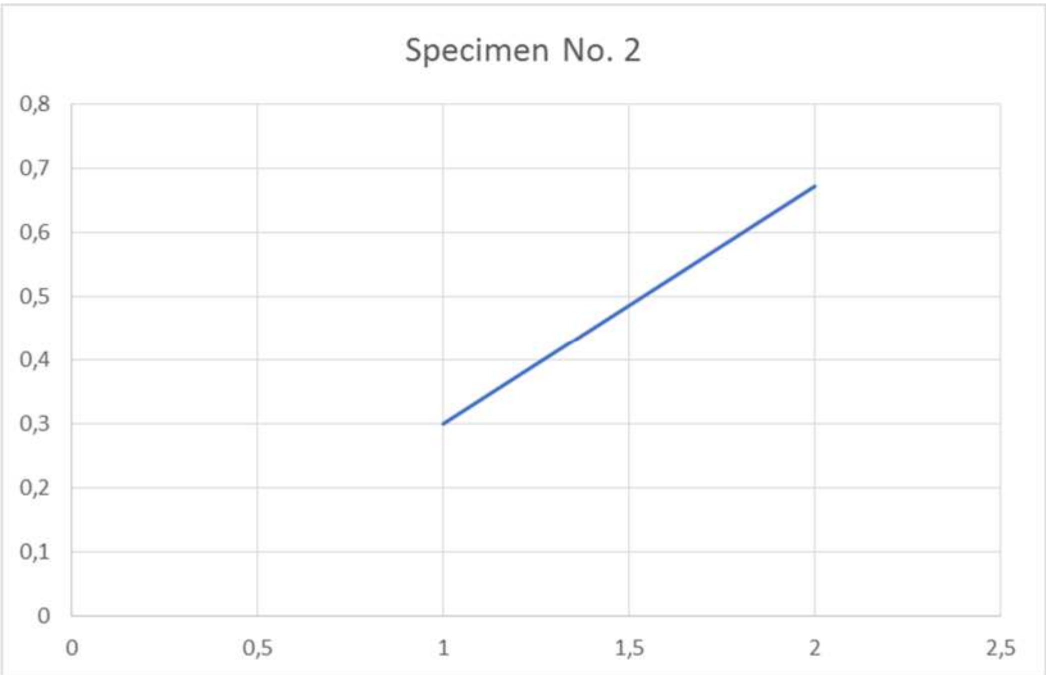


Figure IV.8 the curve of the arrow as a function of the force with notches for $(d/b = 0.3)$.

3-Deflection curve as a function of force with notches for(d/b=0.4):

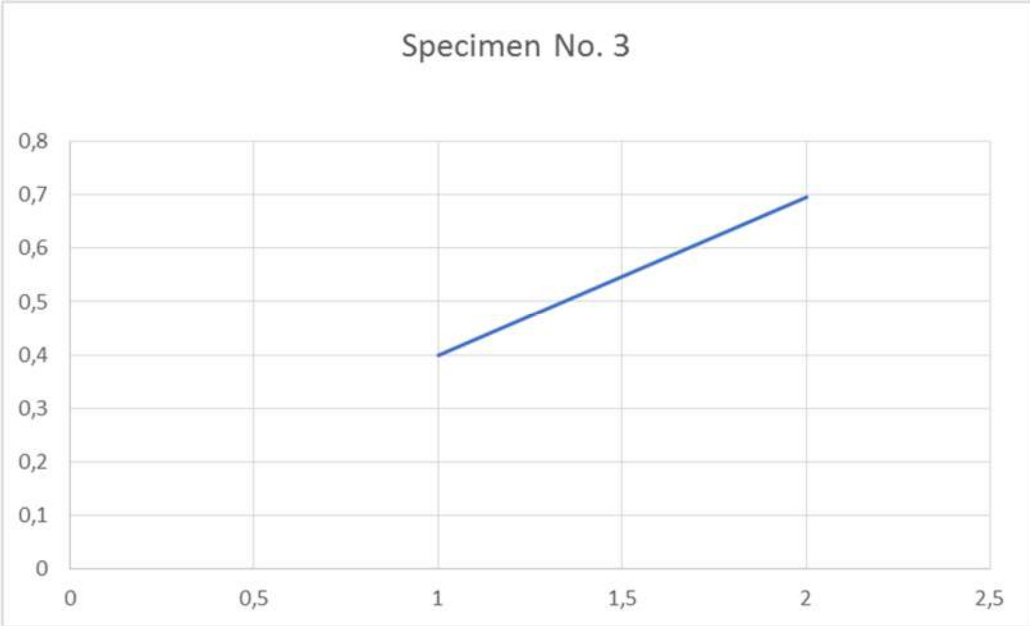
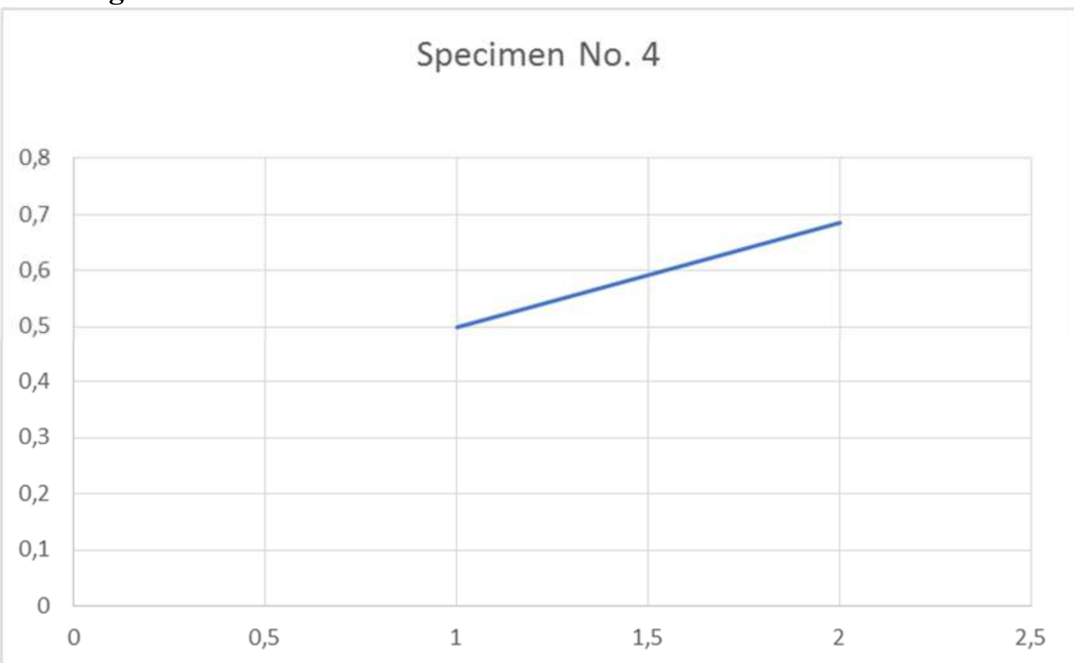


Figure IV.9 the curve of the arrow as a function of the force with notches for $(d/b = 0.4)$.

4-Deflection curve as a function of force with notches for (d/b=0.5):

Figure IV.10 the curve of the arrow as a function of the force with notches for



$(d/b = 0.5)$.

Through examining the deviation curve in relation to the gaps, we observe that as the ratio (d/b) increases, it is accompanied by an increase in the deviation.

 Comparison curve of deflection as a function of force with gaps for (d/b = 0.2), (d/b = 0.3), (d/b = 0.4), (d/b = 0.5).

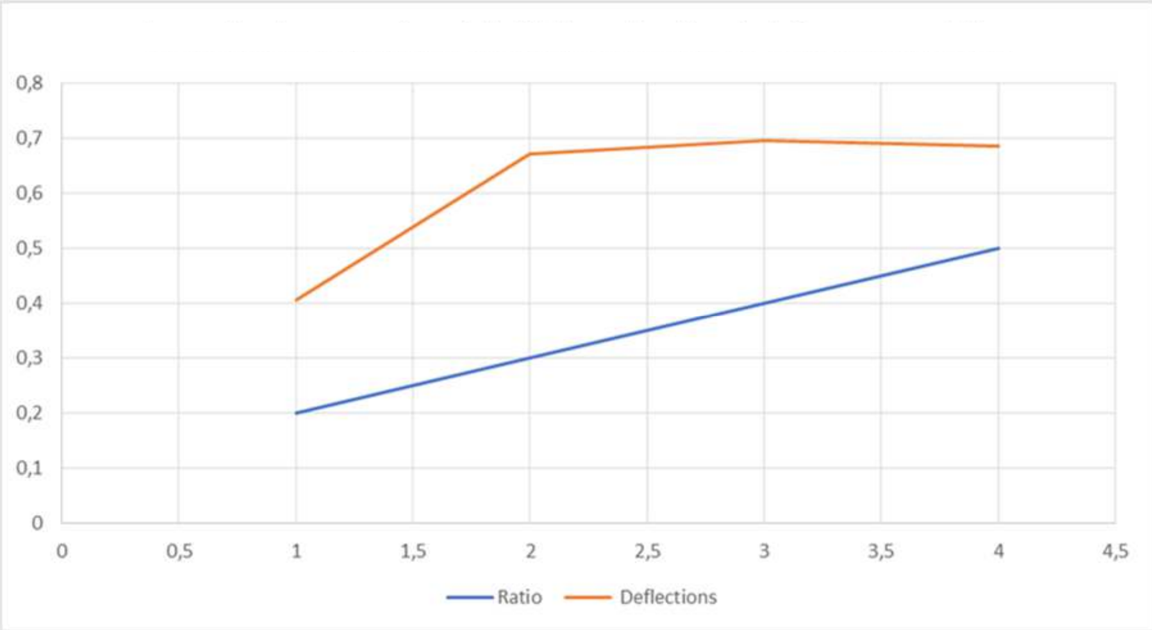


Figure IV.11 the Comparison curve of deflection as a function of force with gaps for (d/b = 0.2), (d/b = 0.3), (d/b = 0.4), (d/b = 0.5).

Through examining the deviation curve in relation to the gaps, we observe that as the ratio (d/b) increases, it is accompanied by an increase in the deviation. However, at the ratio of 0.5, we notice a slight decrease in the deviation curve

Table IV.4.table of divided differences based on Stain points

x	f[x_0]	f[x_0,x_1]	f[x_0,x_1, x_2]	f[x_0,x_1, x_2, x_3]
x_0	0.4057	2.6575	-12.0795	34.6533
x_1	0.6714	0.2416	-1.6835	0
x_2	0.6956	-0.0951	0	0
x_3	0.6861	0	0	0

The Newton interpolation polynomial is given by:

pol(x) = 17.707108x - 43.26747x^2 + 34.6533*x^3 - 1.6822592

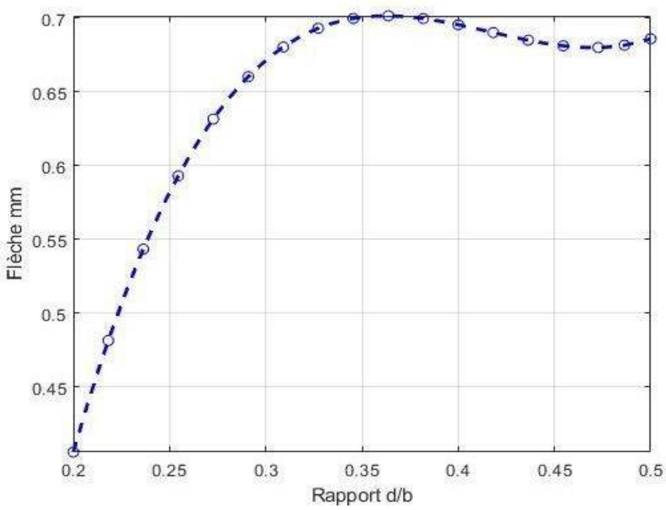


Figure IV.12 the curve represents the rapport (d/b) relationship in terms of the fleche .

By examining the provided data, we can observe certain patterns. First, the deflection, which represents a measure of material deformation, also increases with the size of the notch. This means that the material deforms more under load when the notch is larger. However, it is noted that the deflection does not seem to increase linearly with the d/b ratio. This could indicate that the notch size does not have a direct impact on the plate's deflection.

Table IV.5.table of divided differences based on Stain points.

X	f[x_0]	f[x_0,x_1]	f[x_0,x_1, x_2]	f[x_0,x_1, x_2, x_3]
x_0	0.0005	0.0016	-0.0055	0.0133
x_1	0.0006	0.0005	-1.0.0015	0
x_2	0.0007	0.0002	0	0
x_3	0.0007	0	0	0

The Newton interpolation polynomial for the stress as a function of the d/b ratio is:

pol(x) = 0.00781658x - 0.0174997x^2 + 0.013333*x^3 - 0.000499992

The stress decreases as the d/b ratio increases, indicating that the strength of the plate may decrease with an increase in the size of the notch

Table IV.6.table of divided differences based on Stain points.

x	f[x_0]	f[x_0,x_1]	f[x_0, x_1, x_2]	f[x_0,x_1, x_2, x_3]
x_0	4.4647	16.7040	-117.2400	428.1667
x_1	6.1351	-6.7440	11.2100	0
x_2	5.4607	-4.5020	0	0
x_3	5.0105	0	0	0

The Newton interpolation polynomial for the deformation as a function of the d/b ratio is: pol(x) = 186.647342x - 502.59003x^2 + 428.1667*x^3 - 16.1865008

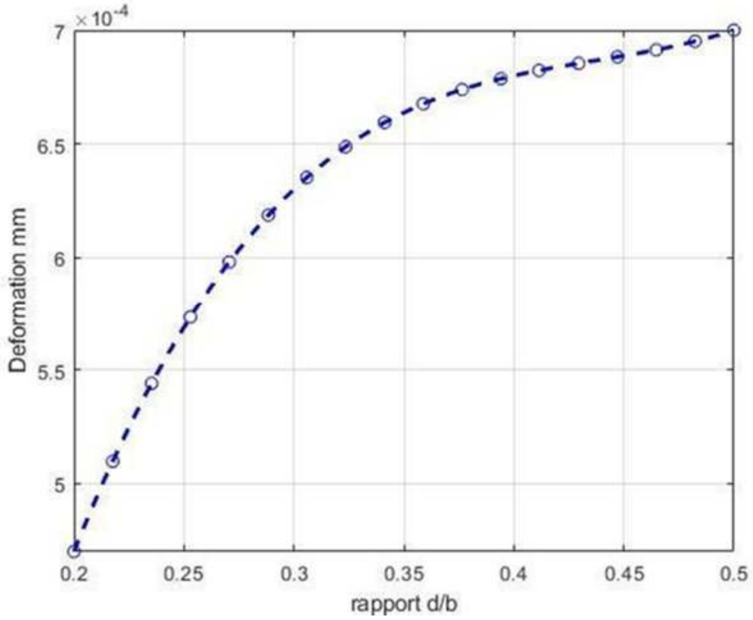


Figure IV.13 the curve represents the rapport (d/b) relationship in terms of the deformation .

The deformation appears to slightly increase with the d/b ratio, suggesting that larger notches result in more deformation in the plate. The obtained results indicate that the size of the notch has a notable effect on the material's behavior under load. Deformation, which could represent a form of distortion, seems to increase with the size of the notch. This suggests that the larger the notch size, the more likely the material is to deform under a given load.

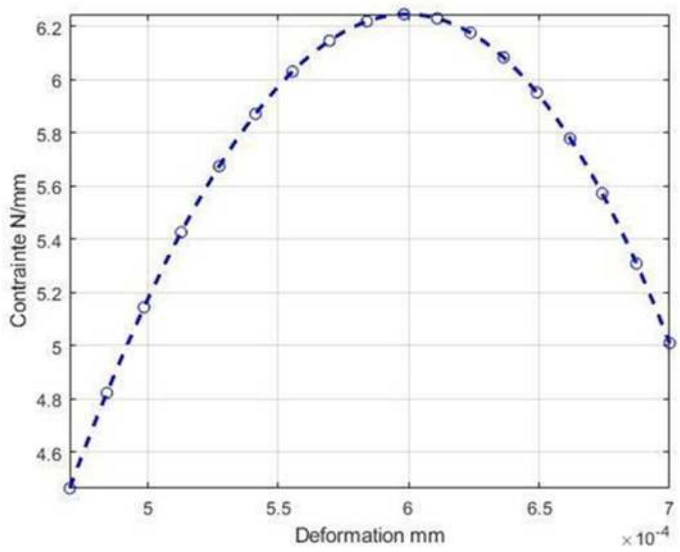


Figure IV .14 the curve represents the deformation (d/b) relationship in terms of the contrainte .

Conclusion :

Some general observations and conclusions:

1 For a sample without a notch, the increase in dimension (thickness * width) appears to have a minimal impact on the deflection, which is slightly larger for the larger dimension sample. This indicates a slight increase in deformation under the same load. Additionally, the stress seems to decrease slightly with the increase in dimension.

2 For samples with small-sized notches, increasing the dimension results in a decrease in deflection, indicating reduced deformation. This can be attributed to increased stiffness with the increase in dimension. The stress also appears to decrease with the increase in dimension.

3 For samples with large-sized notches, there seems to be a general trend of decreasing deflection with the increase in dimension, although it is not uniform. The stress, however, does not follow a clear trend and appears to be influenced by other factors, such as notch size.

4 When comparing samples with and without notches, samples without notches generally have a larger deflection (more deformation) for a given stress. This indicates that notches can effectively increase the stiffness of the material, thereby reducing deformation under load

In summary, the presence and size of notches, as well as the sample dimensions, have a significant impact on the behavior of the composite material under load. This highlights the importance of these factors in the design of composite materials for specific applications. It would be useful to perform more detailed analyses to fully understand the impact of these factors on the material properties.

General conclusion :

The overall objective of this study was to conduct a detailed analysis of the mechanical properties of specific composite materials. The general aspects of composite materials were discussed in Chapter 1, while Chapter 2 delved into the details of the materials and the methods used in the mechanical tests. The third and final chapter focused on a comprehensive experimental study of composite materials made from polyester resins and textile fibers.

In conclusion, the following results can be inferred from this study. It was observed that stress varies with longitudinal strain in two conditions (linear and curved) in the tensile test, while the strength also varies linearly with the load before bending. As for the engineering constants, it was found that they are not symmetrical between the tensile test and the three-point bending test.

In summary, this project provided a detailed and comprehensive analysis aimed at determining the properties of the studied composite material. The obtained results offered an in- depth understanding of the materials' performance and capabilities, providing valuable information for potential use in various applications. The use of polyester resins and textile fibers as the main components of the composite material has specific advantages and challenges, which were discussed and analyzed in this study.

Ultimately, this study contributes to increasing knowledge about composite materials, particularly regarding the mechanical properties of textile fibers and polyester resin. The obtained results provide a basis for future studies and the development of new applications for these composite materials.

In conclusion, this study contributes to increasing knowledge about composite materials, particularly regarding the mechanical properties of textile fibers and polyester resin. The obtained results provide a foundation for future studies and the development of new applications for these composite materials

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