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Submitted in fulfillment of the requirements
for the degree of State Engineer in Mechanical Engineering

Design of an RTM machine for composite material fabrication.

Author:
Meroua LOUNAOUSSI

Presented publicly the 15/07/2023

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Supervisors:	Said RECHAK	Prof	ENP
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En vue de l'obtention du diplôme d'Ingénieur d'Etat en Génie Mécanique

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Conception d'une machine RTM pour l'élaboration des matériaux composites.

Auteur:
Meroua LOUNAOUSSI

Présenté et setounue publiquement le 15/07/2023

Président:	Arezki SMAILI	Prof	ENP
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ملخص

تركز هذه المذكرة على تصميم جهاز لتقنية (RTM) . هدف هذا العمل هو تحديد الأبعاد وتصميم الأجزاء الثابتة والديناميكية للجهاز باستخدام أدوات التصميم المدعوم بالحاسوب (CAD) ، تحديدًا SolidWorks . تتضمن الدراسة تحليل الضغوط التي تتعرض لها كل مكونة ومحاكاة الجهاز، بالإضافة إلى عملية RTM .

الكلمات المفتاحية: تصنيع، تقنية (RTM) ، المواد المركبة، تصميم وتطوير الآلات.

Résumé

Cette dissertation se concentre sur la conception d'une machine de moulage par transfert de résine (MTR). L'objectif de ce travail est de dimensionner et de concevoir les parties statiques et dynamiques de la machine à l'aide d'outils de conception assistée par ordinateur (CAO), en l'occurrence SolidWorks. L'étude comprend l'analyse des contraintes subies par chaque composant et la simulation de la machine ainsi que du processus MTR.

Mots clé: Fabrication, Moulage par transfert de résine (MTR), Matériaux composites, Conception et développement de machine.

Abstract

This dissertation focuses on designing a Resin Transfer Moulding (RTM) machine. The objective of this work is to dimension and design the static and dynamic parts of the machine computer-aided design (CAD) tools, specifically SolidWorks. The study involves analyzing the stresses experienced by each component and simulating the machine, as well as the RTM process.

Key words: Manufacturing, Resin Transfer Molding (RTM), Composite materials, Machine design and development.

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Dedication

To my beloved: Papa & Mama

This present work is dedicated to you, the source of my unwavering support and encouragement throughout my entire life. Despite the sacrifices and hardships you have endured, you have consistently been my guiding light, leading me to this moment.

To my precious Yama Always so kind, always so warm, you are a blessing in my life

To Sarah, Assia, Halla, Lili

You are the steadfast (at times annoying) pillars I cannot imagine my life without. Your unconditional support, through both the challenging and joyous times, has been an invaluable source of strength.

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My lifelong friends who have been by my side in good and in bad since high school and beyond, I am forever grateful for the enduring bond we share.

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The dummies of friends who brought an extra dose of joy and laughter to my school days, I dedicate a special mention. Your presence made every moment more enjoyable, and our memories will forever be cherished.

To my extended family

The Lounaoussi and Mehdaoui clans, I extend my dedication. Your unwavering love and support have played an integral role in shaping who I am today.

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Thank you all from the deepest of my heart.

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RTM	Resine Transfer Moulding
CAD	Computer-Aided Deign
VOC	volatile organic compounds
PMC	Polymer Matrix Composite
CMC	Ceramic Matrix
MMC	Metal Matrix Composite
DSC	Differential Scanning Calorimetry
TGA	Termogravimetric Analysis
SEM	Scanning Electron Microscopy
TEM	TrTansmission electron microscopy
XRD	X-Ray Diffraction
FEA	Finite element analysis
DOE	Design of experiments
FoS	Factor of Security

A	area	m^2
P	power	$\mathrm{W}\ (\mathrm{J\,s^{-1}})$
l	length	m
u	displacement	m
F	Forces	N
U	strain energy density	$\mathrm{J\,m^{-3}}$
k	thermal conductivity	$\mathrm{W\,m^{-1}\,K^{-1}}$.
Q	Heat	W
E	Young's modulus	Pa
μ	Shear Modulus	Pa
λ	Lame's first parameter	Pa
σ	stress	Pa
ϵ	Contraint	Pa
Π	The total potential energy	$\mathrm{W\,s}$
ν	Poisson's ratio	
N	Shape function	
$[B]$	strain-displacement matrix	
$[D]$	material stiffness matrix	
$[K]$	Matrix of rigidity	

GENERAL INTRODUCTION

Manufacturing has been a necessity to human civilization ever since ancient times. Whenever the need calls for it, people have always created and innovated in order to achieve the service or produce the goods they deemed valuable and useful to society. Manufacturing was and continues to be the backbone of the production process for most goods. It is a critical factor for both economy and technology development of society. From an economic standpoint, the power of a nation's industrial capacity is directly proportional to its worth whether it is its ability to produce and export goods or, on the flip side, its inability to meet the needs of the population that results in it having to resort to trade and importation. Manufacturing is thus an essential contributor to a country's economic growth. Moreover, manufacturing propels innovation and technology development leading to create and improve products, processes, and services. It encourages research and development, resulting in the discovery of new materials and techniques that improve in return manufacturing's efficiency and productivity.[1]

To manufacture a specific good, choosing the right material is of utmost importance depending on the required properties and characteristics of the final product. There are several materials used for manufacturing that can be classified into five main categories: metals, ceramics, polymers, semiconductors and composites. Metals are strong, ceramics are hard and wear-resistant, polymers are lightweight and flexible, semiconductors are used for electronic devises, while composites are made of two or more materials combined to create unique properties. Composites can be designed to have specific mechanical, thermal, and electrical properties, making them an essential category to consider when choosing materials for manufacturing.

There are various composite manufacturing processes which can be divided into four main types based on their characteristics: open molding, compression molding, additive manufacturing processes and closed molding. Open molding involves using an open mold where the composite materials (resin and fiber) cure or harden while exposed to the air and placing the reinforcement materials directly into the mold. Compression molding uses heat and pressure to compress the reinforcement materials and the resin into a specific shape. Additive manufacturing uses 3D printing or other additive techniques to create composite parts layer by layer. Closed molding requires injecting the resin into a closed two-sided mold or inside a vacuum bag under pressure. The selection of a specific process depends on various factors such as material properties, part geometry, production volume, and cost.

Resin transfer molding (RTM) is a closed molding process used in composite manufacturing that offers several advantages over other methods. RTM produces high-quality, high-strength, and stiff parts with reduced waste, and can be done with low-VOC (volatile organic compounds) resins, making it an environmentally friendly option. It is also suitable for producing complex shapes with close tolerances and is cost-effective for producing high-performance composite parts. However, there are some limitations that should be considered when choosing a composite manufacturing process, such as high tooling costs, longer cycle times, limited material options, limited part size, and limited design flexibility. These limitations should be taken into account for larger parts or higher volume production runs.**[2]**

In this following work, The objectives are to design and develop a Resin Transfer Molding (RTM) machine for the production of complex geometries using composite materials. The focus is on designing the machine by reverse engineering using the CAD tool SolidWorks. The stresses experienced by each component will be analyzed, and the machine will be simulated to optimize manufacturing parameters and ensure efficient production.

In this dissertation, the following topics will be covered in each chapter:

The first chapter provides an introduction to composites, their evolution, and the different types of composite materials. It discusses matrix materials, reinforcement, and the interface between them, along with the properties and applications of composite materials. Additionally, it explores the characterization of composites and introduces palm date fibers as a specific type of reinforcement material.

The second chapter focuses on the manufacturing process of composite materials, with a specific emphasis on Resin Transfer Molding (RTM). It highlights the advantages and applications of RTM, analyzes existing RTM machines, and explores advancements in RTM technology. The chapter also discusses the components of an RTM system and innovative reinforcement materials, such as the utilization of date palm fibers in the RTM process.

The third chapter delves into the design of an RTM machine, providing an in-depth analysis of its components and their functions. It includes a justification for material selection in the design process, considering the specific requirements of RTM machines.

The fourth chapter focuses on the importance of thermal systems in composite manufacturing, particularly in the RTM process. It discusses different heating methods and technologies, emphasizing the efficiency and uniformity of heat transfer. The chapter also explores the challenges and advancements in thermal management systems for RTM, with a specific focus on heat source design for complete polymerization.

The final chapter introduces SolidWorks Simulation as a tool for numerical simulation. It discusses various simulation methods used, such as stress von Mises, displacement resultants, strain equivalent, and factor of safety. The chapter presents simulation results for different components, including stress plots, displacement plots, strain plots, and factors of safety, providing valuable insights into the behavior and performance of the simulated structures.

CHAPTER

I

GENERAL CONCEPTS OF COMPOSITES

I.1 Introduction

Composites are typically composed of two main components: a reinforcement material that provides the composite with its high strength and stiffness properties and is usually in the form of fibers or particles embedded within the matrix material; and a matrix material that distributes loads and stresses across the reinforcement material, prevents the propagation of cracks or fractures, and is usually a polymer, metal, or ceramic material.

For the reinforcement materials, there are two main types: synthetic fibers and natural fibers. Synthetic fibers are man-made fibers that scale the properties of the reinforcement to higher levels of strength and durability. These synthetic fibers are highly used in both high-tech and mid-tech industries; for instance, carbon, aramid and glass fibers are commonly used in the aerospace, naval and electronic industries whereas nylon, polyester and polypropylene are used in the automobile and service industries. As for the natural fibers, they are formed from renewable and biodegradable sources including plants, animals and minerals.

In the recent years, natural fibers have been the center of attention in various industries in view of their sustainability compared to synthetic fibers as well as their environment friendly impact and recyclability. Their versatility and cost-effectiveness have contributed to that as well as their good mechanical properties and even their aesthetics. All these properties enable natural fibers to substitute synthetic fibers whilst offering at the same time improved performance and comfort in a range of domains mainly in the mid-tech industry such as construction, automotive, textile, ...

In addition to the above mentioned properties and advantages, the incorporation of natural fibers in composite materials opens up new avenues for exploring unique aesthetic possibilities. The natural variations in color, texture, and pattern of fibers like palm date fiber, flax, and hemp can add a touch of natural beauty to the final composite products. These visually appealing composites find applications not only in functional industries but also in the realm of design and architecture, where the integration of eco-friendly materials and visually striking elements is highly sought after. By combining the strength and versatility of natural fibers with the artistic potential they offer, composite materials can transcend their functional purpose and become captivating works of art that inspire creativity and sustainable innovation.

In the following, we will present some basic concepts of composites and elaborate more about palm date fiber reinforcement material.

I.2 Evolution of composites

The use of composites surfaced way back in the ancient times. Around 3400 B.C, Mesopotamians in Iraq were the first to mark history with it, by gluing strips of wood on top of each other at different angles to create plywood. Similarly, Egyptians used linen or papyrus soaked in plaster to make death masks in 2181 B.C. Later on, both societies were the first to construct their houses using mud and combining it with straw to enhance the strength and durability of their habitations.

Another remarkable invention is that of the Mongols. They realized bows using wood, bamboo, bone, cattle tendons, horn and silk bonded with pine resin to obtain superior power and efficiency of these later. That showed to be of a higher accuracy and range, giving the Mongols significant advantages in the warfare.

It wasn'tn however, until the industrial revolution during world war II that composites gained their role it the society. The need for material with greater strength-to-weight ratio was of immediate importance, and composites seemed to be the suitable option. Industries transitioned the laboratory experiments to practical production, and developed synthetic resins by solidifying it through polymerization. This led to the creation of various plastics such as polyester, phenolic and vinyl.

The 1930s was an incredibly important time for the advancement of composites. Glass fibre was introduced by Owens Corning who also started the first fibre reinforced polymer (FRP) industry. The resins engineered during this era are still used to this day and, in 1936, unsaturated polyester resins were patented. Two years later, higher performance resin systems became accessible.

By 1945, fiber-reinforced polymer composites started to be primarily used in various military equipments, including aircraft, tanks, and naval vessels, to enhance their performance and durability. They offered advantages such as corrosion resistance, impact resistance, and improved structural integrity.

In 1946, the first fiberglass-reinforced polymer (FRP) composite boat hull was introduced. Fiberglass offered excellent strength and resistance to water and chemicals to the boat hull. This invention revolutionized the marine industry, as it provided lighter and more durable alternatives to traditional materials like wood or metal.

The automobile industry also recognized the potential of composite materials. In 1947, a significant milestone was marked with the first composite automobile body successfully tested. The composites offered advantages such as reduced weight, improved fuel efficiency, and resistance to rust and corrosion.

And by the mid-1990s, composites started becoming increasingly common for manufacturing processes and construction due to their numerous advantages and low cost-effectiveness.**[3]**

I.3 Types of Composite Materials

Typically, a composite material consists of two constituents: a ***matrix material*** that is usually a polymeric material and is responsible of the mechanical and physical properties of the composite; a ***reinforcement material*** that comes in the form of flaks, particles or, most commonly, fibers; an important phase to mention is the ***interface*** between these two constituents that transfers stress between the matrix and the reinforcement to enhance the mechanical properties of the composite.

The properties of the composite material can be tailored depending on these components to achieve specific characteristics such as: high strength-to-weight ratio, stiffness, toughness, corrosion resistance, thermal stability, electrical conductivity, etc... what enables composites to be used in a wide range of application.

Solid materials can be divided into three categories: ***polymers***, ***metals*** and ***ceramics***. We find both reinforcements and matrix materials in all three categories. This allows to create a limitless number of combinations that exhibit unique properties that cannot be found in any other singular material.

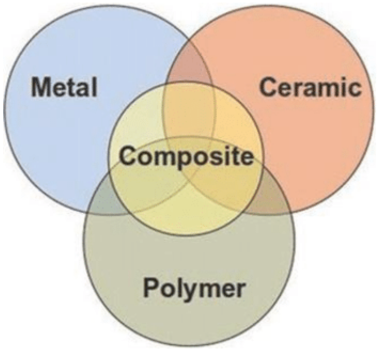


FIGURE I.1: The combination for Composites

I.3.1 Matrix materials

There are several types of composites we can get from these material categories, such as:

1. **Polymer Matrix Composite (PMC):**
   Most Commonly used matrix material in composites, such as epoxy, polyester, and polyurethane. PMCs are lightweight, strong, stiff and have high impact resistance. It can be divided into two major classes: thermosets and thermoplastics.
   - ***Thermosets:*** Thermosetting materials are substances that undergo an irreversible chemical bond reaction process during which its phase transitions from liquid to solid state. Once cured, the component cannot be melted again when exposed to heat.
   - ***Thermoplastics:*** Thermoplastics are materials that can be heated and softened allowing them to be moulded or shaped. Upon cooling, they retain the desired

shape. Unlike thermosets, this later can be melted and remoulded to take another shape when desired.

Thermosets are by far the most widely used matrix resins for structural applications for their resistance properties to solvents and corrosive environments.

2. **Ceramic Matrix (CMC):**
   Utilized in high-temperature applications. CMCs are lightweight, have high temperature resistance, and excellent strength. The key ceramics used as CMC matrices are silicon carbide, alumina, silicon nitride, mullite, and various cements.

3. **Metal Matrix (MMC):**
   A class of materials made by combining a metal matrix reinforced with ceramic or metal fibers or particles. MMCs have excellent strength, stiffness, and wear resistance. The key metallic matrix materials used for structural MMCs are alloys of aluminum, titanium, and iron.

SELECTION CRITERIA: When selecting a matrix, there are certain key criteria to consider. Since the matrix material is the one expected to withstand loads and stresses, mechanical properties such as strength, stiffness, toughness, and fatigue resistance are crucial. If the composite material is suspected to be exposed to reactive substances or corrosion, chemical compatibility of the matrix material should ensure its resistance against them. Thermal properties, including conductivity and expansion coefficient, are as important for effective thermal management. Furthermore, some other factors are to be evaluated before making a choice, such as processing and manufacturing feasibility, environmental resistance, cost, weight, durability, compatibility with reinforcements, and safety considerations.

The figure below summarizes the types of matrix materials discussed in the previous passages.

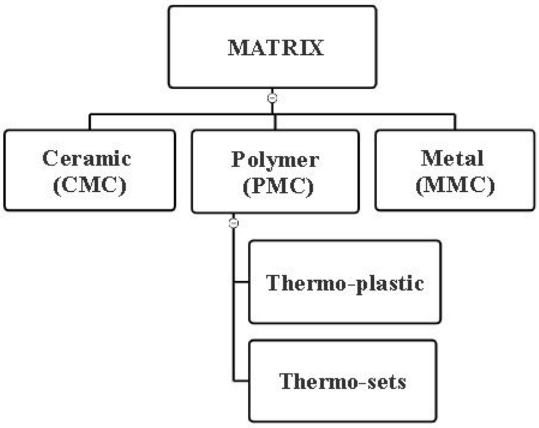


FIGURE I.2: Types of Matrices of Composite Materials

I.3.2 Reinforcement

The orientation and distribution of these forms within the matrix influences significantly the mechanical properties of the composite. Some common types we can find depending on the reinforcements can be:

- ***Fiber Reinforcement:*** Fiber reinforcement is a widely Common reinforcement type that gets incorporated into the matrix to enhance mechanical properties such as high strength and stiffness to the composite structure. Commonly utilized fiber types include carbon fibers, glass fibers, aramid fibers (such as Kevlar).
- ***Particulate Reinforcement:*** Particulate reinforcement adds inorganic or organic particles, such as silica, alumina, or carbon black, to the matrix material. It adds to the hardness, wear resistance, or electrical conductivity.
- ***Flake Reinforcement:*** Flake reinforcement uses thin, flat particles like mica or graphite flakes to the matrix material in order to improve barrier properties, increase thermal conductivity, or enhance dimensional stability. It is particularly used to improve resistance to heat transfer or gas permeability.

SELECTION CRITERIA: Whereas the matrix material is expected to withstand loads and stresses, the reinforcement material is of an important role in improving the mechanical and physical properties of the composite material. It should be able to provide the necessary strength and stiffness to enhance the overall mechanical performance of the composite. The compatibility between the reinforcement and the matrix material is also crucial for effective load transfer and bonding. Other factors to assess are the form and size of the reinforcement, processing compatibility, cost, availability, and the impact on weight and density of the composite. It is also essential to take into account the matrix material selection alongside these criteria to achieve an optimized composite system.

The figure below summarizes the types of reinforcement materials discussed in the previous passage.

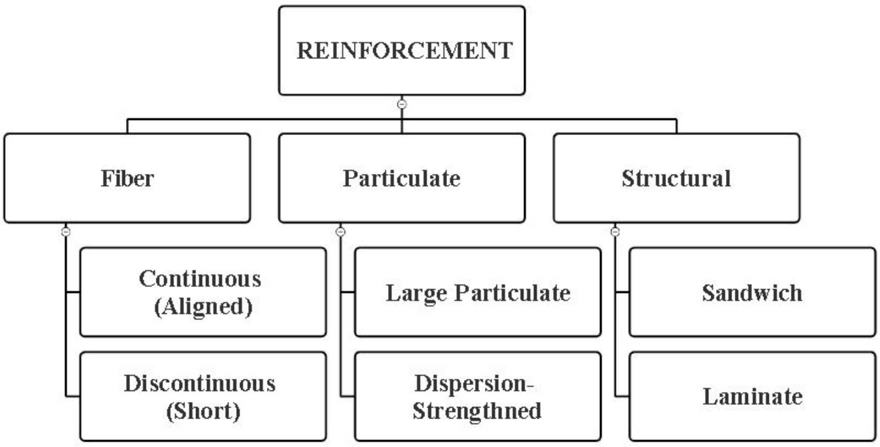


FIGURE I.3: Types of Reinforcements of Composite Materials

I.3.3 Interface

The interface of a composite material is where the matrix and reinforcement materials interact. In order to achieve a strong bond between the said materials, adhesion is required for effective load transfer. The strength and durability of thus interfacial bonding is directly impacted by its nature, be it chemical and mechanical.

Interfacial strength ensures the overall structural integrity of the composite. Deficiencies in it can lead to premature failure or reduced mechanical properties. Compatibility between the matrix and reinforcement materials, factors like thermal expansion and chemical compatibility, helps prevent interfacial mismatches and improves overall performance.

Is it crucial thus to keep The interface from the degradation of environmental factors, chemicals, or mechanical loading. Protective measures should be taken in consideration for maintaining long-term performance. Interfacial modification techniques such as surface treatments or coatings can enhance adhesion, compatibility, and introduce additional functionalities.

I.4 Properties of Composite Materials

Composites properties refer to the physical or chemical characteristics of a material that can be observed at a large scale. These properties depend on many factors such as the materials used in the composition of both the matrix and reinforcement, the composition of the mixture, the microstructure and the arrangement of atoms and molecules within the material, the processing method and conditions used to create the composite, the environment conditions (temperature, pressure, humidity...), the external forces like stress and strain that affect the mechanical properties of the material, etc...

There are some general properties that contribute in the uniqueness of composites materials that set it apart from other materials, including:

Composite Properties	***Definition***
High strength and stiffness	Composites are known for their ability to withstand high stress and resist deformation due to their reinforced structure.
Light weight	Composites have a low density, which makes them lighter than other materials with similar strength and stiffness.
Corrosion resistance	Composites are resistant to corrosion and degradation from exposure to chemicals, moisture, and other environmental factors.
Durability	Composites are durable and have a long lifespan due to their resistance to fatigue, impact, and other forms of damage.
Design flexibility	Composites can be designed to fit a wide range of applications due to their ability to be molded into complex shapes and structures.
Thermal and electrical properties	Composites can have tailored thermal and electrical properties, such as high thermal conductivity or low electrical conductivity, depending on the desired application.
Acoustic properties	Composites can be engineered to have unique acoustic properties, such as sound absorption or reflection, making them useful in applications such as noise barriers or musical instruments.
Fire resistance	Composites can be designed to have high resistance to fire and heat, making them suitable for use in high-temperature application.
Biocompatibility	Composites can be engineered to be biocompatible, meaning they do not cause a negative reaction when in contact with livingtissue, making them useful in medical applications such as implants or prosthetics.
Environmental friendliness	Composites made from renewable or recycled materials can have a lower carbon footprint than traditional materials, making them more environmentally friendly.
Cost effectiveness	Composites can often be manufactured at a lower cost than traditional materials, making them an attractive option for a wide range of applications.
Wear resistance	Composites can have excellent wear resistance, making them suitable for use in applications where materials are subjected to friction and abrasion.
Magnetic properties	Composites can be designed to have magnetic properties, making them useful in applications such as magnetic storage devices.

TABLE I.2: General properties contributed to composites

I.5 Application of composite materials

The unique properties of composite materials such as their improved performance, durability, and cost-effectiveness, make them an ideal choice for a wide range of applications in both high-tech and mid-tech industries.

In high-tech industries, composite materials are commonly used in aerospace and defense applications, where high-performance materials are required to withstand extreme conditions. They are particularly used in the manufacturing of aircraft parts, such as wings, fuselages, and tail sections.

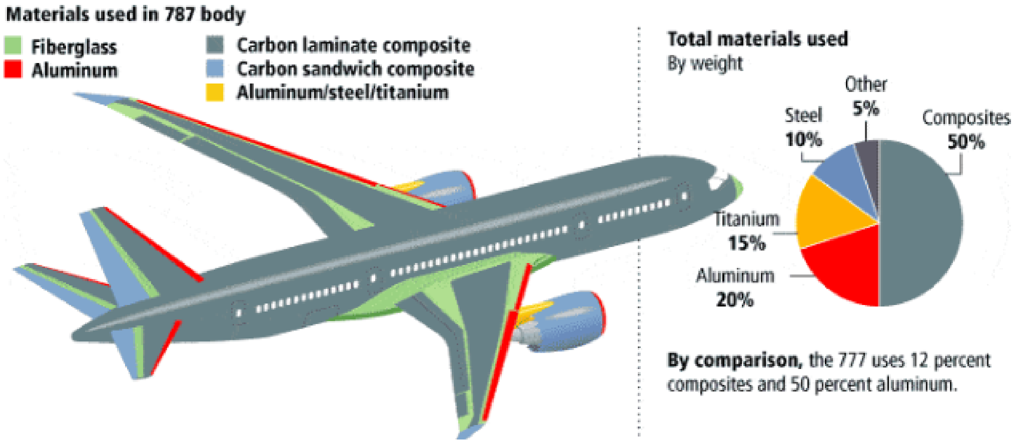


FIGURE I.4: Most Common Materials used in Air crafts.**[4]**

Composite materials are also widely used in the construction of satellites and space vehicles. The extreme temperatures and radiation exposure in space make composite materials an ideal choice for these applications, as they are lightweight and durable, with excellent thermal and electrical properties.

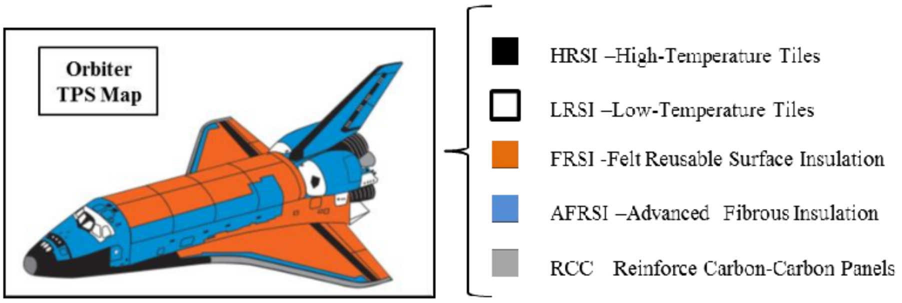


FIGURE I.5: Configuration of a TPS Space Shuttle Orbiter.**[5]**

In mid-tech industries, composite materials are used in a wide range of applications, including automotive, sports equipment, and construction. In the automotive industry, composite materials are used to manufacture parts such as body panels, hoods, and spoilers, which are lightweight and provide improved fuel efficiency. In sports equipment, composite materials are used in the manufacturing of golf club shafts, tennis rackets, and bicycle frames, providing improved strength and durability.

Composite materials are also widely used in construction, where they are used to reinforce concrete structures and provide additional strength and durability. For example, composite materials are used in the construction of bridges, where they provide improved corrosion resistance and can be designed to withstand heavy loads and extreme weather conditions.

FIGURE I.6: Application of Composites and hybrid materials in various high-tech and mid-tech industries **[6]**

I.6 Characterization of composite materials

Material characterization is the process of evaluating and examining a material's properties and behaviours at both the macro and micro scales in order to select the appropriate materials for specific applications. This requires the determination of certain properties of interest such as the physical, mechanical, thermal, chemical and electrical properties, Numerous tests and experiments are conducted using specialised equipment and instruments. An analyse is then conducted to experimented stuff to interpret the results and understand the material's structure, composition and performance characteristics.

For composite materials, this is particularly important because the characteristics or properties of the material may change with orientation. There are many standard test methods for composite materials depending on the industry or intended application **[7]**.

1. **MACROSCOPIC SCALE:**

   At the macro scale, composite materials are characterized by their overall mechanical properties, such as their strength, stiffness, and toughness. These properties are typically measured using basic tests such as tensile tests, flexural tests, impact tests, and compression tests under different loading conditions **[8]**.

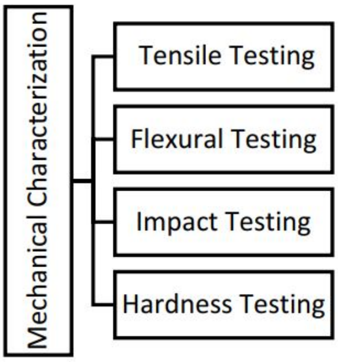


FIGURE I.7: Various mechanical characterization techniques **[9]**

The thermal analysis in another hand is measured using techniques such as: Thermal Conductivity Measurement (determining the ability of a composite material to conduct heat), Differential Scanning Calorimetry (DSC measures the heat flow into or out of a material as it undergoes heating or cooling),and Thermogravimetric Analysis (TGA measures the weight change of a material as a function of temperature).

As for the electrical measurement techniques, Electrical Conductivity Measurement, Four-probe resistivity measurements and impedance spectroscopy are commonly employed methods for measuring electrical conductivity. Permittivity, dielectric loss, and electrical breakdown strength can also be determined by the Dielectric Analysis, a method of measuring the response of a material to an applied electric field at different frequencies.

2. **MICROSCOPIC SCALE:**

The characterization of composites at this scale involves studying the arrangement and distribution of the constituent materials and any defects that may exist in the material at a microscopic level. This analysis provides crucial insights into the physical properties and behavior of the composite, including its strength, stiffness, and fatigue resistance. It uses photons, electrons, ions or physical cantilever probes to unravel the structure and composition of a sample of the composite. Common techniques include:

Scanning Electron Microscopy (SEM),an important method that provides high-resolution images of the composite material's microstructure, allowing researchers to study the size, shape, and distribution of the constituent materials and to study the interface between the different materials.

For nano-composite materials (composites made up of nano-particles), the adequate technique is Transmission electron microscopy (TEM). TEM is a more precise method to provide even higher resolution images than SEM and can be used to study the internal structure of the constituent materials at the atomic level.

X-Ray Diffraction (XRD) is another particularly useful technique for studying crystalline materials and can be used to identify the constituent materials in a composite. XRD measures the diffraction of X-rays by the composite material's crystal lattice, providing information about its crystal structure, phase composition, and defects.**[10]**

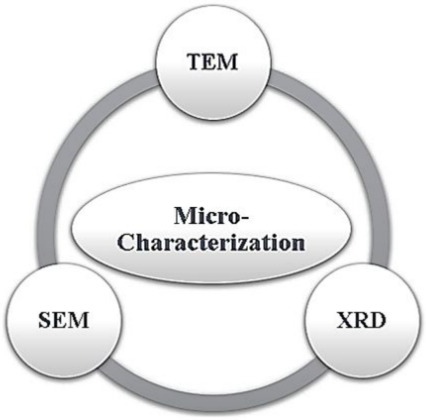


FIGURE I.8: Some common techniques of Microscopic Scale Characterization

In addition to the aforementioned techniques, digital and analytical approaches have become increasingly important in the characterization of composite materials. These methodologies use computational tools and sophisticated analysis methods to enhance the understanding of the composite material's properties, behavior, composition and performance.

Digital approaches use computer based-methods, numerical models and simulations to study the behavior of composite materials. A widely used application of it is the Finite element analysis (FEA). FEA divides the composite material into several small elements (meshing) and translate it to mathematical equations and then solve them, what enables the prediction of the behavior of the material under different loads and conditions. This prediction capability helps in optimizing the performance of the material and maximizes the desired results.

As for the analytical approaches, statistical methods and data analysis techniques are applied to empiric data. Statistical analysis helps identify trends and relationships between material properties, manufacturing parameters, and performance metrics. Techniques such as regression analysis (examination of the relationship between a dependent variable and other independent variables), multivariate analysis (analysis of relationships and patterns among multiple variables simultaneously), and design of experiments (DOE) enable researchers to optimize composite manufacturing processes and predict material behavior based on data obtained through direct observation or experimentation.

I.7 Palm date fibers

Palm date fibers or palm fibers are natural fibers extracted from the leaves of palm trees, which grow abundantly in tropical regions such as Southeast Asia, Africa, and South America. These fibers have a unique set of properties and advantages that make them an attractive material for various applications. Ecologically, their main advantage consist in their biodegradability and eco-friendliness as they do not harm the environment, and they can decompose naturally over time.

Moreover, their production does not require the use of infinite resources making them a sustainable, low cost and widely available option unlike other materials based on the synthetic fibers. Furthermore, The process of extracting palm date fibers from palm trees is simple and requires minimal resources. The leaves are cut and stripped of their fibers, which are then cleaned, dried, and spun into yarn. This process is not only low-cost but also requires less water and energy than the production of synthetic fibers.**[11]**

Palm date fibers are also moisture-resistant and have excellent thermal insulation properties, which make them suitable for use in building insulation, as well as in clothing and bedding.

Review of Research on Date Palm Fiber-Based Composites:

Due to the above mentioned advantages and for its unique characterization, research on the utilization of date palm fibers as reinforcement materials in composites has gained significant attention. Scientists are conducting to this days numerous studies and researches including:

1. Material Characterization: Studies focus on characterizing date palm fibers to understand their mechanical, thermal, and physical properties. The mechanical tests, such as tensile, flexural, and impact strength evaluations, have been conducted to determine the reinforcing potential of date palm fibers. Date palm fiber-based composites have demonstrated promising mechanical properties.**[12]**

   As for The thermal properties, including thermal stability and decomposition behavior, researchers have been analyzing them using techniques such as thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). Thermal properties of date palm fiber composites indicate increased thermal stability compared to the neat matrix; its presence showed to be enhancing the thermal resistance of the composites, making them suitable for applications requiring thermal insulation or resistance to high temperatures.

   Whereas for the physical properties, including density and moisture absorption, they are influenced by the fiber content and processing techniques. Date palm fiber composites generally exhibit lower density compared to neat matrix materials, contributing to their lightweight nature.

2. Composite Processing Techniques: Date palm fibres have been incorporated into composite matrices using a number of different processing methods. Hand lay-up, compression moulding, extrusion, and injection moulding are typical examples. Researchers have examining surface modifications and treatments of date palm fibres to improve adhesion with the matrix material because of the fiber-matrix interface that is critical to composite performance.

3. Performance and Potential Applications: Date palm fiber composites are shown to be potential for various applications. Their lightweight properties and good performance makes them suitable for industries such as automotive, construction, and packaging.

CHAPTER

II

THE PROCESS OF RTM

To create a composite material, a process must be followed. This includes selecting the materials to be used, preparing them for use, mixing them together, applying heat and pressure to bond them, and finishing the final product. The specific process can vary depending on the materials being used and the desired characteristics of the composite material. Common materials used in composites include metals, ceramics, polymers, fibers, and natural materials. By combining these materials, composites can be created with unique properties such as increased strength, durability, or heat resistance.

II.1 Manufacturing of Composite Materials

Most common composite manufacturing processes can be divided into four main types based on their characteristics:

Manufacturing Process	***Characteristics***	***Examples***
Open Molding	- Reinforcement material is dispersed in an open mold - Resin is poured over the reinforcement material. - Resin is exposed to the air to cure or harden. - Possible to quickly produce large parts. - Inexpensive but requires intense labour. - Uneven resin distribution	- Hand Lay-up - Spray-up - Filament Winding
Closed Molding	- The reinforcement material is pre-formed before molding. - The reinforcement is placed in a closed mold and then compressed. - Possibility of producing high-quality parts with a good surface finish. - Can be expensive to acquire the equipment and set up. - Used to manufacture complex part geometries.	- Vacuum Infusion Processing - Compression Molding - Resin Transfer Molding (RTM)
Additive Manufacturing	- Consists of building up a part layer by layer. - Design possibilities are numerous. - Used to produce complex geometries. - Expensive equipments . - Slow production rate.	- Fused Deposition Modeling (FDM) - Stereolithography (SLA) - Selective Laser Sintering (SLS)
Cast Polymers Molding	- Mold system consists of parts to enclose the reinforcement material and resin. - Consistent resin distribution. - Ability to produce complex part geometries. - Requires high initial investment	- Solid Surface Molding - Gel Coated Cultured Stone Molding

TABLE II.2: Most common composite manufacturing processes **[2]**

(A) Closed molding (B) Open molding

(C) Cast polymer (D) Additive manufacturing

FIGURE II.1: Composite manufacturing processes**[2]**

II.2 Resin Transfer Molding (RTM)

RTM is a closed-mold composite manufacturing process. In RTM, pre-formed fibers are placed into a two-part mold, and the mold is then closed. Resin is injected into the closed mold under pressure, displacing air and impregnating the fibers. The part is cured under heat and pressure and then cooled either naturally or by a cooling system.

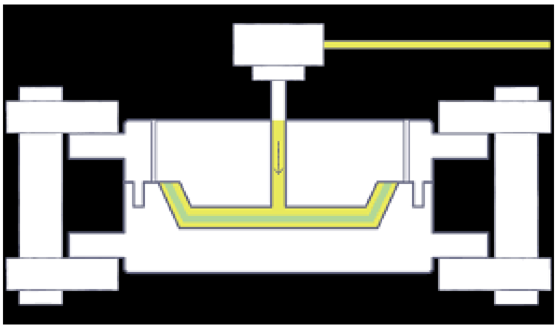


FIGURE II.2: Resin Transfer molding**[2]**

II.2.1 Advantages

RTM is gaining more and more in popularity in comparison to other processes thanks to its performance in various industries and to its numerous benefits such as:

- Complex and Lightweight Production: Yet strong in extreme details thanks to the use of fiber reinforcements and resin.
- Wide Range of Material Options: RTM is flexible in material selection as it is compatible with a variety of fiber reinforcements.
- Good Surface Finish: RTM is a closed mold process, meaning that air traps or resin streaks are reduced (Add to it the vacuum system that is an essential element in almost every RTM machine). This provides a high-quality and smooth surface finish on the molded parts that is aesthetically pleasing.
- Cost Efficiency: RTM equipment is initially more expensive than the other molding processes, so small volume production can be disadvantageous. High volume production in another hand offers cost advantages. This cost-effectiveness shows in RTM's reduced labor costs if automated and even without it, needlessness of final retouches and effective material usage for a minimal waste.
- Improved Quality and Consistency: RTM offers better control over the resin impregnation process compared to other molding methods. This leads in a consistent resin distribution and improved overall part quality.
- Reduced Cycle Time: RTM typically offers faster production cycles compared to traditional hand lay-up methods.
- Controlled Process Parameters: RTM enables precise control over key process parameters such as resin flow rate, pressure, and cure time. This optimizes the process for specific part geometries, ensuring consistent quality, dimensional accuracy, and mechanical properties.

II.2.2 Application

RTM is widely used in the production of high-quality composite materials for their:

1. Structural Performance: The resin impregnation and void content in RTM is controlled, what leads to high-quality laminates with superior structural performance, including strength, stiffness, and fatigue resistance.
2. Volume Production: RTM is suitable for high-volume production. It has a rather faster cycle times compared to other processes, increasing productivity and reducing manufacturing costs.

3. High-Quality Surface Finish: RTM produces parts with very well surface finish, so additional surface treatments or secondary operations are not needed.
4. Consistent and Controlled Manufacturing: RTM allows for precise control over fiber orientation, resin content, and void content. This control ensures consistent and repeatable manufacturing, resulting in reliable and predictable mechanical properties.
5. Versatility: RTM enables manufacturing a wide range of complex parts, including wind turbine blades,aerospace structures, automotive components and much more.

II.2.3 Analysis of Existing RTM Machines and their Limitations:

The analysis of existing RTM machines reveals both notable advancements and persistent limitations in current technology. Here is an overview of the existing RTM machines and their limitations:

1. Machine Design and Features: Existing RTM machines vary in design and features, but common elements include a two-part mold, injection system, temperature control, and pressure application. Advanced machines incorporate automation and control systems to enhance accuracy. They often provide options for controlling resin flow, curing parameters, and mold temperature as well.
2. Limitations and Challenges:
   - Resin Flow Control: Achieving efficient and uniform resin flow throughout the mold remains a challenge. Inadequate flow can lead to voids and inconsistent fiber impregnation.The Complex part geometries and variations in fiber orientation only adds up to these challenges.
   - Temperature Control: Maintaining precise and uniform temperature control throughout the mold is crucial for proper resin curing. Uneven temperature distribution can result in insufficient or excessive curing, leading to compromised mechanical properties and part defects.
   - Scalability and Flexibility: Some RTM machines face limitations in these terms. Adapting the machine setup for different part sizes, shapes, and production volumes can be time-consuming and require extensive reconfiguration.
   - Mold Release and Part Removal: Demolding and removing cured parts from the mold can be challenging, especially for complex or large structures. In some

    cases, additional mold release agents or complex mold designs are required, leading to added production steps and costs.

3. Impact on Quality, Productivity, and Cost-effectiveness: The limitations of existing RTM machines can have several implications:
    - Quality: Inefficient resin flow and inadequate temperature control can result in inconsistent part quality, including voids and variations in mechanical properties. These issues require additional post-processing, impacting overall product quality and reliability.
    - Productivity: Challenges in resin flow control, temperature control, and scalability can lead to longer cycle times and lower production rates.
    - Cost-effectiveness: The limitations in existing RTM machines can increase production costs. Inefficient resin flow, inadequate temperature control, and complex mold designs may require additional material usage, longer processing times, and increased labor or equipment costs.

II.2.4 Advances in RTM Technology and Applications

Resin Transfer Molding (RTM) technology has also seen significant advancements and expanded applications. Key advancements include:

- Resin formulation: Development of specialized resins with improved flow characteristics, cure kinetics, and mechanical properties to optimize the RTM process.
- Mold design and optimization: Advanced modeling and simulation techniques are used to optimize mold designs to ensure proper resin flow and minimize defects.
- Process monitoring and control: Researchers have developed sensors and monitoring systems to assess the process parameters, from temperature, pressure, and resin flow, to enabling real-time process control and quality assurance.
- Hybrid RTM processes: Integration of other manufacturing methods, such as preforming techniques , with RTM to enhance part quality, reduce cycle times, and increase process flexibility.
- Expanding applications: RTM technology is being applied in various industries, including automotive, aerospace, wind energy, and sports equipment, due to its ability to produce complex, lightweight, and high-performance composite parts.

II.3 Components of an RTM System: Tools and Equipment

An RTM system comprises various tools and equipment that facilitate the resin transfer molding process. The components of an RTM system typically include:

- Mold: The mold is a crucial component in RTM, as it defines the shape and surface finish of the final composite part. It is typically made of rigid materials such as metal or composite and consists of two halves that can be separated for part removal.
- Injection system: The injection system includes components responsible for delivering resin into the mold cavity. It typically consists of a resin reservoir, pumps, valves, and pressure regulators to control the flow and pressure of the resin during injection.
- Vacuum system: A vacuum system is used to remove air and gases from the mold cavity and preform before resin injection. It ensures proper impregnation of the fibers and reduces the risk of voids or defects in the final part.
- Heating and cooling system: RTM often requires precise temperature control for resin viscosity and curing. Heating and cooling systems, such as heating blankets or temperature-controlled platens, are employed to achieve the desired thermal conditions during the process.
- Monitoring and control devices: Various sensors, gauges, and control systems are used to monitor and control important process parameters such as temperature, pressure, and flow rates. These devices ensure consistent and reliable production of composite parts.
- Demolding equipment: such as hydraulic or mechanical systems, assists in separating the mold halves and removing the cured composite part without causing damage.

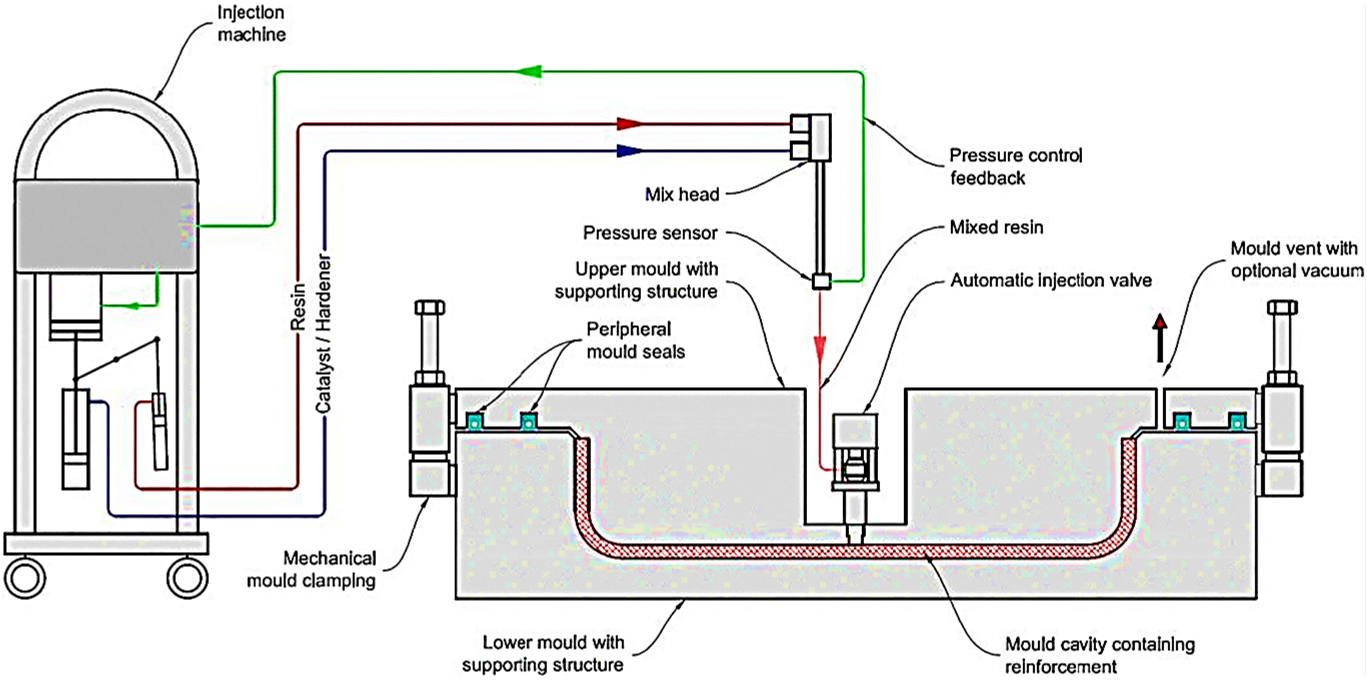


FIGURE II.3: Process of the RTM **[14]**

II.4 Kinetic Chain in RTM: Flow of Materials and Processes

The kinetic chain in RTM refers to the flow of materials and processes involved in the manufacturing cycle. It consists of several sequential steps that ensure the proper infusion of resin and consolidation of the composite part. The key stages in the kinetic chain of RTM typically include:

1. Mold preparation: The mold is prepared by applying release agents and mold sealers to facilitate part removal and prevent resin leakage.
2. Preform placement: Dry fiber preforms, which are cut to the desired shape and orientation, are placed in the mold cavity. These preforms act as the reinforcement material.
3. Mold closure: The mold is closed and sealed to create a closed system for resin injection.
4. Resin injection: Liquid resin is injected into the mold cavity under controlled pressure. The resin flows through the fiber preforms, impregnating them.
5. Resin cure: After the resin infusion, the composite part undergoes a curing process to solidify the resin and achieve the desired mechanical properties.

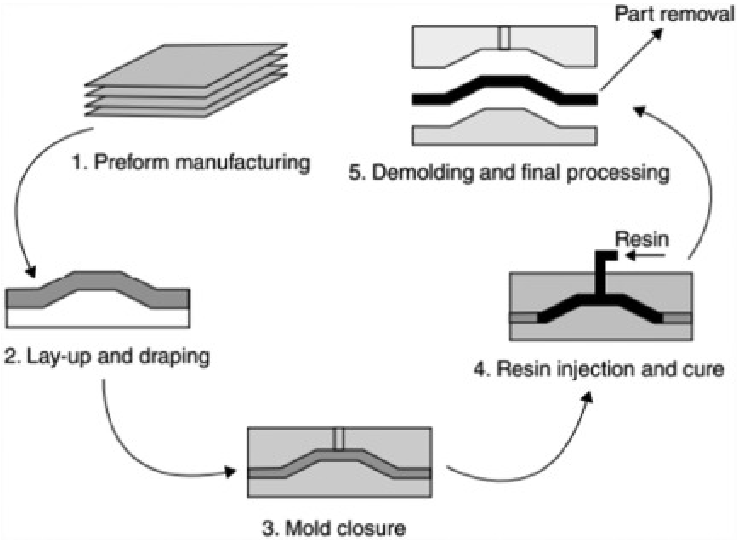


FIGURE II.4: Kinetic Chain in RTM **[13]**

6. Mold opening and part removal: Once the resin is cured, the mold is opened, and the composite part is removed.

CHAPTER

III

RTM MACHINE DESIGN

III.1 Description of the machine

Our RTM machine has being already developed, so we will be employing reverse engineering techniques to meticulously draw a detailed SolidWorks design. This machine integrates an average cylinder with a pressure multiplier, enabling the simultaneous heating and pressing of two molds. Throughout the process, the reinforcement is delicately positioned onto the heated mold surface, followed by the closure of the mold through the controlled descent of the counter-mold. The duration of the pressing stage is intricately linked to the necessary polymerization time specific to the polyester resin employed, we will assume a resin polymerization time of 1 hour (3600 seconds).

Upon the completion of the pressing phase, the mold is opened to eject the finished part. With a typical molding pressure reaching approximately 100 bars, optimal material properties and structural integrity are ensured.

The tailored design of the RTM machine is crafted to effortlessly accommodate a mold measuring 210 mm in width, 10 mm in thickness, and 620 mm in length. These precisely specified dimensions correspond seamlessly to those required for an industrial-scale machine, perfectly suited to address the demands of larger-scale production requirements.

In addition to the SolidWorks design crafted through reverse engineering, our primary objective encompasses conducting a comprehensive static analysis of the RTM machine. This thorough examination will enable us to evaluate its structural endurance and mechanical stability under diverse loading conditions. By analyzing factors such as stress distribution, deformation, and safety margins, we are dedicated to optimizing the design and ensuring the machine's ability to withstand the demands of industrial production.

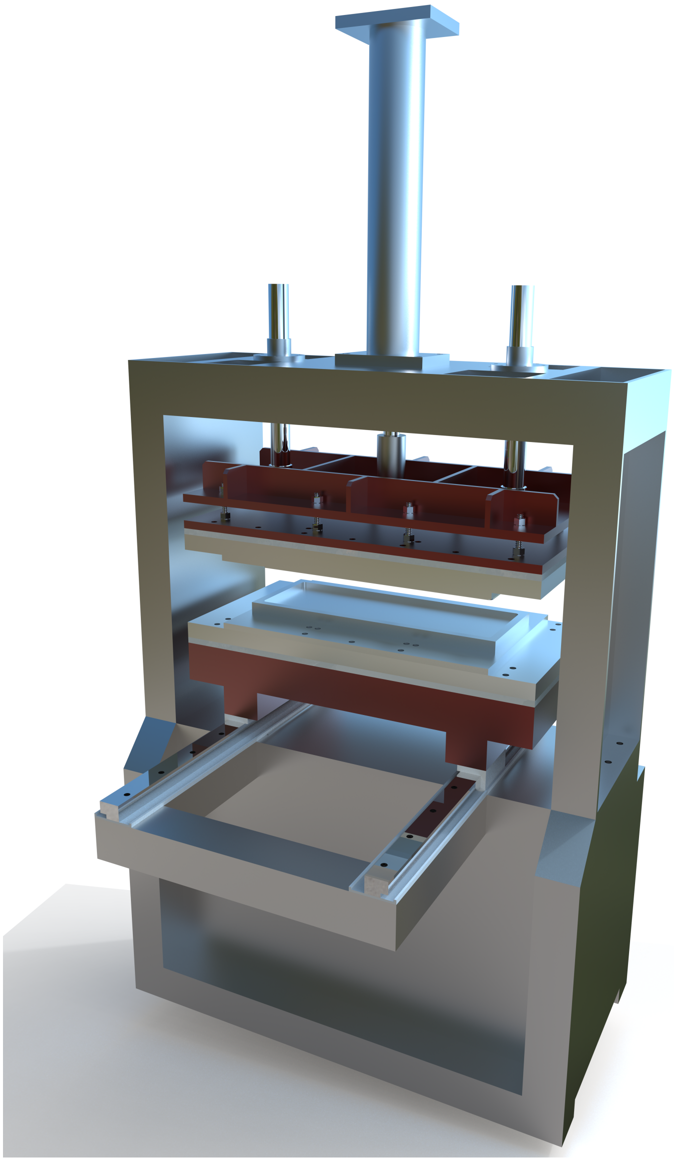


FIGURE III.1: Assembly of the RTM Machine

III.2 Components of an RTM machine

Here's a breakdown of each component and the design choices along with material selection justifications:

III.2.1 Mold:

The mold is a crucial component in the RTM process as it defines the shape and dimensions of the final product. It should be designed to withstand high pressures and temperatures. The mold can be made of materials like steel or aluminum. Steel molds offer excellent durability and dimensional stability, but they are more expensive. Aluminum molds are lighter and easier to machine, which can reduce manufacturing costs. We will assume an aluminium mold for a final product of dimensions of 620mm long, 210mm large and 10 mm thick. We choose for our mold the material: aluminium alloy 7075-T6 , so it can withhold the big load and temperature rise in the process of RTM.

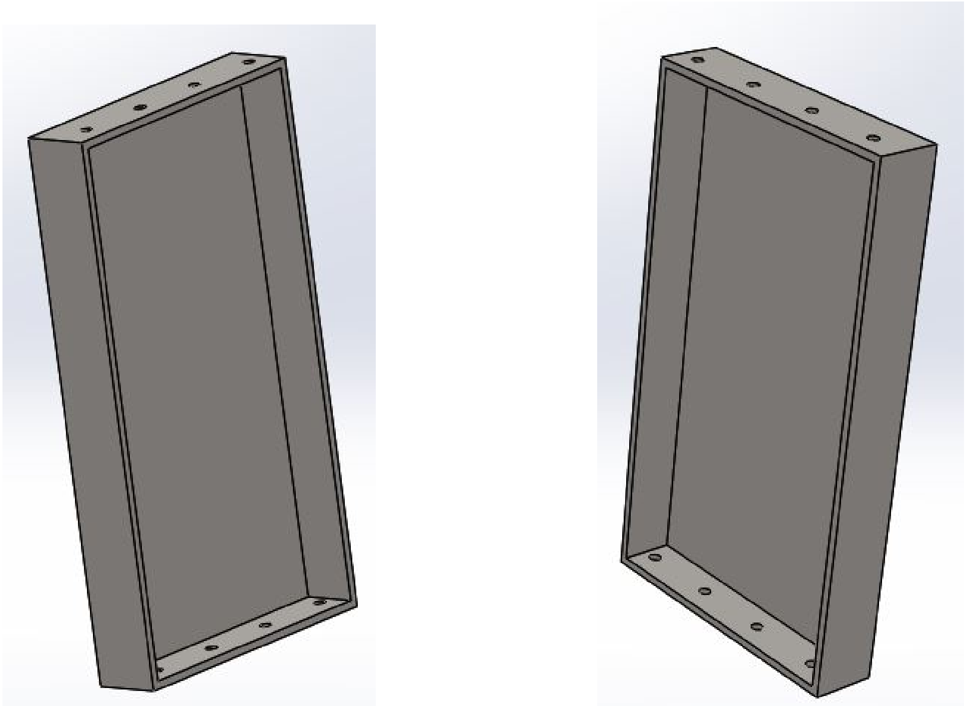
(A) Upper Mold

(B) Lower Mold

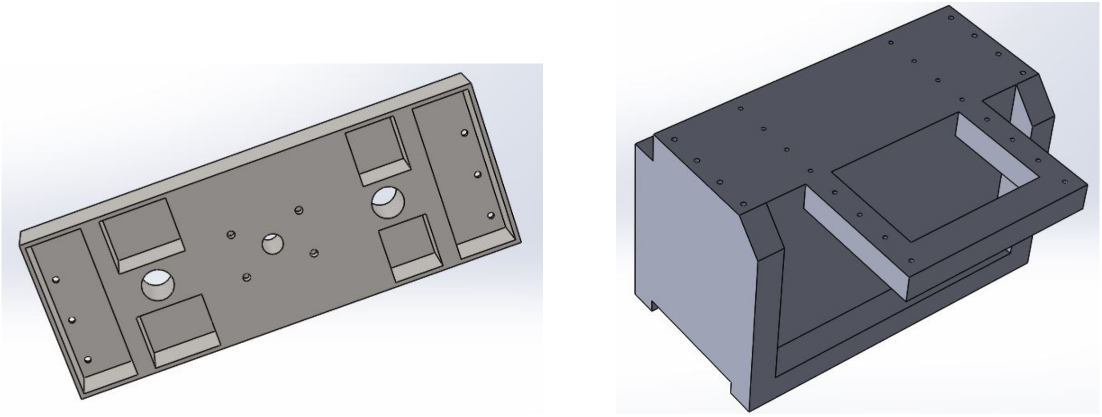
FIGURE III.2: Mold Of The RTM Machine

III.2.2 Frame:

The frame provides structural support to the RTM machine. It has to be be rigid to handle the loads and vibrations during the process. Steel is a common choice for frame construction due to its strength, stability, load-bearing capacity and ability to withstand the forces generated during the RTM process. 1.0037 (S235JR). This is the most used structural material in Algerian manufacturing.



(A) Right Frame (B) Left Frame

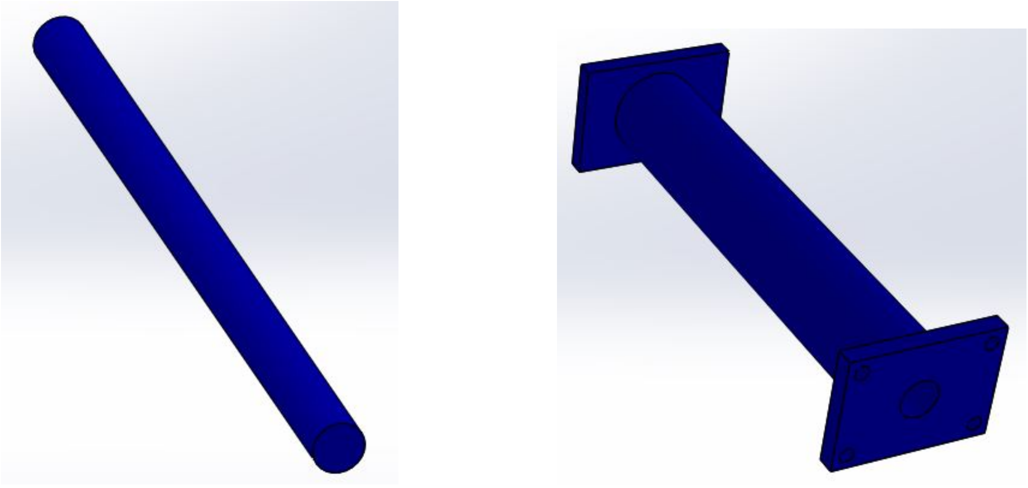


(C) Top Frame (D) Bottom Frame

FIGURE III.3: Frame Of The RTM Machine

III.2.3 Pneumatic multiplier cylinder:

The pneumatic multiplier cylinder is responsible for applying pressure to the mold during resin injection. The cylinder should be designed to provide sufficient force and control for consistent resin distribution. Materials like stainless steel or aluminum alloy can be used for the cylinder, considering their high strength-to-weight ratio and resistance to corrosion. For this, we choose the ASTM A36 Steel.



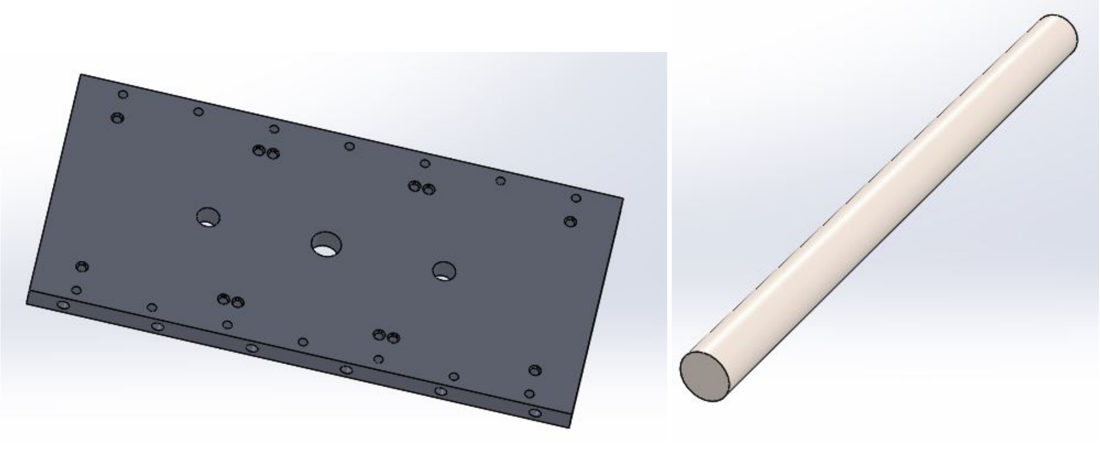
(A) Piston

(B) Cylinder Body

FIGURE III.4: Pneumatic Multiplier Cylinder Of The Machine

III.2.4 Aluminum heating plates:

Aluminum heating plates are used to heat the mold and cure the resin. Aluminum has excellent thermal conductivity, which allows for efficient heat transfer and uniform heating. Additionally, aluminum is lightweight and has good resistance to corrosion, making it suitable for this application. The aluminum used is the 7075-T6 (SN) for its high yield strength and thermal conductivity. As for the resistors, we choose the steel 1.2343 (X38CrMoV5-1) for its disponibility and compatibility with the heat resistance.



(A) Heating Plate

(B) Resistor

FIGURE III.5: Aluminum Heating Plate Of The RTM Machine

III.2.5 Heat Insulating Plates:

Insulating sheets are placed between the aluminum heating plates and the mold to prevent heat loss. They help maintain a stable and uniform temperature within the mold during the curing process. Materials like silicone or fiberglass reinforced with epoxy resin can be used as insulating sheets due to their good thermal insulation properties. One of the most used materials used for this is Ceramic Porcelain, the one we will be working with.

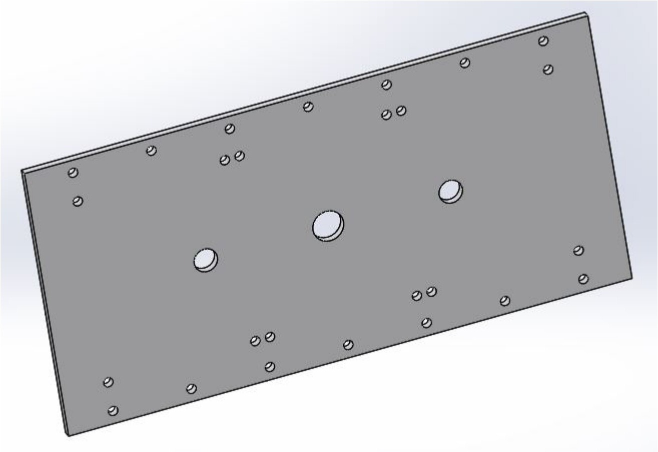
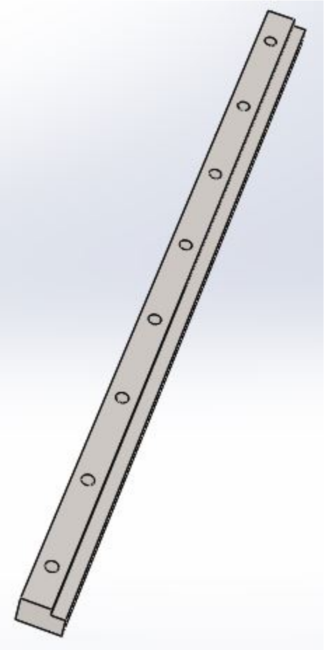


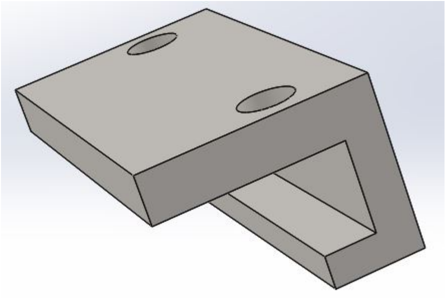
FIGURE III.6: Heat Insulating Plate Of The RTM Machine

III.2.6 Support for the plates:

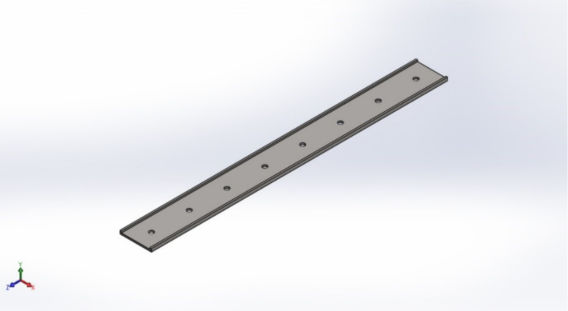
The support structure for the heating plates should provide stability and ensure proper alignment. Steel or aluminum alloy can be used for the support structure due to their strength and stability. The design should consider the weight of the plates and the forces exerted during operation. We will be assuming the same steel material for these supports as the structural ones. (1.0037 (S235JR)).



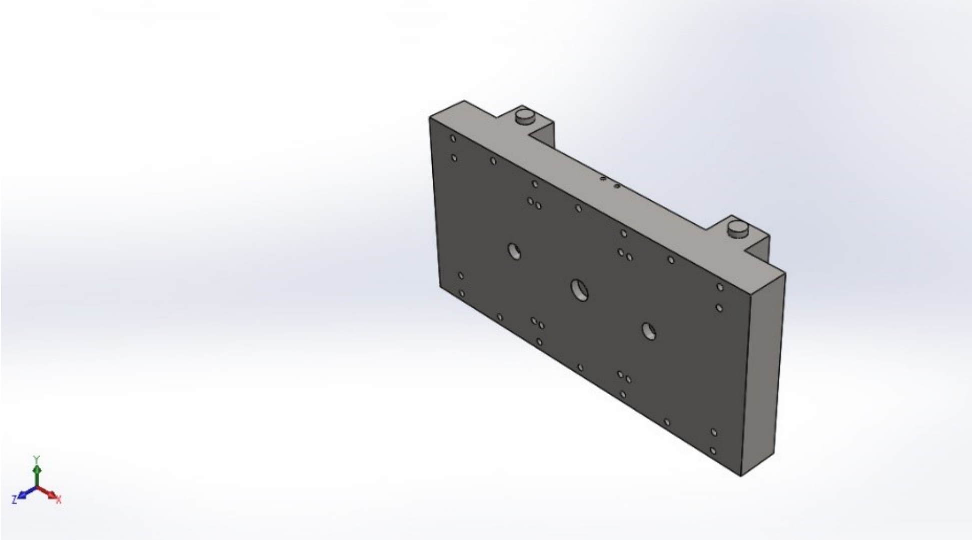
(A) Lower Slide



(B) Upper Slide



(C) Lower Support

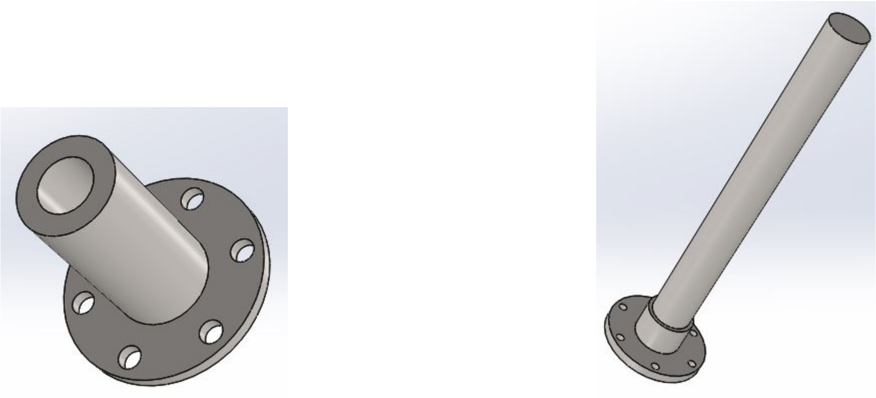


(D) Bottom Support

FIGURE III.7: Support Mechanism For Plates Of The RTM Machine

III.2.7 Linear guide system:

The linear guide system ensures precise movement of the mold during resin injection and curing. It should be designed to handle the loads and provide smooth motion. Materials like hardened steel or aluminum alloy can be used for the guide rails and bearings. These materials offer low friction, high durability, and good dimensional stability. The same steel will be used for these as well: 1.0037 (S235JR).



(A) Center Vertical Guidance Ring (B) Vertical Guidance ring

(C) Top Support (D) Support Plate

FIGURE III.8: Linear Guidance System

Justification for material selection:

the material selection for each component of the RTM machine is driven by factors such as strength, thermal conductivity, corrosion resistance, weight considerations, durability, dimensional stability, and cost-effectiveness. By carefully selecting the appropriate materials for each component, the RTM machine can achieve optimal performance, reliability, and efficiency throughout the resin transfer molding process.

- Steel: Selected for the mold, frame, and guide rails due to its strength, stability, and high load-bearing capacity.
- Aluminum: Chosen for heating plates due to its excellent thermal conductivity, lightweight nature, and corrosion resistance.
- Stainless steel: Used for the pneumatic multiplier cylinder for its strength, resistance to corrosion, and suitability for high-pressure applications.
- Ceramic: Selected for insulating sheets due to their good thermal insulation properties.

CHAPTER

IV

THERMAL SYSTEM

Thermal systems play a crucial role in composite manufacturing, particularly in processes like Resin Transfer Molding (RTM), where precise temperature control is essential during the polymerization process. Here's an explanation of the importance of thermal systems in composite production and an overview of heating methods and technologies used for temperature control:

IV.1 Importance of Thermal Systems in Composite Manufacturing:

Thermal systems are essential in composite manufacturing for several reasons:

1. Polymerization: Composite materials typically involve the use of a resin matrix that undergoes polymerization to achieve its final properties. Polymerization is a chemical reaction that requires controlled heating to initiate and progress at the desired rate. The thermal system provides the necessary heat to facilitate polymerization and ensure proper curing of the resin.

2. Material Properties: The temperature during the polymerization process affects the mechanical, thermal, and physical properties of the composite. Optimal temperature control enables the achievement of desired material properties, such as strength, stiffness, and dimensional stability. Improper temperature control can result in incomplete curing, leading to reduced performance and compromised product quality.
3. Process Efficiency: Efficient and uniform heat transfer throughout the composite part is crucial for achieving consistent material properties and minimizing defects. Effective thermal systems help maintain uniform temperature distribution, ensuring that the entire part cures simultaneously and reducing the risk of variations in mechanical properties.

IV.2 Heat Transfer

IV.2.1 Different Heating Methods and Technologies:

Various heating methods and technologies are used to achieve optimal temperature control during the polymerization process in composite production. Some commonly employed techniques include:

1. Convection Heating: In convection heating, heated air or gas is circulated around the mold or part, transferring heat through convection. It is a widely used method due to its versatility and ease of implementation. However, achieving uniform temperature distribution can be challenging, especially in complex part geometries.
2. Electric Heating: Electric heating systems use resistive elements or induction coils to generate heat directly within the mold or part. This method offers precise temperature control and efficient heat transfer. Electric heating systems are often preferred for their flexibility, rapid response, and ease of automation.
3. Infrared (IR) Heating: Infrared heating utilizes electromagnetic radiation to transfer heat directly to the part's surface. IR heating offers rapid and localized heating, enabling selective heating of specific areas. However, achieving uniform temperature distribution throughout the part can be challenging, particularly in thick or complex structures.

IV.2.2 Efficiency and Uniformity of Heat Transfer:

Several factors influence the efficiency and uniformity of heat transfer in composite production:

1. **Mold Design:** The design of the mold and the placement of heating elements impact heat transfer. Proper positioning and arrangement of heating elements help achieve uniform temperature distribution across the mold surface and, subsequently, the composite part.
2. **Heat Transfer Medium:** The selection of a suitable heat transfer medium, such as air, liquid, or solid, affects the efficiency and uniformity of heat transfer. The medium's properties, flow rate, and distribution mechanisms play a crucial role in achieving desired temperature control.
3. **Thermal Insulation:** Adequate thermal insulation of the mold and surrounding areas prevents heat loss to the environment and promotes efficient heat transfer into the composite. Insulation materials and techniques should be carefully selected to minimize heat loss and maintain a stable temperature environment.

IV.2.3 Challenges and Advancements in Thermal Management Systems for RTM:

Thermal management in RTM, specifically for date palm fiber composites, presents unique challenges and requirements:

1. Fiber-Matrix Compatibility: Date palm fiber composites may require specific temperature profiles to ensure proper adhesion and impregnation of the fibers with the matrix. Achieving compatibility between the fiber, matrix, and thermal system is crucial to maximize composite performance.
2. Fiber Orientation and Placement: Date palm fibers have inherent variations in length, alignment, and distribution. Thermal management systems should account for these variations and provide adequate heat transfer to ensure uniform curing and maintain fiber alignment.
3. Process Optimization: Optimization of heating parameters, including temperature, heating rate, and curing time, is essential for achieving desired material properties

while minimizing defects. Advanced process monitoring and control systems can help optimize these parameters and ensure consistent quality.

Advancements in thermal management systems for RTM include the development of simulation tools for predicting heat transfer, sensor technologies for real-time monitoring of temperature distribution, and advanced control systems for precise temperature control.

IV.3 Heat Source Design for Complete Polymerization

IV.3.1 Specific requirements and challenges of the polymerization process in RTM:

The polymerization process in RTM poses specific requirements and challenges that need to be addressed in the heat source design. These may include factors such as the desired curing temperature, the heat transfer characteristics of the composite material, the required heating rate, and the overall process time constraints. Challenges may arise from the need for precise temperature control, the avoidance of overheating or under-heating, and ensuring uniform heating throughout the mold.

IV.3.2 Evaluation of heat source options:

1. Electric heaters: Electric heaters are commonly used in RTM machines due to their flexibility, controllability, and ease of integration. They can provide efficient heating through direct contact with the mold or by indirect means such as radiant heating. Electric heaters offer a wide range of power options, allowing for precise control over the heating process. However, they may require careful consideration of electrical safety, insulation, and power supply requirements.
2. Hot oil systems: Hot oil systems utilize a heat transfer fluid, such as thermal oil, to transfer heat to the mold. They offer excellent temperature control and uniform heating due to the circulation of the fluid. Hot oil systems are suitable for high-temperature applications and can be efficiently controlled using temperature controllers and circulation pumps. However, they require additional equipment for heating and circulation, and their operation involves considerations such as fluid leakage and maintenance.

3. Infrared radiation: Infrared (IR) radiation can provide localized and rapid heating in RTM processes. It offers direct and efficient heat transfer to the composite material, bypassing the need for conduction or convection. IR heating can be achieved using IR lamps or panels placed strategically around the mold. While offering fast heating and precise control, the selection and placement of IR radiation sources require careful consideration to ensure uniform heating and prevent overheating in specific areas.

IV.3.3 Selection of heat source design:

1. Configuration and placement considerations: The configuration and placement of the heat source should be optimized to ensure uniform heating across the mold and minimize temperature variations. Factors such as the size and shape of the mold, the arrangement of the composite material, and the heat transfer characteristics of the selected heat source option need to be taken into account. Additionally, thermal shielding and insulation measures should be considered to minimize heat loss and maintain the desired temperature profile.
2. Power requirements and calculations: The power requirements of the heat source depend on factors such as the size of the mold, the desired curing temperature, and the heating rate required for polymerization. Power calculations should consider the thermal properties of the composite material, the mold material, and the heat transfer mechanisms involved. These calculations help determine the appropriate power capacity and electrical specifications required for the heat source.
3. Control mechanisms and feedback systems: To achieve precise temperature control, various control mechanisms and feedback systems can be employed. Temperature sensors placed strategically within the mold can provide real-time temperature feedback, enabling the control system to adjust the heat source accordingly. Proportional-integral-derivative (PID) controllers are commonly used to regulate the heat source output based on the temperature feedback. The selection and implementation of control mechanisms should be carefully considered to ensure accurate and stable temperature control during the polymerization process.

By evaluating different heat source options, considering their advantages and limitations, and making informed selections based on the specific requirements and challenges of the RTM polymerization process, an appropriate heat source design can be chosen. The configuration, power requirements, and control mechanisms should be carefully designed to ensure effective heat transfer, uniform heating, and precise temperature control throughout the mold.

IV.3.4 Choice of the heat source

In our RTM machine, the power source is the resistors. Resistors are electrical components that are commonly used to control the flow of electric current in a circuit and dissipate electrical energy in the form of heat.

Using resistors as a heat source in the RTM (Resin Transfer Molding) process offers several advantages. Firstly, resistors provide excellent control over the generated heat by allowing the adjustment of electrical current flow. This enables precise temperature control during the RTM process, ensuring optimal conditions for polymerization. Secondly, resistors offer flexibility as they can be designed in various configurations and sizes to match the specific power requirements and mold geometries. They can be strategically placed in multiple zones within the mold, promoting uniform heating throughout the entire surface. Moreover, resistors are known for their reliability and durability, ensuring a long operational lifespan.

IV.4 Thermal Calculation

To perform the thermal calculations for the RTM machine, we will consider the heat transfer mechanisms and thermal properties of the components involved. The main focus will be on the heating system and the mold, as these are crucial for maintaining the desired temperature range during the RTM process. Here’s a detailed report on the calculations and methods used:

IV.4.1 Heat Generation:

Considering the existing machine, let’s estimate the power of each resistor to be around **1 kW**.

IV.4.2 Material Properties:

Aluminum (1060 Alloy):

- Thermal Conductivity: $k_{aluminum}$= 200 W/(m·K)
- Thermal Expansion Coefficient:$\alpha_{aluminum}$ = 2.4e-05 /K

Steel (1.0037):

- Thermal Conductivity: k_{steel} = 14 W/(m·K)
- Thermal Expansion Coefficient: α_{steel} = 1.1e-05 /K

Ceramic Porcelain:

- Thermal Conductivity: $k_{ceramic}$ = 1.4949 W/(m·K)
- Thermal Expansion Coefficient: $\alpha_{ceramic}$ = 1.08e-05 /K

Aluminium 7075-T6 (SN): The material of the heated plates.

- Thermal Conductivity: k_{al} = 130 W/(m·K)
- Specific heat:960 J/(kg.K)

Steel 1.2343 (X38CrMoV5-1): Resistor's material.

- Thermal Conductivity: k_{st} = 14 W/(m·K)
- Specific heat:440 J/(kg.K)

IV.4.3 Energy Balance:

The total heat generated by the 12 resistors can be calculated using the following calculation:

$$Q_{heat} = 12 \times P_{resistor} = 12 \times 1000 = \boxed{12kW} \tag{IV.1}$$

The total heat generated will be around **12 kW**

IV.4.4 Simulation of the Aluminium Plate

By meshing the plate by a total Nodes of 865052 and a Total Elements of 594012 of Maximum Aspect Ratio of 6.8561.

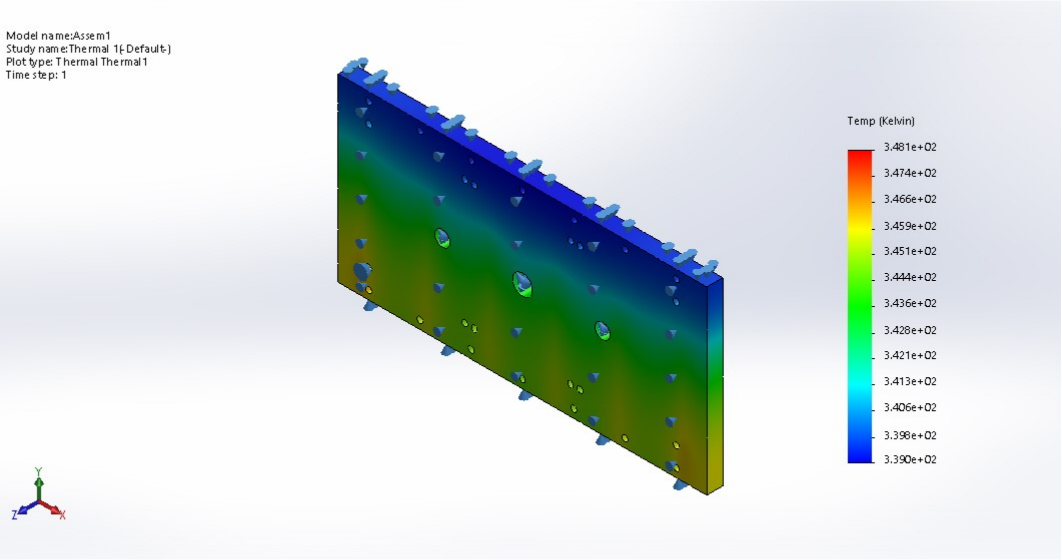


FIGURE IV.1: Thermal Simulation of the Aluminium Plate

The minimal temperature being 339 Kelvin at node 292, and the maximal being 348 Kelvin at node 860691.

The temperature difference between these two nodes is relatively small, indicating that the heat is evenly distributed across the plate. This uniform temperature distribution is desirable in many applications as it ensures consistent curing and mechanical properties of the composite material being processed. It suggests that the RTM machine is effectively maintaining a consistent temperature throughout the plate, which is important for achieving high-quality and reliable composite products.

CHAPTER

V

NUMERICAL SIMULATION

When designing an RTM machine, having insights into the behavior of materials under the different types of loads it will experience is a must to predict failure points and select appropriate materials. The way to this is to do some necessary calculations to help ensure the safety, durability, and efficiency of the machine as well as the product to be produced.

V.1 SolidWorks Simulation

SolidWorks is a powerful solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) software tool. It is used for performing static analysis and simulation of structures and components to examine their behaviour under designed loads and boundary conditions.

To simulate the components of our RTM machine, the steps to be followed are:

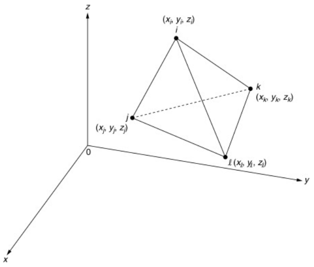


FIGURE V.1: Four-node tetrahedral element

V.1.1 Static simulation:

V.1.1.1 Preparing the Simulation:

First, we need to create a 3D model of each component of the RTM machine. Then, we assign the appropriate material to each component, as mentioned in the previous chapter. This step is particularly important as it determines the mechanical properties of the component, such as Young's modulus and Poisson's ratio. Next, we define the fixtures or boundary conditions to understand how the structure is supported. Finally, we apply the loads or forces to the model.

V.1.1.2 Discretization:

Discretization is the process of dividing the structure into smaller elements or meshes -such as triangles or quadrilaterals for 2D analysis and tetrahedra or hexahedra for 3D analysis- to break down complex problems into a group of simpler sub-problems. Each element is defined by its nodes, and the nodes are connected to form a mesh.

Tetrahedral meshes, which are pyramid shaped elements with four triangular faces, are commonly used in SolidWorks simulation due to their ability to accurately represent complex geometries and handle deformation. They allow for efficient analysis of stress and strain of the solid object.

Tetrahedral nodes are typically located at its vertices, each node possesses three degrees of freedom, representing the independent displacements or rotations it can have. These degrees of freedom correspond to the x, y, and z axes, allowing for movement in three-dimensional space.

In the scheme below, the nodes of a tetrahedral element are typically numbered from 1 to 4. The first three nodes (1, 2, and 3) are associated with the three vertices of the base triangle of the tetrahedron, and the fourth node (4) is associated with the apex or top vertex of the tetrahedron.

The mesh density can be adjusted to ensure accurate results; the finer the mesh, the more precise the analysis is. Each mesh serves as an approximation of the continuous part, allowing for the calculation of stresses, strains and displacements at discrete points within the model. By meshing the model, complex problems of the structure can be solved numerically using finite element methods.

The Finite Element Method (FEM) is a numerical technique used to solve differential equations by discretizing the problem domain into finite elements. The method aims to minimize the total energy of the system by finding the equilibrium solution.

To derive the Finite Element Method (FEM) equation in 3D, we should follow these steps:

- **Approximation:**
  Let's consider a tetrahedral element with four nodes labeled as node 1, node 2, node 3, and node 4. Let's approximate the displacement field within each element using trilinear shape functions:
  Shape function for node 1:

  $$N_1(x, y, z) = \frac{(1-x)(1-y)(1-z)}{8}$$

  Shape function for node 2:

  $$N_2(x, y, z) = \frac{(1+x)(1-y)(1-z)}{8}$$

  Shape function for node 3:

  $$N_3(x, y, z) = \frac{(1+x)(1+y)(1-z)}{8}$$

  Shape function for node 4:

  $$N_4(x, y, z) = \frac{(1-x)(1+y)(1-z)}{8}$$

Shape function for node 5:

$$N_5(x, y, z) = (\frac{(1-x)(1-y)(1+z)}{8}$$

Shape function for node 6:

$$N_6(x, y, z) = \frac{(1+x)(1-y)(1+z)}{8}$$

Shape function for node 7:

$$N_7(x, y, z) = \frac{(1+x)(1+y)(1+z)}{8}$$

Shape function for node 8:

$$N_8(x, y, z) = \frac{(1-x)(1+y)(1+z)}{8}$$

Here, (x, y, z) are the coordinates within the element, and the shape functions are defined in terms of these coordinates.

- **Strain-Displacement Relationship:**
  The strain vector ϵ is related to the nodal displacement vector u through the strain-displacement matrix [B]. The strain-displacement matrix [B] is derived by differentiating the shape functions with respect to the spatial coordinates (x, y, z). The strain-displacement matrix [B] is given by:

  $$[B]_x = \frac{\partial N}{\partial x} \quad , \quad [B]_y = \frac{\partial N}{\partial y} \quad , \quad [B]_z = \frac{\partial N}{\partial z}$$

  For example, the strain-displacement matrix for node 1 is given by:

  $$[B]_1 = [-1, -1, -1, 0, 0, 0]$$

  $$[B]_2 = [1, 0, 0, -1, -1, -1]$$

  The strain-displacement matrix [B] will have dimensions 6x12, where 6 represents the number of strain components (normal strains and shear strains) and 12 represents the number of nodal displacements $(u_1, v_1, w_1, u_2, v_2, w_2, u_3, v_3, w_3, u_4, v_4, w_4)$.

- **Energy Functional:**
  The total potential energy Π of the system is expressed as the integral of the strain

energy density U over the problem domain:

$$\Pi = \int (U - W) dV \tag{V.1}$$

The strain energy density U is given by:

$$U = \frac{1}{2} \int (\epsilon^T [D] \epsilon) dV \tag{V.2}$$

[D] is the material stiffness matrix that relates the stress σ to the strain ϵ. For linear elasticity, [D] is a 6x6 matrix:

$$[D] = \begin{pmatrix} \lambda + 2\mu & \lambda & \lambda & 0 & 0 & 0 \\ \lambda & \lambda + 2\mu & \lambda & 0 & 0 & 0 \\ \lambda & \lambda & \lambda + 2\mu & 0 & 0 & 0 \\ 0 & 0 & 0 & \mu & 0 & 0 \\ 0 & 0 & 0 & 0 & \mu & 0 \\ 0 & 0 & 0 & 0 & 0 & \mu \end{pmatrix}$$

λ represents the Lamé's first parameter (also known as the Lame's constant or the first Lame's parameter), and μ represents the shear modulus (also known as the elastic modulus or the second Lame's parameter).

The values of λ and μ depend on the material properties and can be derived from the Young's modulus, E, and Poisson's ratio, ν, using the following equations:

$$\lambda = \frac{E\nu}{(1 + \nu)(1 - 2\nu)} \tag{V.3}$$

$$\mu = \frac{E}{2(1 + \nu)} \tag{V.4}$$

E is the Young's modulus, and ν is the Poisson's ratio.

- **Energy Minimization:**
  Next, we have to Differentiate the energy functional Π with respect to the nodal displacements u and set the derivatives to zero to achieve equilibrium:

  $$\frac{\partial \pi}{\partial u} = 0$$

  This step leads to a system of equations relating the nodal displacements and forces.

Let's consider the variation of the potential energy with respect to the nodal displacements. Using the chain rule, we can express this derivative as:

$$\frac{\partial \Pi}{\partial u} = \int (\frac{\partial U}{\partial \epsilon})^T \frac{\partial \epsilon}{\partial u} dV \tag{V.5}$$

Here, $\frac{\partial U}{\partial \epsilon}$ represents the derivative of the strain energy density U with respect to the strains ϵ, and $\frac{\partial \epsilon}{\partial u}$ represents the derivative of the strains ϵ with respect to the nodal displacements u.

We can rewrite the above equation as:

$$\int (\frac{\partial U}{\partial \epsilon})^T \frac{\partial \epsilon}{\partial u} dV = 0 \tag{V.6}$$

Now, we consider the strain-displacement relationship

$$\epsilon = [B]u$$

[B] is the strain-displacement matrix, u represents the vector of nodal displacements, and ϵ is the strain vector.

Substituting the strain-displacement relationship into the equation, we have:

We obtain the following equation:

$$\int (\frac{\partial U}{\partial \epsilon})^T [B]^T dV = 0 \tag{V.7}$$

By expanding the integral over the entire domain by summing the contributions from all elements:

$$\int (\frac{\partial U}{\partial \epsilon})^T [B]^T dV = \sum (\int (\frac{\partial U}{\partial \epsilon})^T [B]^T dV)_e = 0 \tag{V.8}$$

This equation represents a system of equations relating the nodal displacements u and forces F:

$$[K]u = F \tag{V.9}$$

The [K] matrix is the global stiffness matrix, and it is obtained by assembling the element stiffness matrices contributed by each element.

The u vector represents the nodal displacements, and F represents the vector of nodal forces.

Each element stiffness matrix is derived from the virtual work equation applied to that element, which equates the virtual work done by internal forces to the virtual work done by external forces.

- **Assembling:**
  Next we assemble the contributions from each element to form the global system of equations. we should consider the connectivity between elements and nodes. Each element will contribute to multiple nodes in the global system. The virtual work principle to each element should be applied separately. The virtual work principle states that the virtual work done by the internal forces within the element should be equal to the virtual work done by the external forces.

  The virtual work done by the internal forces is expressed within an element as the integral of the strain energy density multiplied by the virtual strain over the element. While the virtual work done by the external forces can be expressed as the integral of the virtual forces multiplied by the virtual displacements over the element.

- **Stiffness Matrix:**
  By applying the virtual work principle to each element, derive the element stiffness matrices. The element stiffness matrix for each tetrahedral element can be obtained by integrating the strain-displacement matrix $[B]^T$, the material stiffness matrix [D], and the element volume over the element. The element stiffness matrix for each element represents the contributions to the global stiffness matrix from that element. By assembling the element stiffness matrices, we form the global stiffness matrix, K. The global stiffness matrix relates the nodal displacements u to the internal forces within the system.

- **Nodal Forces and Displacements:**
  We Compute the nodal forces F by multiplying the stiffness matrix K by the nodal displacements u:

  $$F = Ku$$

  F represents the vector of nodal forces, K is the global stiffness matrix, and u represents the vector of nodal displacements.

- **Applying Boundary Conditions:**
  We Apply the appropriate boundary conditions to the system, fix displacements by specifying the known displacements at certain nodes, such as $u = [u_k nown]$ at specific nodes. we modify the corresponding entries in the global stiffness matrix and the nodal force vector F. The applied forces should be Specified forces (pressure, traction, etc.)

at certain surfaces or nodes. Then we'll incorporate these forces into the nodal force vector F.

- **Solution:**
  After applying the boundary conditions, we solve the system of equations

  $$Ku = F$$

  we obtain the nodal displacements u that satisfy the energy minimization principle. This can be done using appropriate numerical techniques, such as direct methods (e.g., Gaussian elimination) or iterative methods (e.g., conjugate gradient).

- **Post-Processing:**
  Once the nodal displacements are known, other quantities of interest, such as stresses and strains, can be computed. We Compute stresses using Hooke's law:

  $$\sigma = [D]\epsilon$$

  σ being the stress vector, [D] is the material stiffness matrix, and ϵ is the strain vector. We use the strain-displacement matrix [B] and the nodal displacements u to compute strains. Finally, we'll evaluate quantities of interest, such as stress and strain, at specific points within the elements or at the nodes.

V.1.1.3 Solving Equilibrium Equations in SolidWorks:

SolidWorks Simulation solves the equilibrium equations to determine the displacements and stresses in the model. The equilibrium equations relate the applied loads and displacements of each element. The equations are solved iteratively using direct solvers or matrix algebra techniques, such as the finite element method. The matrices to be used in FEM are:

- Global Stiffness Matrix (K_{global}):
  The size of the stiffness matrix will be $(N + 1) \times (N + 1)$, where N is the number of finite elements. The general form of the global stiffness matrix is given by:

$$\begin{pmatrix} K_{00} & K_{01} & 0 & 0 & ... & 0 \\ K_{10} & K_{11} & K_{12} & 0... & 0 & \\ 0 & K_{21} & K_{22} & K_{23} & ... & 0 \\ 0 & 0 & K_{32} & K_{33} & ... & 0 \\ . & . & . & . & ... & . \\ . & . & . & . & ... & . \\ 0 & 0 & 0 & 0 & ... & K_{NN-1} \\ 0 & 0 & 0 & 0 & ... & K_{NN} \end{pmatrix}$$

Each K_{ij} represents the element stiffness matrix associated with the interaction between nodes i and j. The stiffness matrix is symmetric, so$K_{ij} = K_{ji}$.

- Displacement Vector (u):

  The size of the displacement vector will be $(N + 1) \times 1$. The general form of the displacement vector is given by:

  $$\begin{Bmatrix} u_0 \\ u_1 \\ u_2 \\ . \\ . \\ . \\ u_N \end{Bmatrix}$$

  Each u_i represents the nodal displacement associated with node i.

- Force Vector (f_global):

  The size of the force vector will also be $(N + 1) \times 1$. The general form of the force vector is given by:

  $$\begin{Bmatrix} f_0 \\ f_1 \\ f_2 \\ . \\ . \\ . \\ f_N \end{Bmatrix}$$

  Each f_i represents the nodal force associated with node i due to the distributed pressure load.

In the Finite Element Method (FEM), there is a relation between the global stiffness matrix (K_global), displacement vector (u), and force vector (f_global) that can be expressed as follows:

$$K_{global} \times u = f_{global}$$

This equation represents the equilibrium of forces within the system. The global stiffness matrix relates the nodal displacements to the nodal forces through matrix multiplication.

V.2 Methods used

There are certain quantities in engineering that are essential for understanding and analyzing the behavior of materials under different conditions. They help assess the structural integrity, deformation, failure potential, and safety of the designs. In SolidWorks Simulation, most commonly analyzed quantities are:

V.2.1 Stress von Mises:

Stress is the measure of the internal resistance within a material when subjected to external forces or loads that determines whether the material can withstand said loads in real-world applications. The stress von Mises is a scalar value that represents the combined effect of normal and shear stresses on a material. It is often used as a criterion to assess the material's **failure** or **yielding**. The von Mises stress is calculated using the principal stresses ($\sigma_1, \sigma_2, \sigma_3$) obtained from the stress analysis:

$$\sqrt{2}\sigma_{VM} = \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \tag{V.10}$$

It provides an overall measure of the stress state and is used to compare against the material's yield strength. Yield strength is a mechanical property that is typically determined through mechanical testing (specifically a tensile test). It is by comparing it with the maximum stress in a structure of the material, that it is possible to assess whether it will remain within the elastic region or enter the plastic region, where permanent deformation occurs.

V.2.2 Displacement Resultants (Res Disp):

Displacement resultants provide information about the overall displacement behavior of the structure or component. They represent the total displacement or deformation in a specific direction or magnitude. The displacement resultants can include values such as maximum displacement, displacement components (X, Y, Z), or resultant displacement magnitudes. Only when there are displacements that there are stress and strain on the material.

V.2.3 Factor of Safety (FoS):

The factor of safety is a critical concept used in engineering to ensure the reliability and safety of structures and components. It is the ratio of the maximum allowable stress or load that a structure can withstand when the load/stress is applied::

$$FoS = \frac{\text{Maximum Allowable Stress}}{\text{Applied or Expected Stress}} \tag{V.11}$$

If the minimum FoS is greater than 1, it indicates that the structure will be able to withstand a load or stress level that is higher than the expected load. This shows the safety margins and indicates that the structure can handle an additional strength. Otherwise, the structure should be revised and appropriate modifications should be made. However, it's crucial to find an appropriate balance between safety and efficiency because an unnecessary higher factor of safety increases the weight, cost, or complexity of the structure.

V.3 Simulation Results

V.3.1 Upper Mold

By applying a solid mesh of a Total number of Nodes of 17045, Total number of Elements of 9388, and a Maximum Aspect Ratio of 5.0719, we find:

FIGURE V.2: Discretization of the Upper Mold

The mold is fixated on the other side where it is in contact with the rest of the structure. We apply on the upper face the pressure applied by the pressure multiplier(100 bars).

We apply on the mold the temperature loads previously mentioned as well to simulate the effect of the thermal system.

V.3.1.1 Volumetric Properties

Property	**Value**	**Unit**
Mass	20.75	kg
Volume	7.68e-3	m^3
Density	2700	kg/m^3

TABLE V.1: Volumetric Properties of the Upper Mold

V.3.1.2 Material Properties: 7075-T6 (SN)

Property	Value	Unit
Yield strength	505	MPa
Tensile strength	570	MPa
Elastic modulus	72000	MPa
Poisson's ratio	0.33	

TABLE V.2: Material Properties of the Upper Mold

V.3.1.3 Reaction Force of the load

Sum Z
3.06623e+06 N

TABLE V.3: Reaction Force of the load

V.3.1.4 Stress Plot

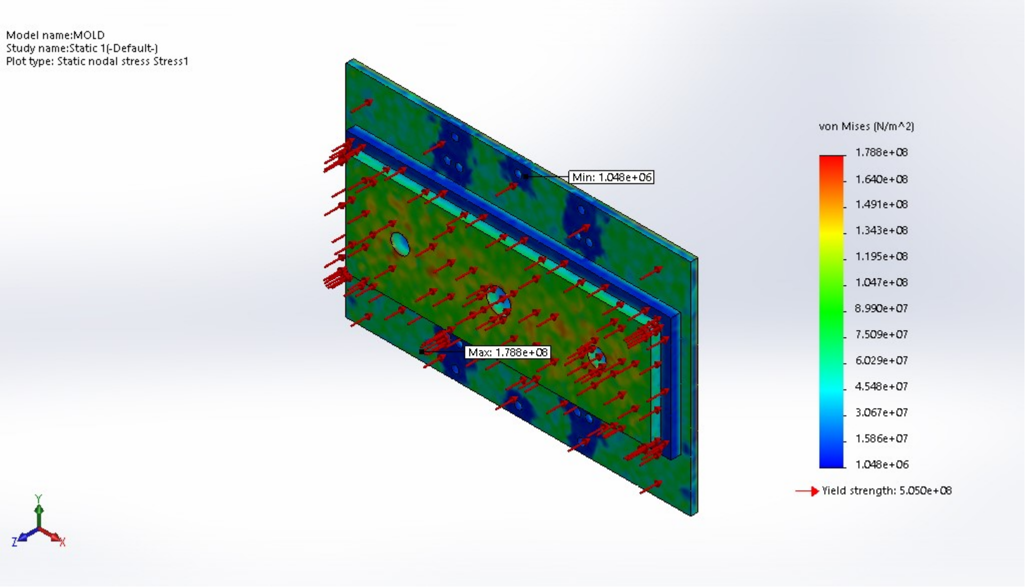


FIGURE V.3: Stress Plot of the Upper Mold

From the plot, we notice a minimum stress of 1.048 MPa, and a maximum of 178.8 MPa.

V.3.1.5 Displacement Plot

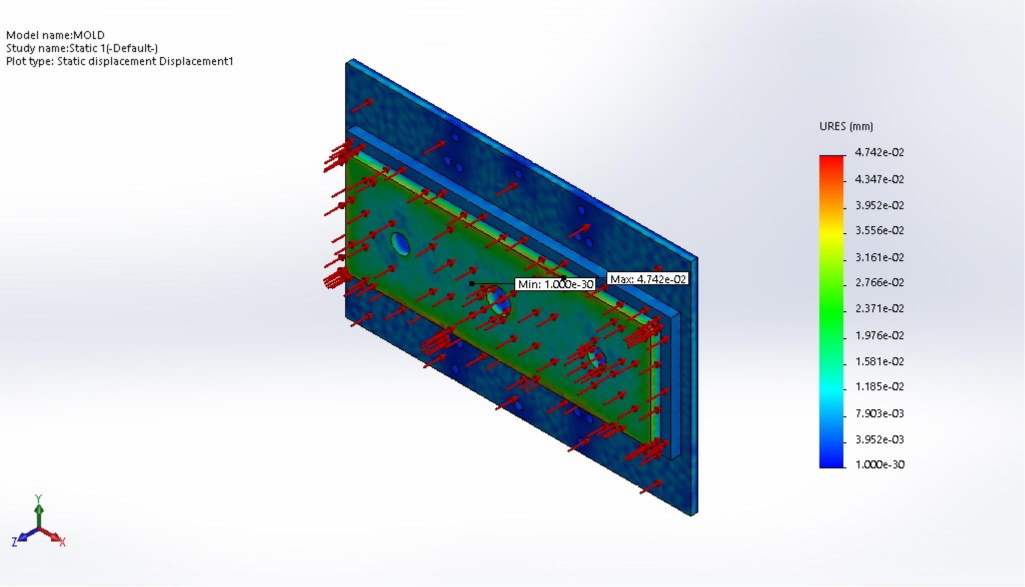


FIGURE V.4: Displacement Plot of the Upper Mold

From the plot, we notice that the minimal displacement is of 0 mm, and a maximum displacement of 0.047 mm.

V.3.1.6 Strain Plot

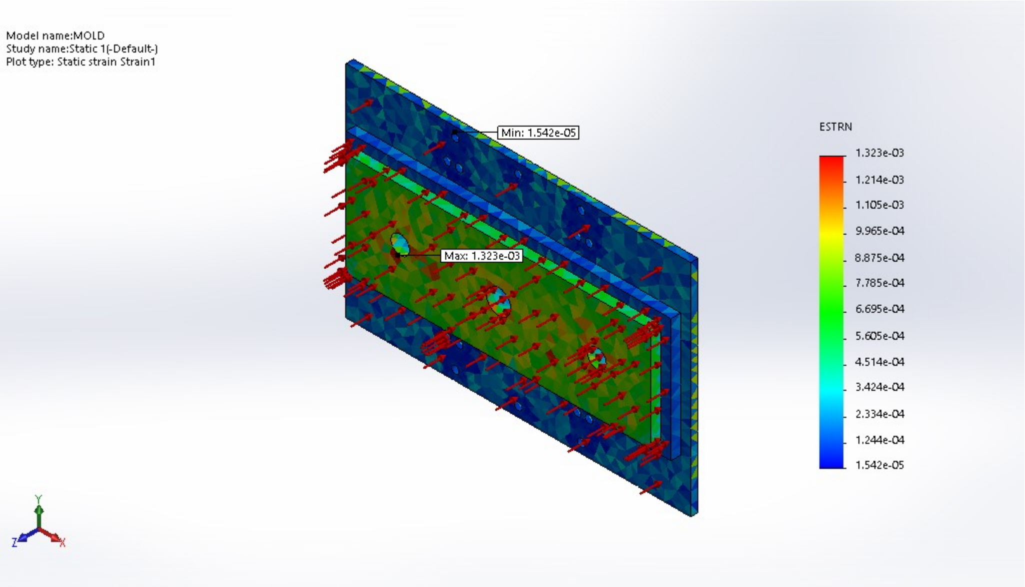


FIGURE V.5: Strain Plot of the Upper Mold

We notice from the plot a minimum strain of 1.542e-05 and a maximum strain of 1.323e-03.

V.3.1.7 Factor of Safety

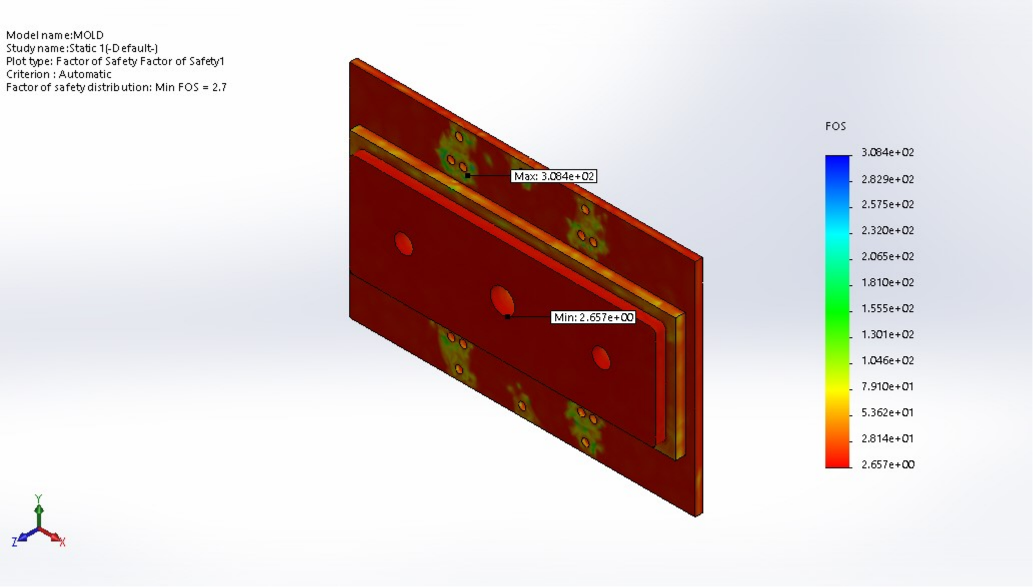


FIGURE V.6: Strain Plot of the Upper Mold

As shown in the picture above, the minimum FoS is 2.65.

Conclusion

The static simulation of the upper mold in the RTM machine yielded insightful results. The yield strength of the material was found to be superior to the maximum stress observed, indicating that the upper mold can withstand the applied load without exceeding its material's limit. The Factor of Safety (FoS) was calculated to be above the minimum requirement of 2.65, suggesting an adequate safety margin. Additionally, the displacement values indicated minor deformations at specific nodes, while the strain values remained within an acceptable range. These findings indicate that the upper mold's structural performance meets the desired criteria and can safely withstand the applied loads during the RTM process.

V.3.2 Lower Mold

By applying a solid mesh of a Total number of Nodes of 15439, Total number of Elements of 8238, and a Maximum Aspect Ratio of 5.9468, we find:

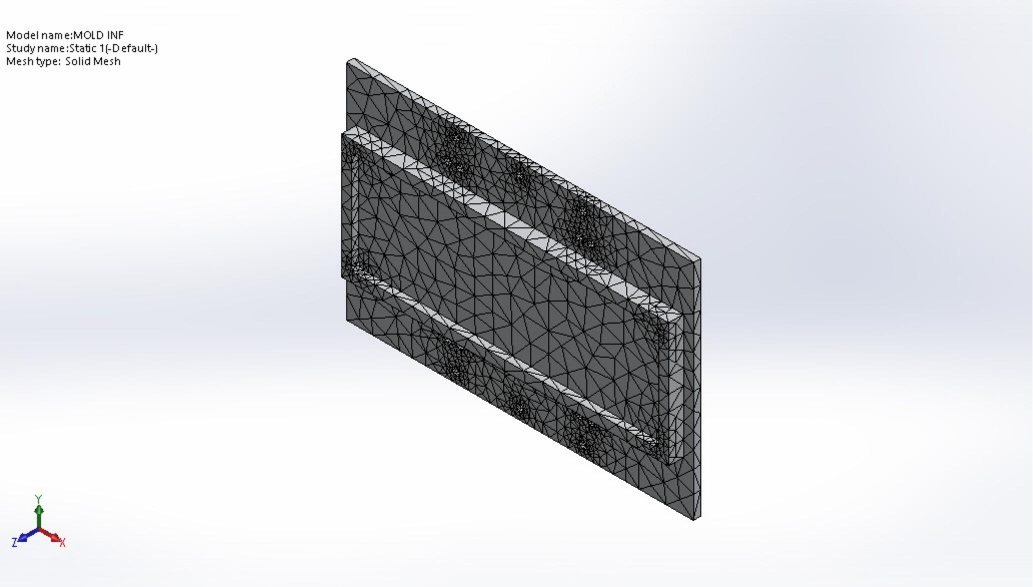


FIGURE V.7: Discretization of the lower Mold

The mold is fixated on the other side where it is in contact with the rest of the structures. We apply on the upper face the reaction of the pressure applied by the pressure multiplier, it will have the same intensity (100 bars) but in the opposite sens.

V.3.2.1 Volumetric Properties

Property	**Value**	**Unit**
Mass	27.8972	kg
Volume	1.03e-2	m^3
Density	2700	kg/m^3

TABLE V.4: Volumetric Properties of the Upper Mold

V.3.2.2 Material Properties

Same material as the Upper mold.

V.3.2.3 Reaction Force of the load

Sum Z
3.12527e+06 N

TABLE V.5: Reaction Force of the load

V.3.2.4 Stress Plot

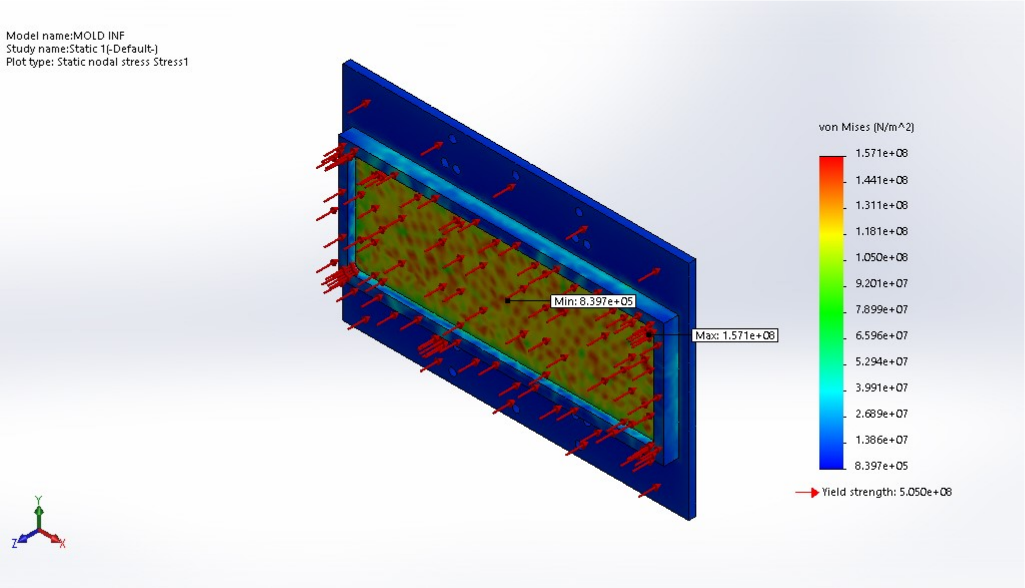


FIGURE V.8: Stress Plot of the Lower Mold

From the plot, we notice a minimum stress of 0.839 MPa, and a maximum of 157.1 MPa.

V.3.2.5 Displacement Plot

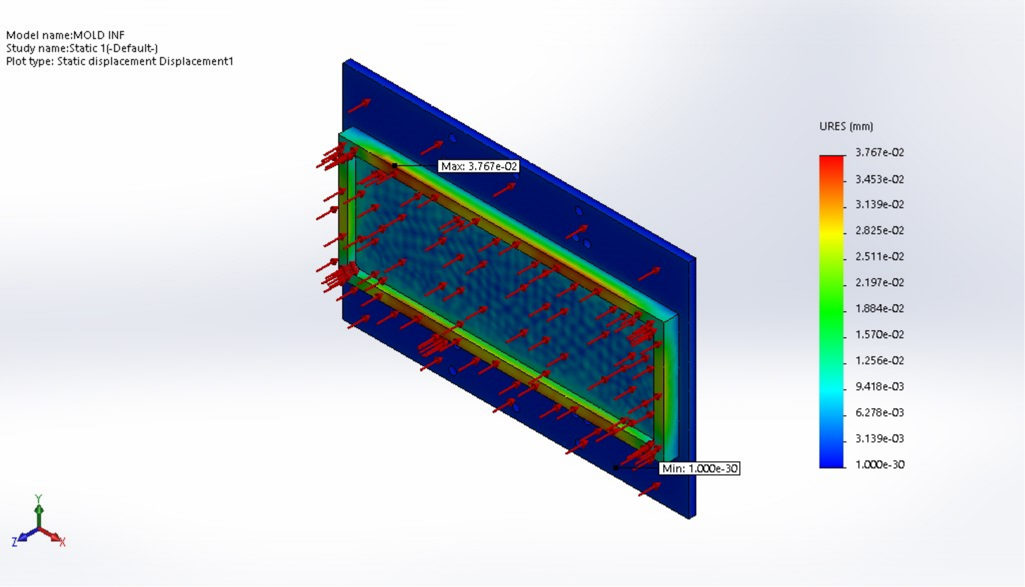


FIGURE V.9: Displacement Plot of the Lower Mold

From the plot, we notice that the minimal displacement is of 0 mm , and a maximum displacement of 0.038 mm.

V.3.2.6 Strain Plot

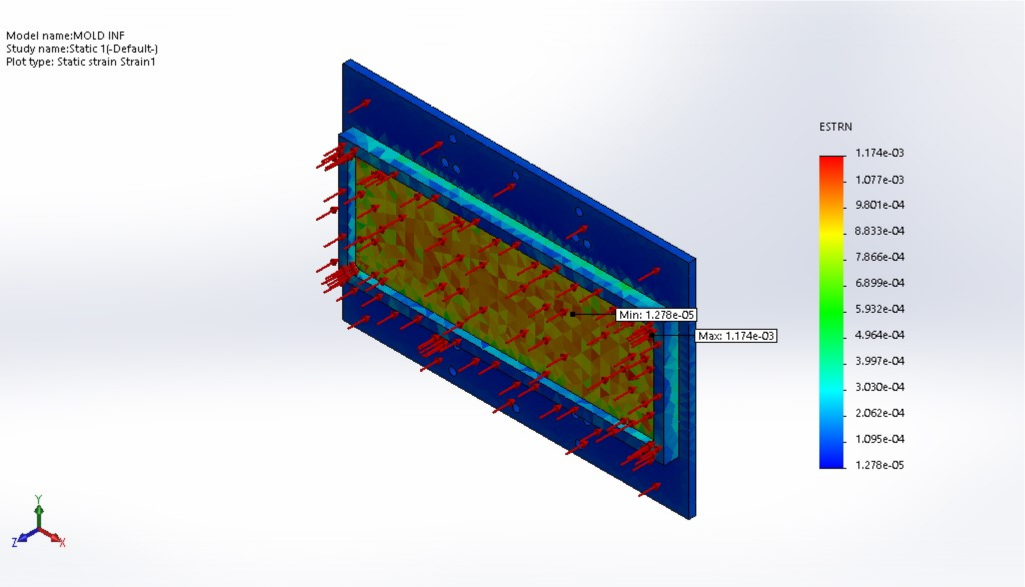


FIGURE V.10: Strain Plot of the Lower Mold

We notice from the plot a minimum strain of 1.278 e-05 and a maximum strain of 1.174 e-03.

V.3.2.7 Factor of Safety

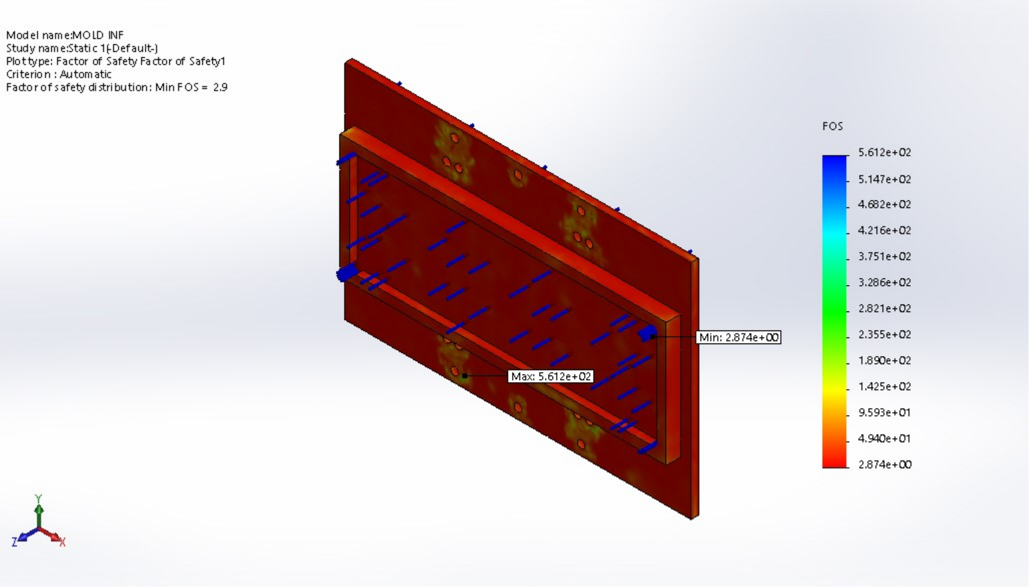


FIGURE V.11: Strain Plot of the Lower Mold

As shown in the picture above, the minimum FoS is 2.87.

Conclusion

From the static simulation of the lower mold in the RTM machine : The yield strength of the material was found to be superior to the maximum stress observed, indicating that the lower mold can withstand the applied load without exceeding its material's limit. The Factor of Safety (FoS) was calculated to be above the minimum requirement of 2.87, suggesting an adequate safety margin. Additionally, the displacement values indicated minor deformations at specific nodes, while the strain values remained within an acceptable range. These findings indicate that the lower mold's structural performance meets the desired criteria and can safely withstand the applied loads during the RTM process.

V.3.3 Aluminium Plate

By applying a solid mesh of a Total number of Nodes of 872440, Total number of Elements of 607940, and a Maximum Aspect Ratio of 9.0339, we find:

FIGURE V.12: Discretization of the Aluminium Plate

Both aluminium plates are fixated on the other side where it is in contact with the rest of the structures opposite to the mold direction. They will result the same analysis. We apply on the upper face the pressure applied by the pressure multiplier (100 bars).

The simulation was done with the resistors being stuffed inside of the plates to have accurate results.

V.3.3.1 Volumetric Properties

Property	**Value**	**Unit**
Mass	42.2106	kg
Volume	1.56e-2	m^3
Density	2700	kg/m^3

TABLE V.6: Volumetric Properties of the Aluminium Plate

V.3.3.2 Material Properties

Property	**Value**	**Unit**
Yield strength	27.57	MPa
Tensile strength	68.94	MPa
Elastic modulus	69	GPa
Poisson’s ratio	0.33	

TABLE V.7: Material Properties of the Aluminium Plate

V.3.3.3 Reaction Force of the load

Sum Z
-3.99491e+06 N

TABLE V.8: Reaction Force of the load

V.3.3.4 Stress Plot

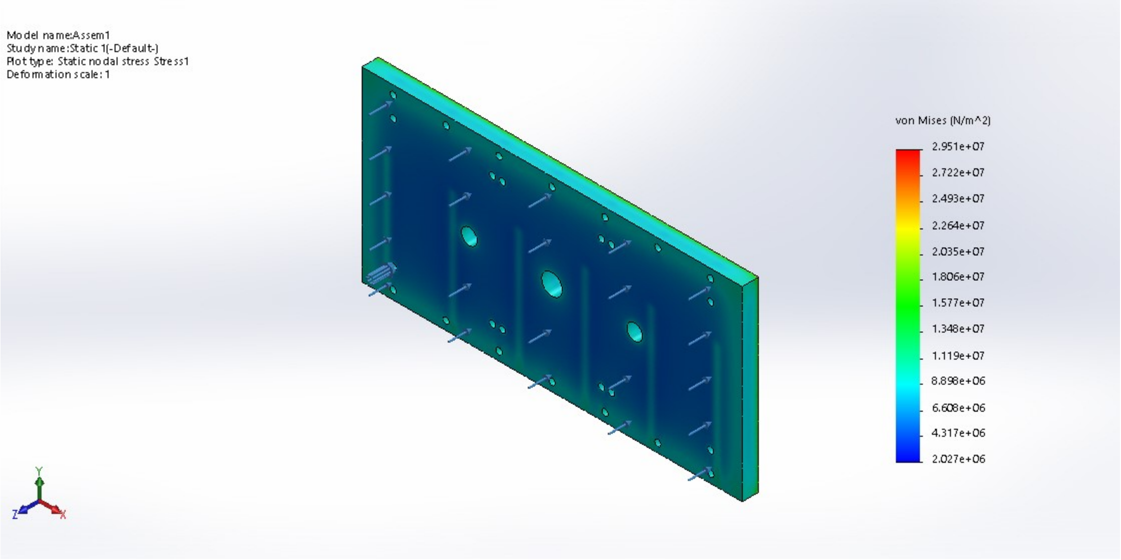


FIGURE V.13: Stress Plot of the Aluminium Plates

From the plot, we notice a minimum stress of 2.03 MPa, and a maximum of 29.51 MPa.

V.3.3.5 Displacement Plot

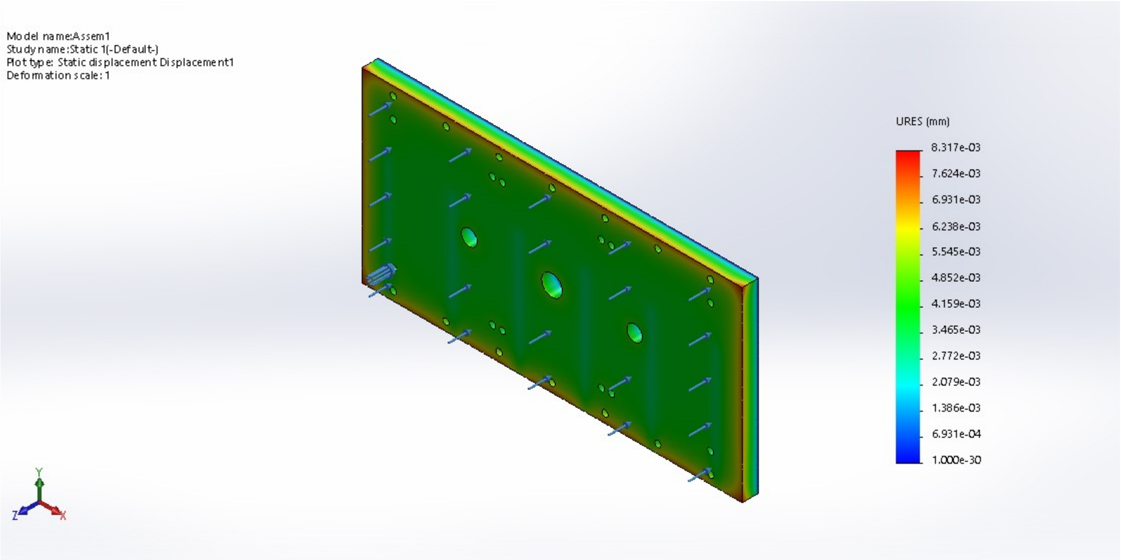


FIGURE V.14: Displacement Plot of Aluminium Plate

From the plot, we notice that the minimal displacement is of 0 mm, and a maximum displacement of 0.008 mm.

V.3.3.6 Strain Plot

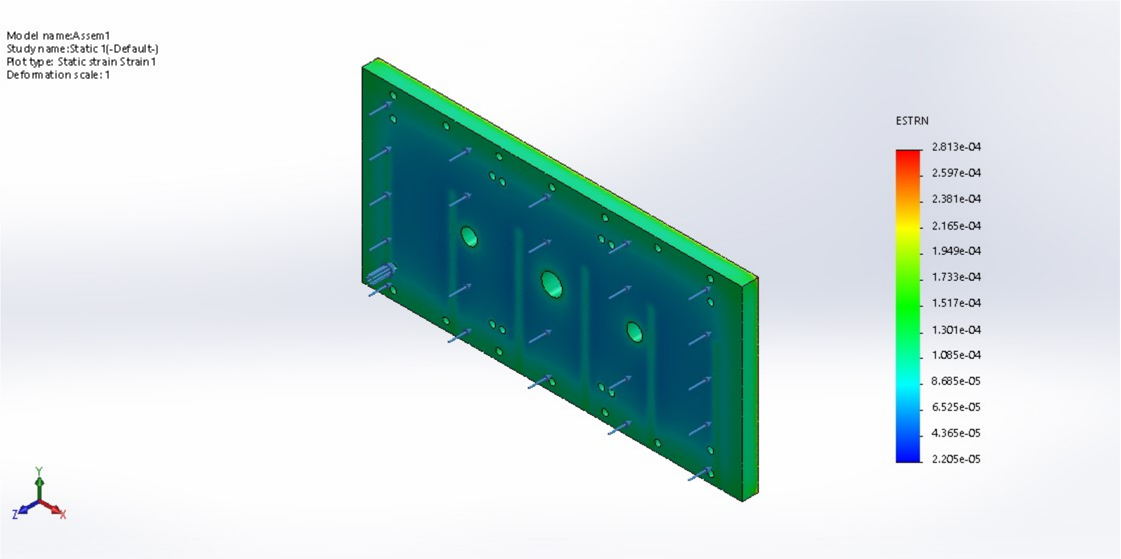


FIGURE V.15: Strain Plot of Aluminium Plates

We notice from the plot a minimum strain of 2.21e-05 and a maximum strain of 2.81e-04.

V.3.3.7 Factor of Safety

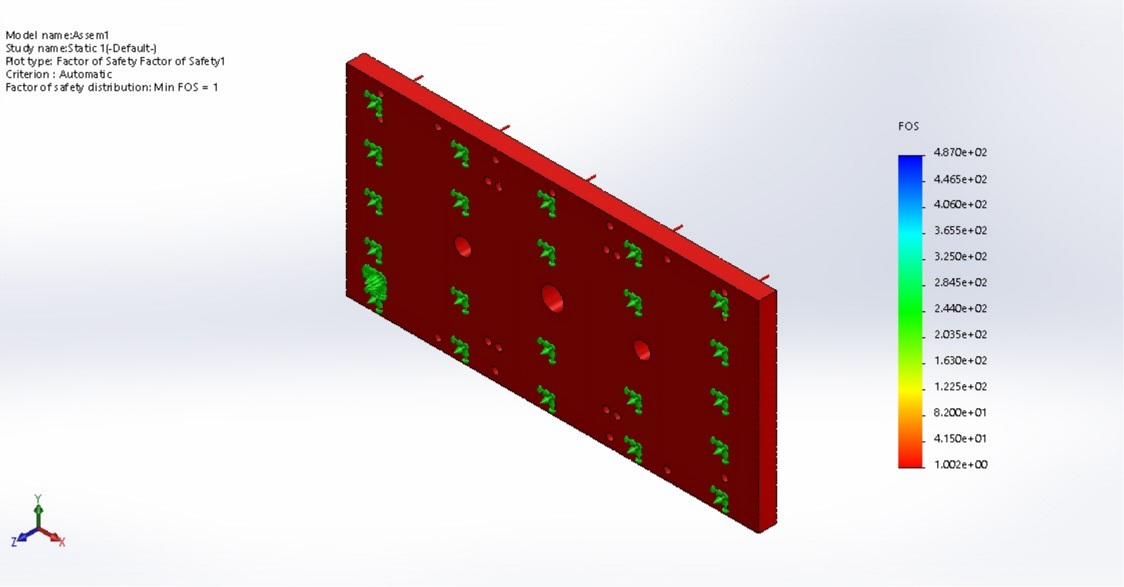


FIGURE V.16: Strain Plot of Aluminium Plates

As shown in the picture above, the minimum FoS is 1.002.

Conclusion

The static simulation of the aluminium plates: The yield strength of the material was found to be superior to the maximum stress observed, indicating that the plate can withstand the applied load without exceeding its material's limit. The Factor of Safety (FoS) was calculated to be above the minimum requirement of 1.002, which is dangerously close to the limit but is acceptable. Additionally, the displacement values indicated minor deformations at specific nodes, while the strain values remained within an acceptable range. These findings indicate that the aluminium plate's structural performance meets the desired criteria and can safely withstand the applied loads during the RTM process.

V.3.4 Insulation Plate

By applying a solid mesh of a Total number of Nodes of 24350, Total number of Elements of 13015, and a Maximum Aspect Ratio of 5.7677, we find:

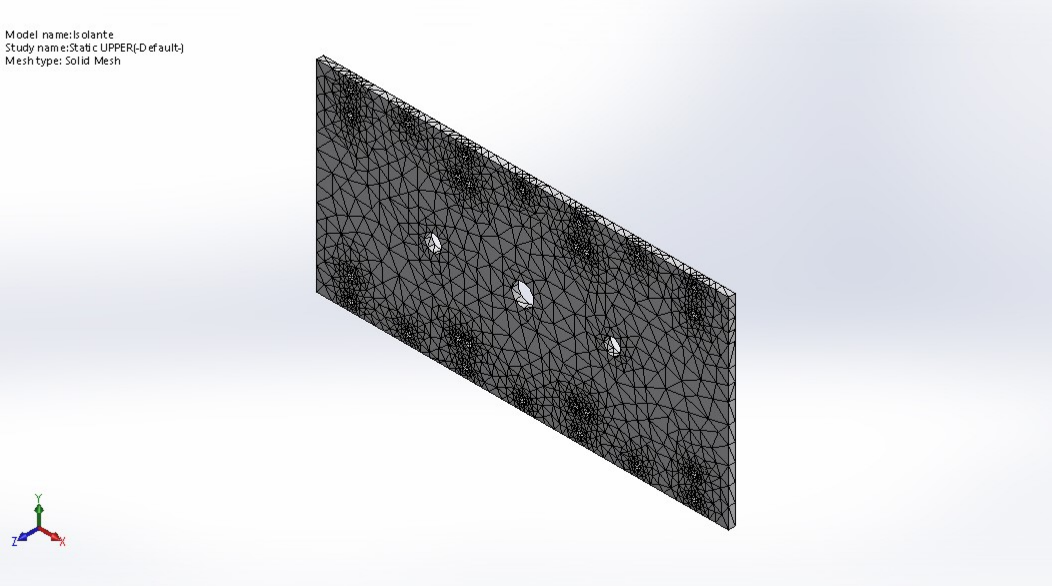


FIGURE V.17: Discretization of the Insulation Plate

Insulation Plate is fixated on the aluminium plate. The pressure is applied on the upper face by the pressure multiplier (100 bars).

Both the upper and lower configurations of the plate will give the same results.

V.3.4.1 Volumetric Properties

Property	Value	Unit
Mass	13.9785	kg
Volume	0.00607761	m^3
Density	2300	kg/m^3

TABLE V.9: Volumetric Properties of the Insulation Plate

V.3.4.2 Material Properties

Property	**Value**	**Unit**
Yield strength	172.34	MPa
Tensile strength	551.49	MPa
Elastic modulus	220.59	GPa
Poisson's ratio	0.22	

TABLE V.10: Material Properties of the Insulation Plate

V.3.4.3 Reaction Force of the load

SUM Z
-4.0518e+06 N

TABLE V.11: Reaction Force of the load

V.3.4.4 Stress Plot

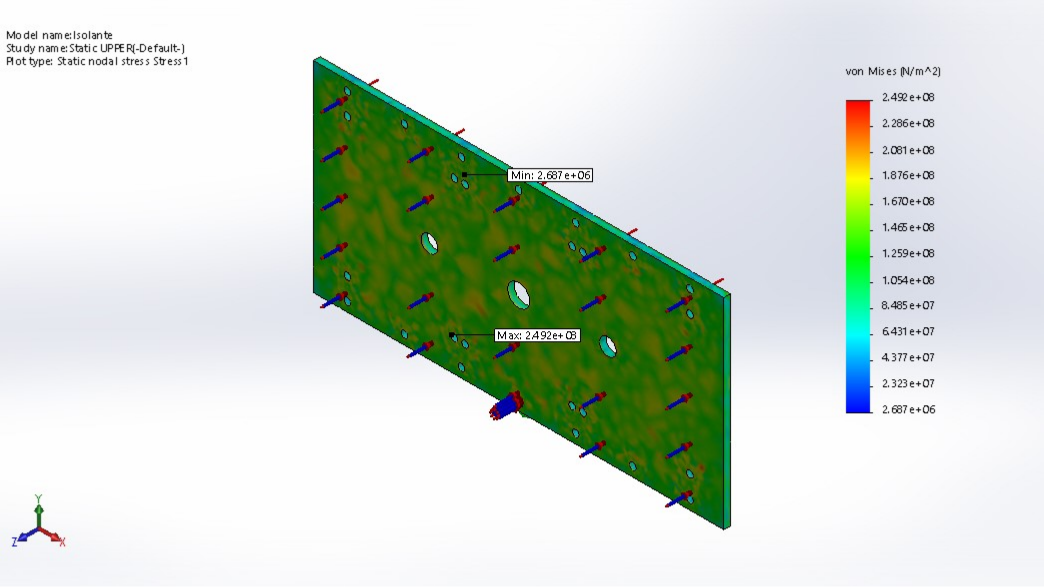


FIGURE V.18: Stress Plot of the Insulation Plates

From the plot, we notice a minimum stress of 2.69 MPa, and a maximum of 249.2 MPa.

V.3.4.5 Displacement Plot

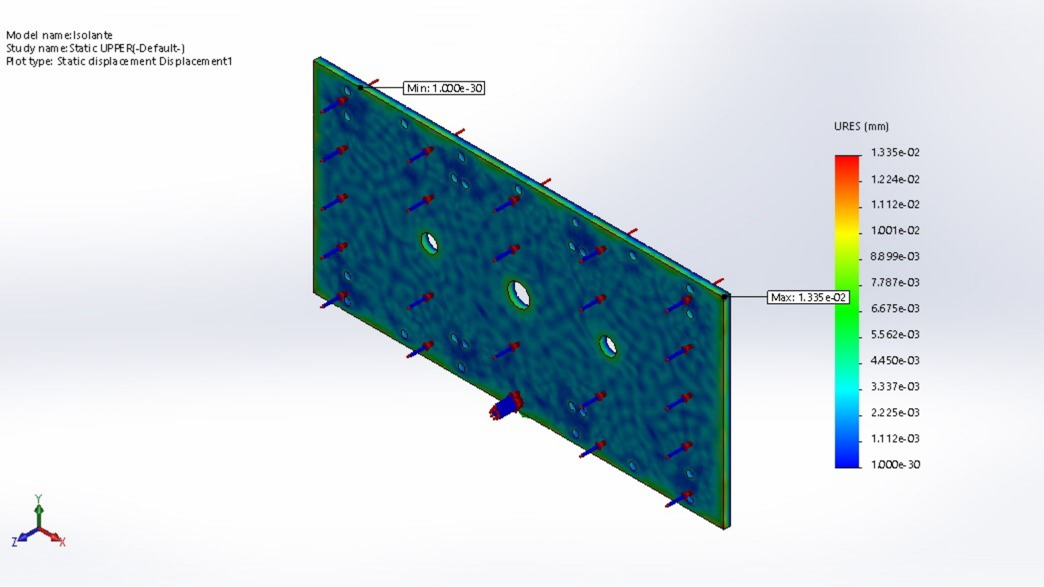


FIGURE V.19: Displacement Plot of Insulation Plate

From the plot, we notice that the minimal displacement is of 0 mm, and a maximum displacement of 0.013 mm.

V.3.4.6 Strain Plot

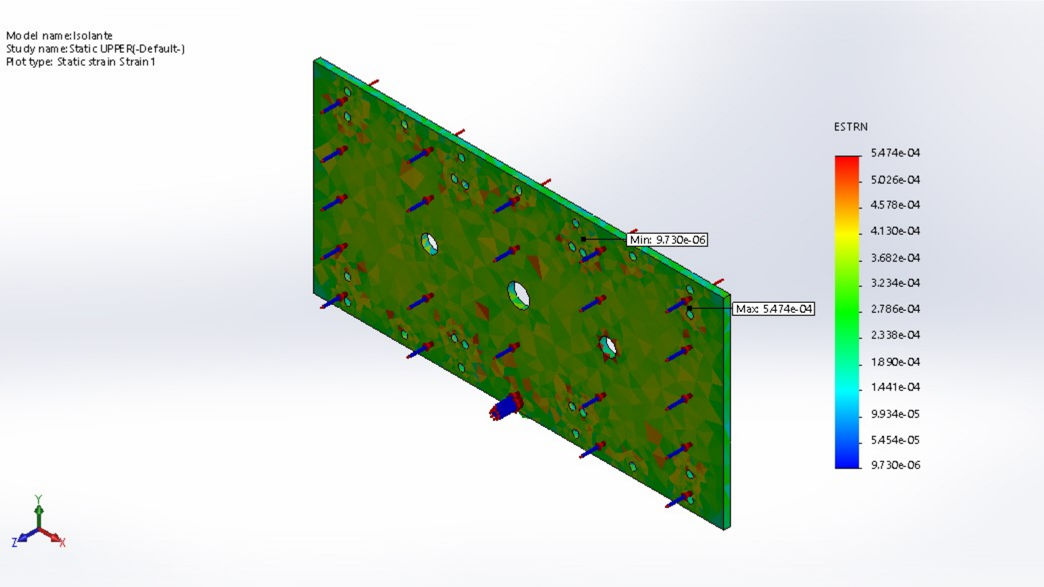


FIGURE V.20: Strain Plot of Insulation Plates

We notice from the plot a minimum strain of 9.73e-06 and a maximum strain of 5.47e-04.

V.3.4.7 Factor of Safety

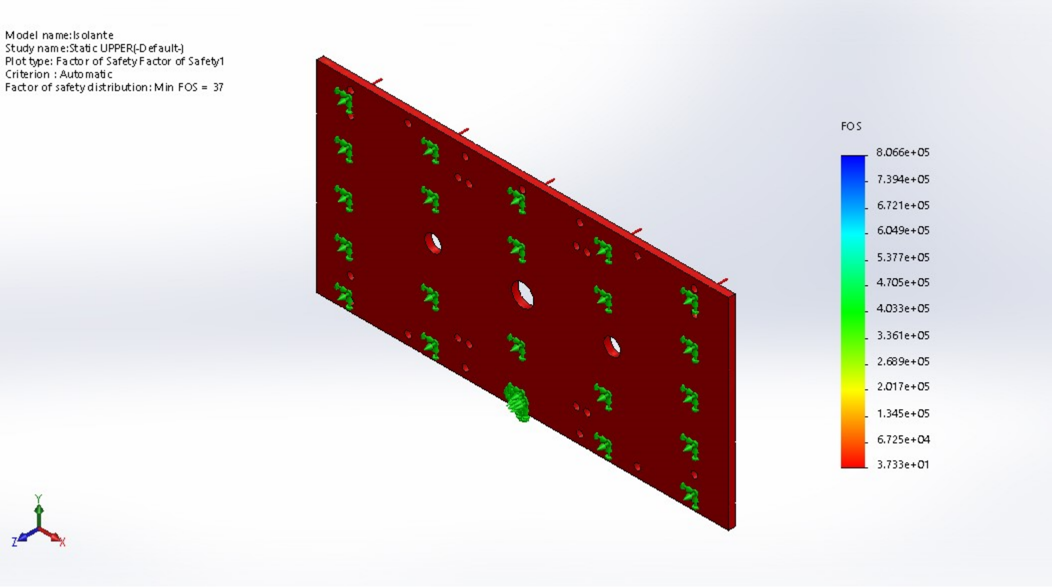


FIGURE V.21: Strain Plot of Insulation Plates

As shown in the picture above, the minimum FoS is 37.

Conclusion

The static simulation of the insulation plates: The yield strength of the material was found to be much superior to the maximum stress observed, indicating that the plate can withstand the applied load without exceeding its material's limit. The Factor of Safety (FoS) was calculated to be above the minimum requirement of 37, which is way too safe. Additionally, the displacement values indicated minor deformations at specific nodes, while the strain values remained within an acceptable range. These findings indicate that the insulation plate's structural performance meets the desired criteria and can safely withstand the applied loads during the RTM process.

V.3.5 Lower Frame

By applying a solid mesh of a Total number of Nodes of 15584, Total number of Elements of 9111, and a Maximum Aspect Ratio of 92.75, we find:

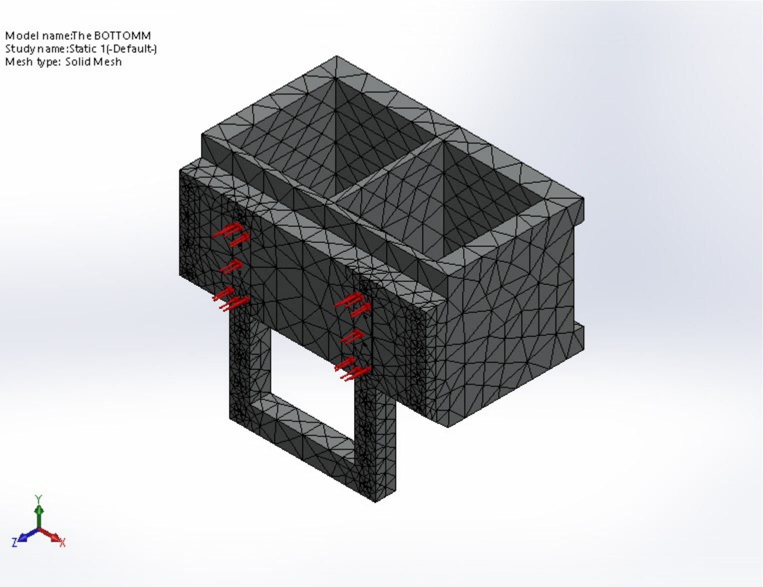


FIGURE V.22: Discretization of the Lower Frame

The Lower Frame is fixated on the floor. The pressure is applied on its upper face by the pressure multiplier (100 bars).

V.3.5.1 Volumetric Properties

Property	**Value**	**Unit**
Mass	1772.06	kg
Volume	0.23	m^3
Density	7800	kg/m^3

TABLE V.12: Volumetric Properties of the Lower Frame

V.3.5.2 Material Properties

Property	Value	Unit
Yield strength	235	MPa
Tensile strength	360	MPa
Elastic modulus	210	GPa
Poisson's ratio	0.28	

TABLE V.13: Material Properties of the Lower Frame

V.3.5.3 Reaction Force of the load

Sum Z
94003 N

TABLE V.14: Reaction Force of the load

V.3.5.4 Stress Plot

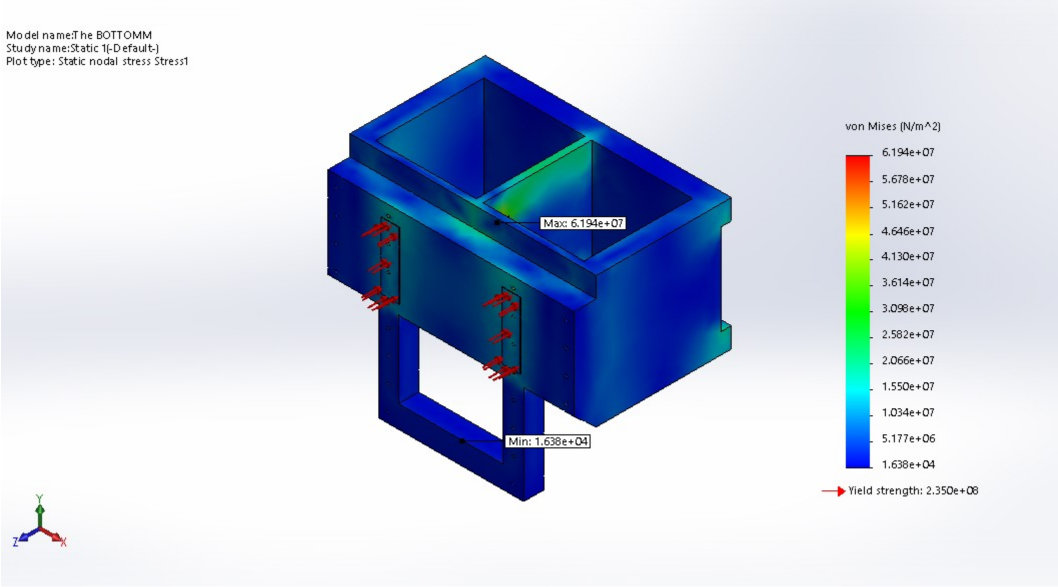


FIGURE V.23: Stress Plot of the Lower Frame

From the plot, we notice a minimum stress of 0.016 MPa, and a maximum of 61.94 MPa.

V.3.5.5 Displacement Plot

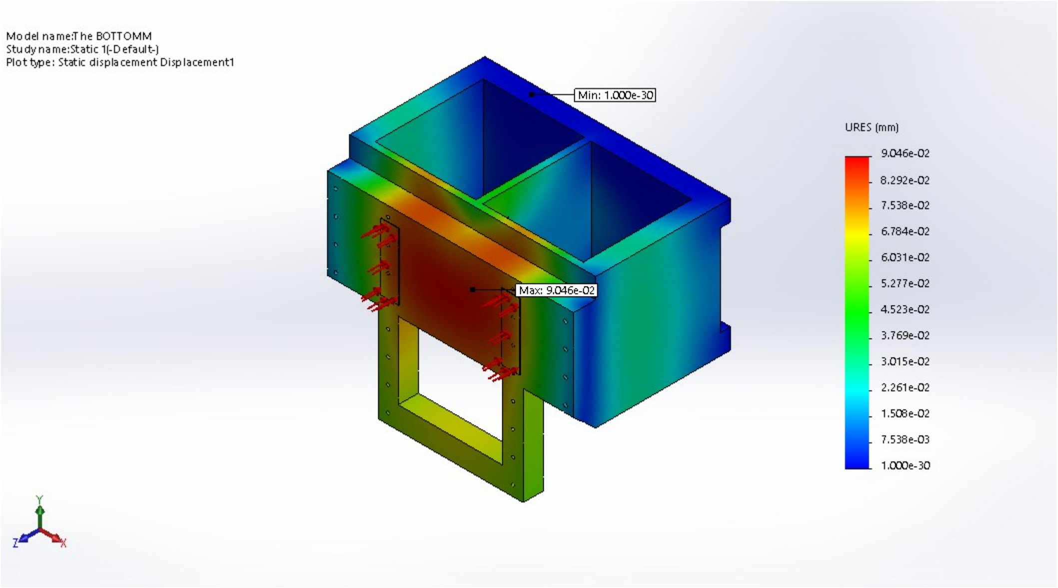


FIGURE V.24: Displacement Plot of Lower Frame

From the plot, we notice that the minimal displacement is of 0 mm, and a maximum displacement of 0.0904 mm.

V.3.5.6 Strain Plot

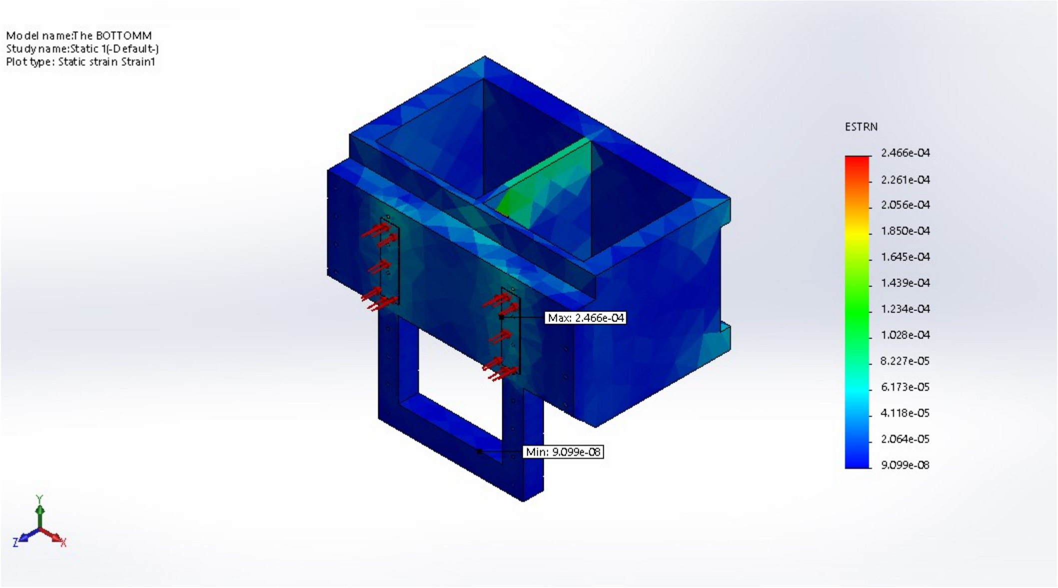


FIGURE V.25: Strain Plot of Lower Frame

We notice from the plot a minimum strain of 9.099e-08 and a maximum strain of 2.466e-04.

V.3.5.7 Factor of Safety

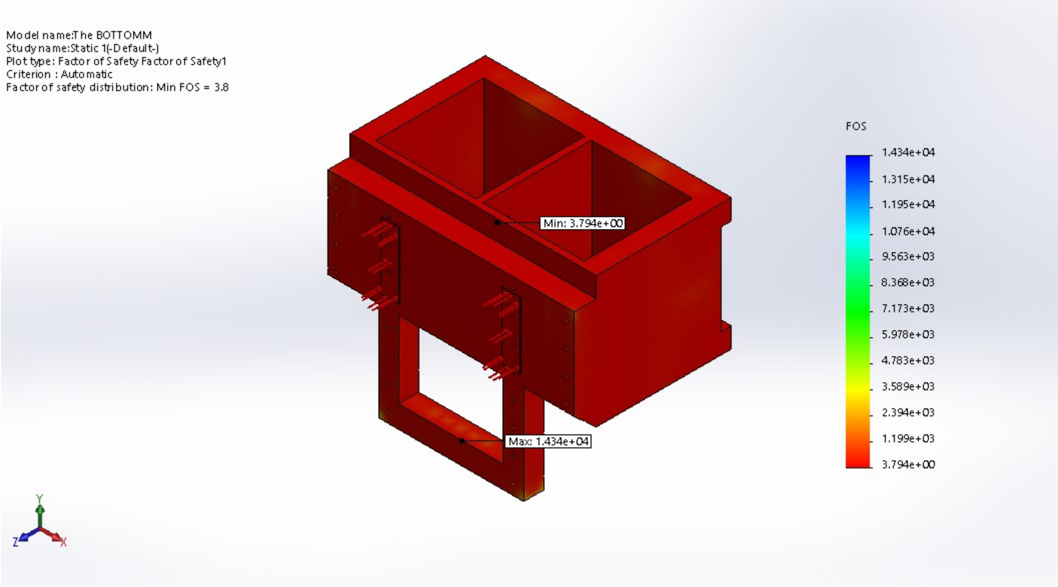


FIGURE V.26: Strain Plot of Lower Frame

As shown in the picture above, the minimum FoS is 3.7.

Conclusion

The static simulation of the lower frame: The yield strength of the material was found to be superior to the maximum stress observed, indicating that the plate can withstand the applied load without exceeding its material's limit. The Factor of Safety (FoS) was calculated to be above the minimum requirement of 3.7, which is safe. Additionally, the displacement values indicated minor deformations at specific nodes, while the strain values remained within an acceptable range. These findings indicate that the frame's structural performance meets the desired criteria and can safely withstand the applied loads during the RTM process.

V.3.6 Top Support

By applying a solid mesh of a Total number of Nodes of 21993, Total number of Elements of 12064, and a Maximum Aspect Ratio of 199.75, we find:

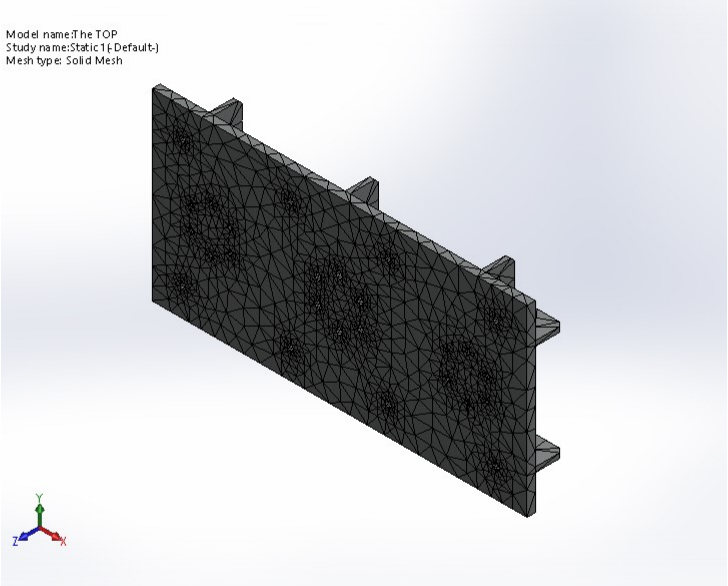


FIGURE V.27: Discretization of the Top Support

The Top support is fixated on the top frame. The pressure is applied on its upper face by the pressure multiplier (100 bars).

V.3.6.1 Volumetric Properties

Property	**Value**	**Unit**
Mass	83.73	kg
Volume	0.011	m^3
Density	7800	kg/m^3

TABLE V.15: Volumetric Properties of the Top Support

V.3.6.2 Material Properties

Property	Value	Unit
Yield strength	235	MPa
Tensile strength	360	MPa
Elastic modulus	210	GPa
Poisson’s ratio	0.28	

TABLE V.16: Material Properties of the Top Support

V.3.6.3 Reaction Force of the load

Sum Z
-77189.5 N

TABLE V.17: Reaction Force of the load

V.3.6.4 Stress Plot

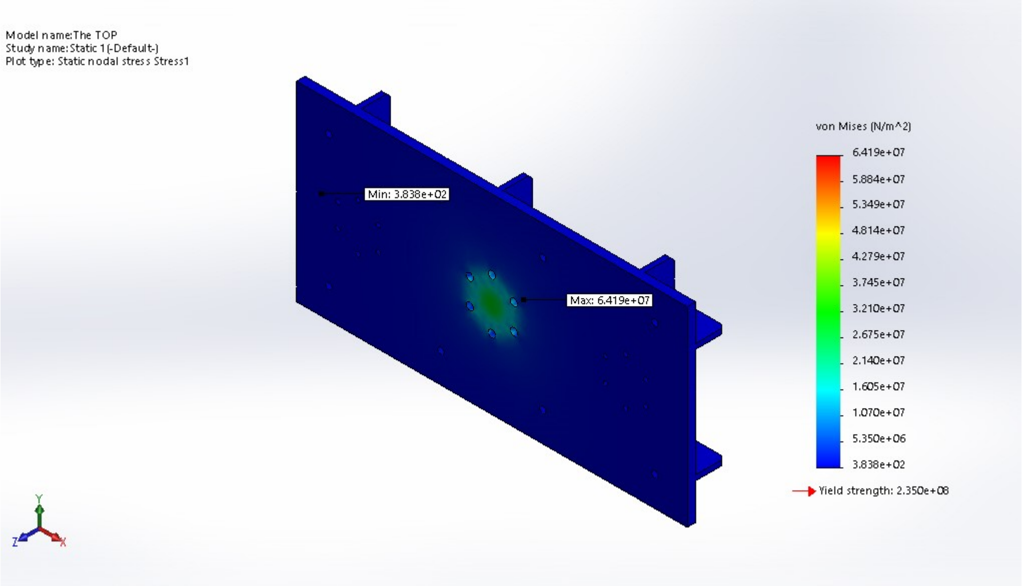


FIGURE V.28: Stress Plot of the Top Support

From the plot, we notice a minimum stress of 3.83e-04 MPa, and a maximum of 64.19 MPa.

V.3.6.5 Displacement Plot

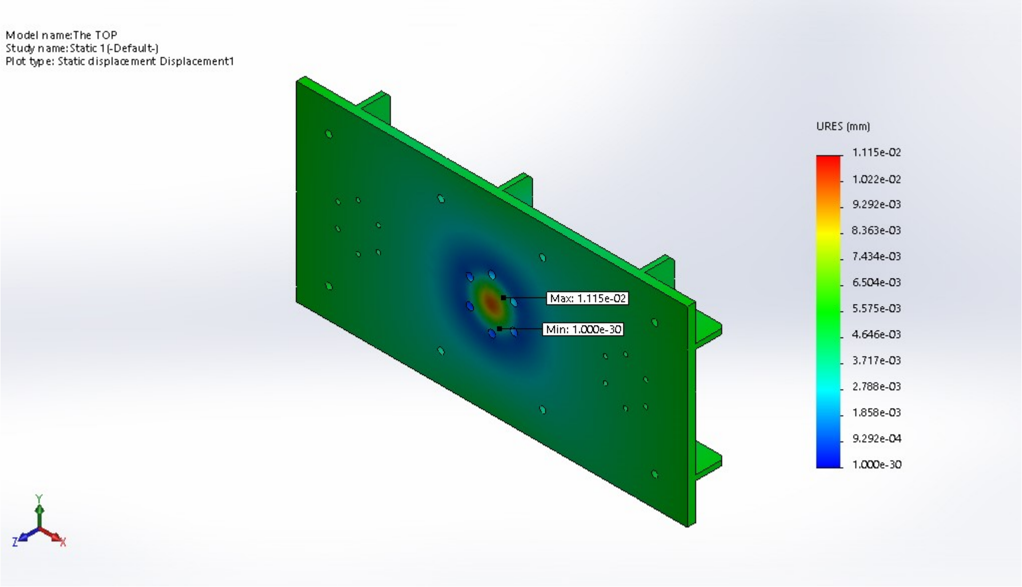


FIGURE V.29: Displacement Plot of Top Support

From the plot, we notice that the minimal displacement is of 0 mm, and a maximum displacement of 0.0115 mm.

V.3.6.6 Strain Plot

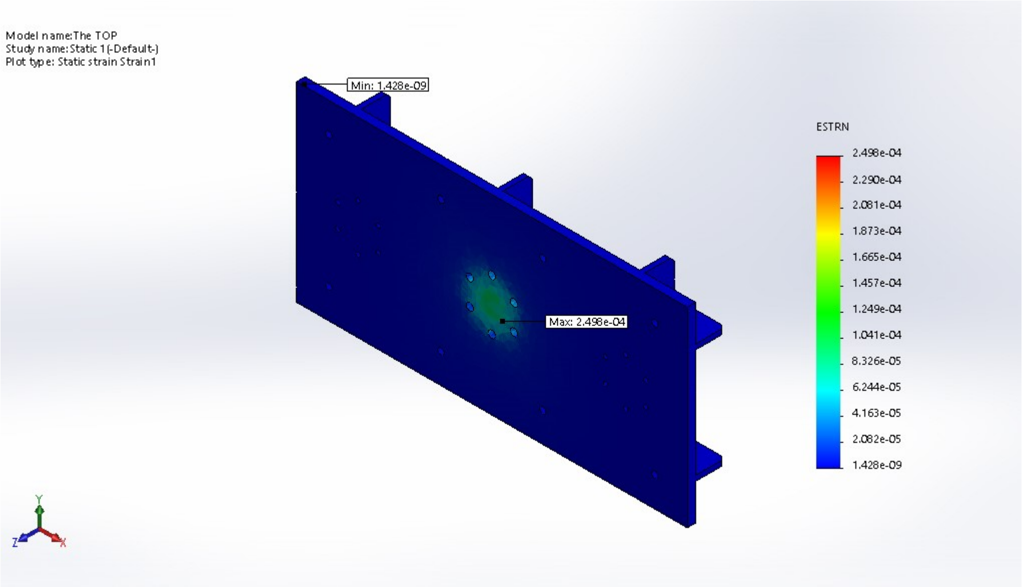


FIGURE V.30: Strain Plot of Top Support

We notice from the plot a minimum strain of 1.428e-09 and a maximum strain of 2.498e-04.

V.3.6.7 Factor of Safety

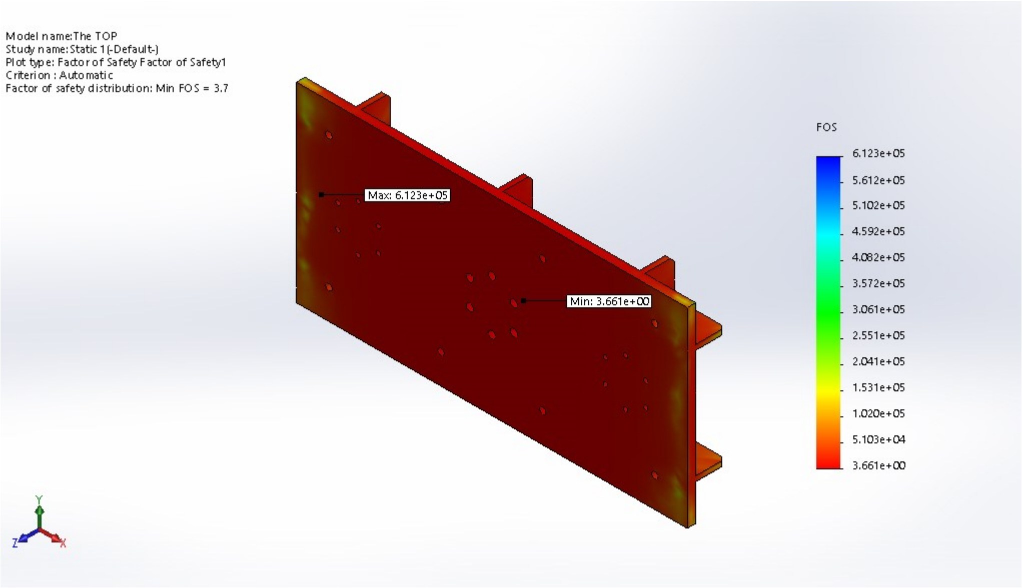


FIGURE V.31: Strain Plot of Top Support

As shown in the picture above, the minimum FoS is 3.6.

Conclusion

The static simulation of the Top Support: The yield strength of the material was found to be superior to the maximum stress observed, indicating that the plate can withstand the applied load without exceeding its material's limit. The Factor of Safety (FoS) was calculated to be above the minimum requirement of 3.6, which is safe. Additionally, the displacement values indicated minor deformations at specific nodes, while the strain values remained within an acceptable range. These findings indicate that the support's structural performance meets the desired criteria and can safely withstand the applied loads during the RTM process.

V.3.7 Support Plate

By applying a solid mesh of a Total number of Nodes of 26371, Total number of Elements of 14726, and a Maximum Aspect Ratio of 5.5556, we find:

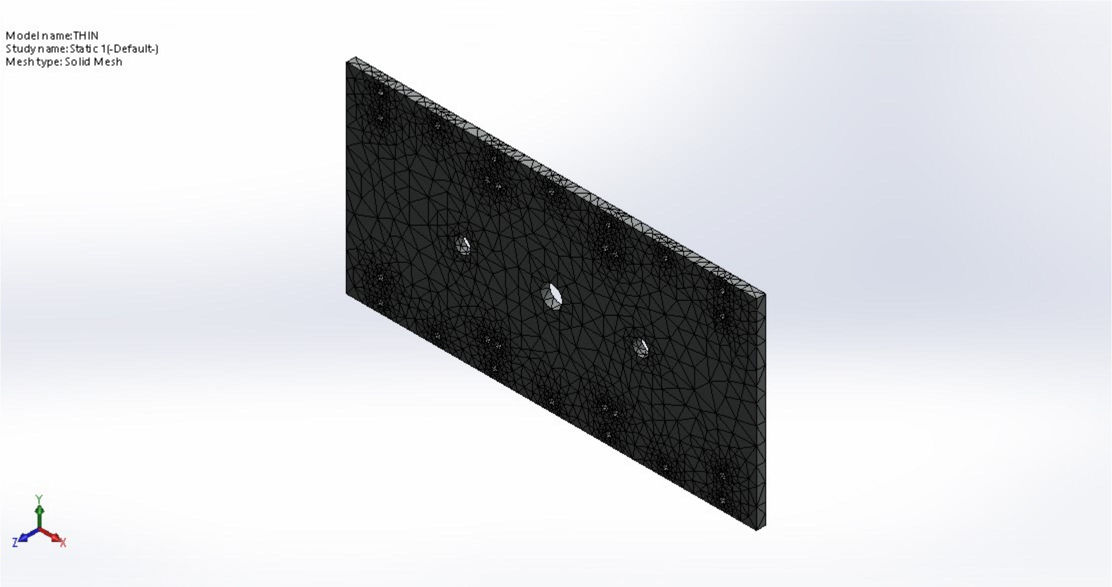


FIGURE V.32: Discretization of the Support Plate

The Support Plate is fixated by bolts with the top Support. The pressure is applied on its upper face by the pressure multiplier (100 bars).

V.3.7.1 Volumetric Properties

Property	Value	Unit
Mass	63.2071	kg
Volume	0.00810347	m^3
Density	7800	kg/m^3

TABLE V.18: Volumetric Properties of the Support plate

V.3.7.2 Material Properties

Property	**Value**	**Unit**
Yield strength	235	MPa
Tensile strength	360	MPa
Elastic modulus	210	GPa
Poisson’s ratio	0.28	

TABLE V.19: Material Properties of the Support plate

V.3.7.3 Reaction Force of the load

Sum Z
-4.05178e+06 N

TABLE V.20: Reaction Force of the load

V.3.7.4 Stress Plot

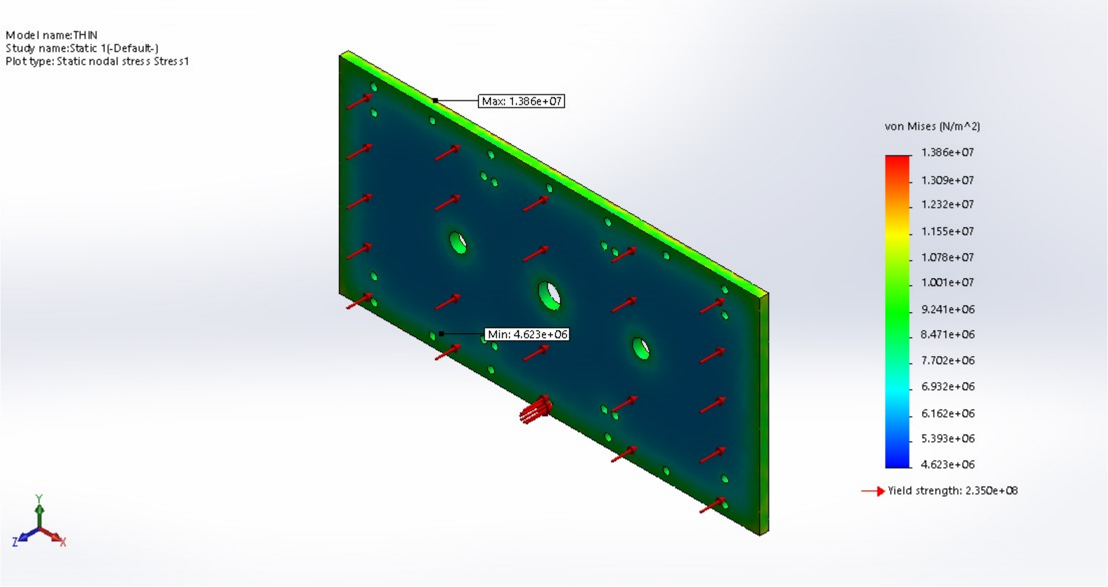


FIGURE V.33: Stress Plot of the Support Plate

From the plot, we notice a minimum stress of 4.62 MPa and a maximum of 13.86 MPa.

V.3.7.5 Displacement Plot

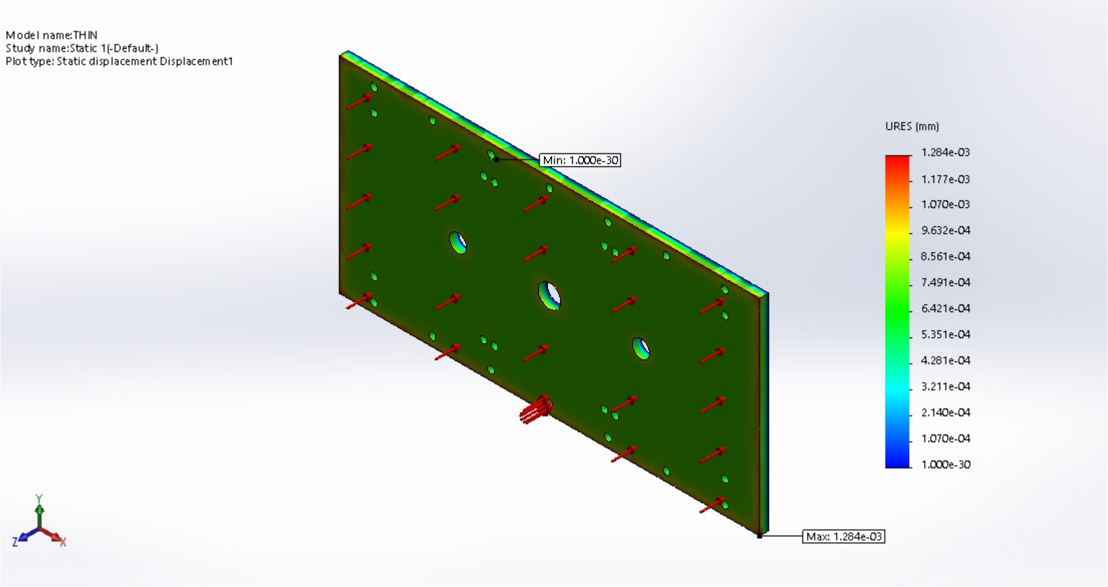


FIGURE V.34: Displacement Plot of Support Plate

From the plot, we notice that the minimal displacement is of 0 mm, and a maximum displacement of 1.28e-03 mm.

V.3.7.6 Strain Plot

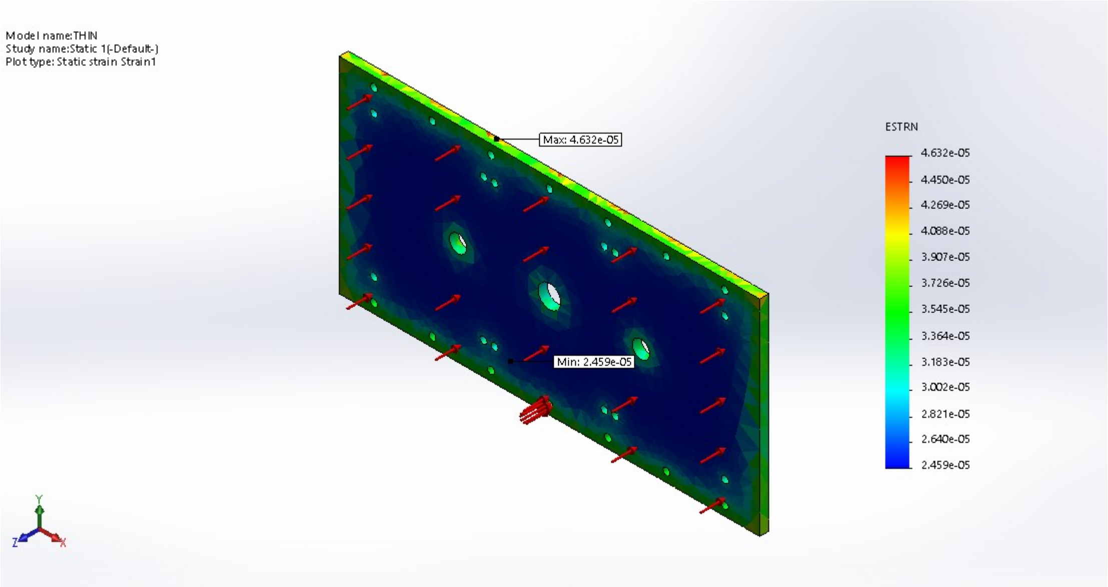


FIGURE V.35: Strain Plot of Support Plate

We notice from the plot a minimum strain of 2.46e-05 and a maximum strain of 4.63e-05.

V.3.7.7 Factor of Safety

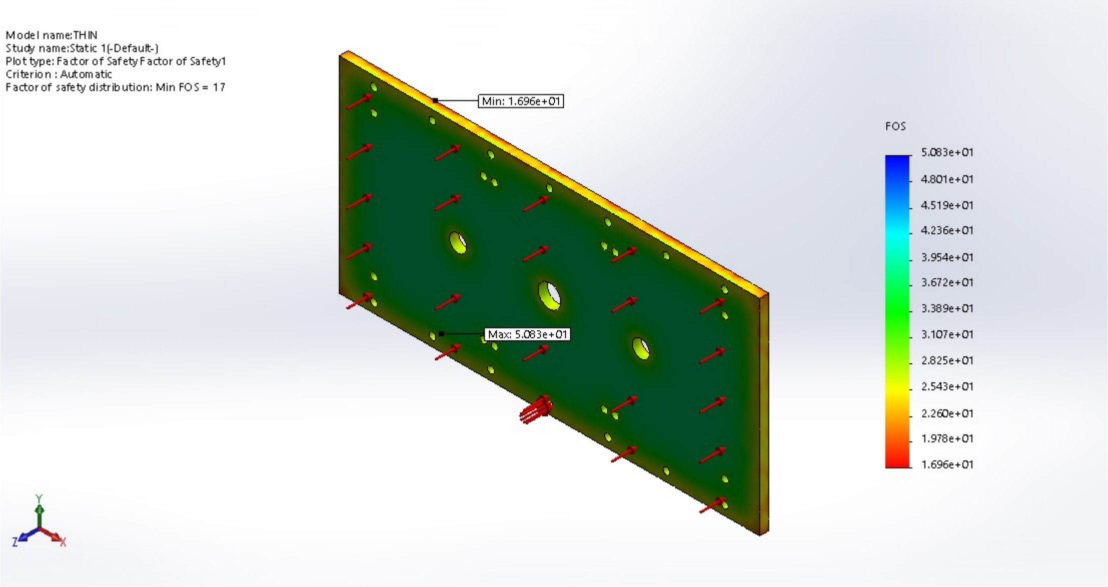


FIGURE V.36: FoS Plot of Support Plate

As shown in the picture above, the minimum FoS is 16.9.

Conclusion

The static simulation of the Support Plate: The yield strength of the material was found to be superior to the maximum stress observed, indicating that the plate can withstand the applied load without exceeding its material's limit. The Factor of Safety (FoS) was calculated to be above the minimum requirement of 16.9, which is very safe. Additionally, the displacement values indicated minor deformations at specific nodes, while the strain values remained within an acceptable range. These findings indicate that the support's structural performance meets the desired criteria and can safely withstand the applied loads during the RTM process.

V.3.8 Lower Support

By applying a solid mesh of a Total number of Nodes of 20506, Total number of Elements of 9781, and a Maximum Aspect Ratio of 5.1956, we find:

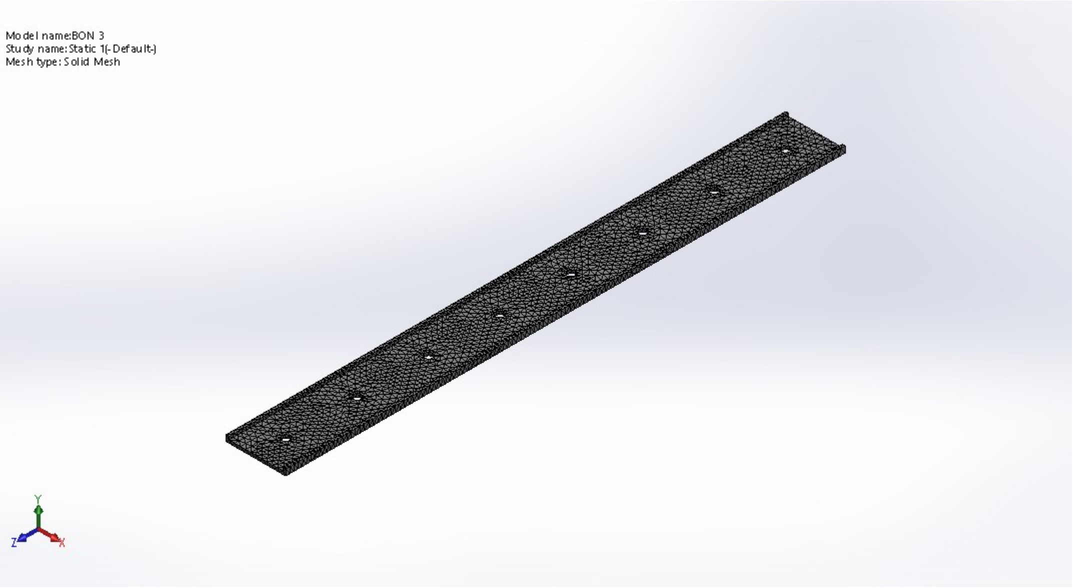


FIGURE V.37: Discretization of the Lower Support

The Lower support is fixated on the bottom frame. The pressure is applied on its upper face by the pressure multiplier (100 bars).

V.3.8.1 Volumetric Properties

Property	**Value**	**Unit**
Mass	3.98	kg
Volume	5.1e-4	m^3
Density	7800	kg/m^3

TABLE V.21: Volumetric Properties of the Lower Support

V.3.8.2 Material Properties

Property	Value	Unit
Yield strength	235	MPa
Tensile strength	360	MPa
Elastic modulus	210	GPa
Poisson’s ratio	0.28	

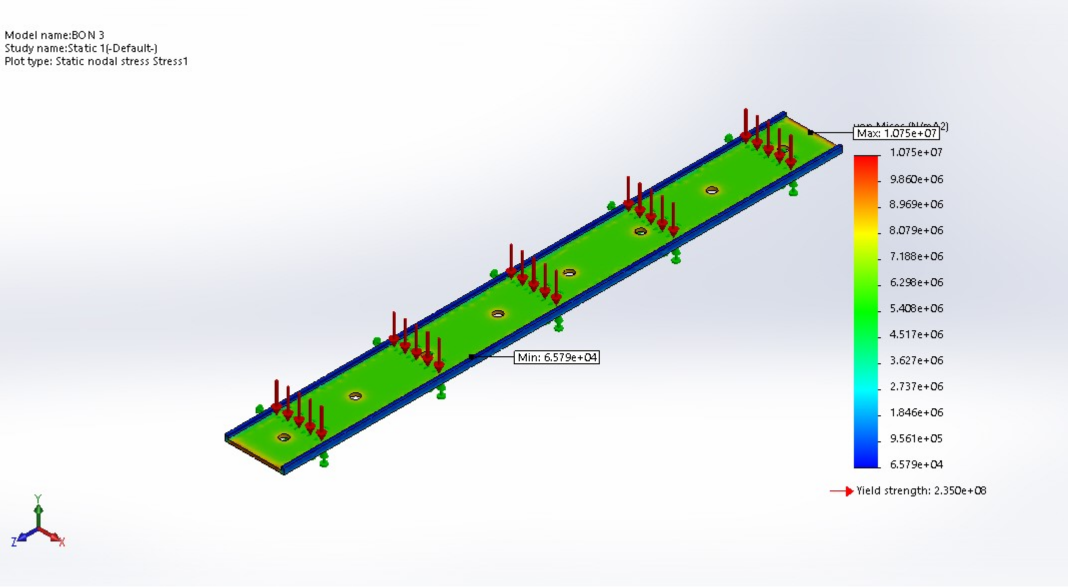
TABLE V.22: Material Properties of the Lower Support

V.3.8.3 Reaction Force of the load

Sum Z
833692 N

TABLE V.23: Reaction Force of the load

V.3.8.4 Stress Plot



Model name:BO N 3
Study name:Static 1(-Default-)
Plot type: Static nodal stress Stress1

FIGURE V.38: Stress Plot of the Lower Support

From the plot, we notice a minimum stress of 6.58e-2 MPa and a maximum of 10.75 MPa.

V.3.8.5 Displacement Plot

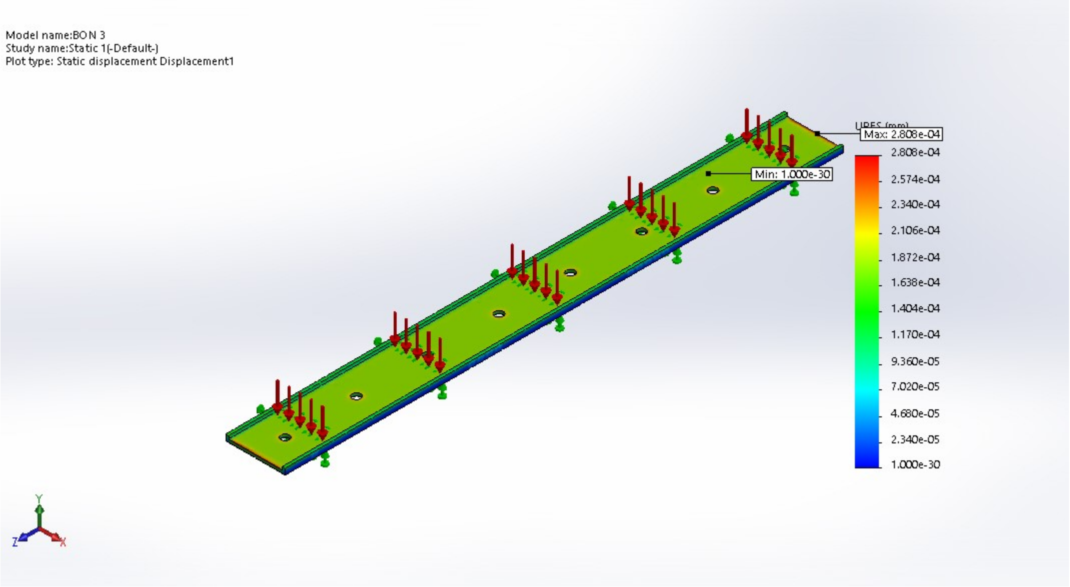


FIGURE V.39: Displacement Plot of Lower Support

From the plot, we notice that the minimal displacement is of 0 mm, and a maximum displacement of 2.808e-04 mm.

V.3.8.6 Strain Plot

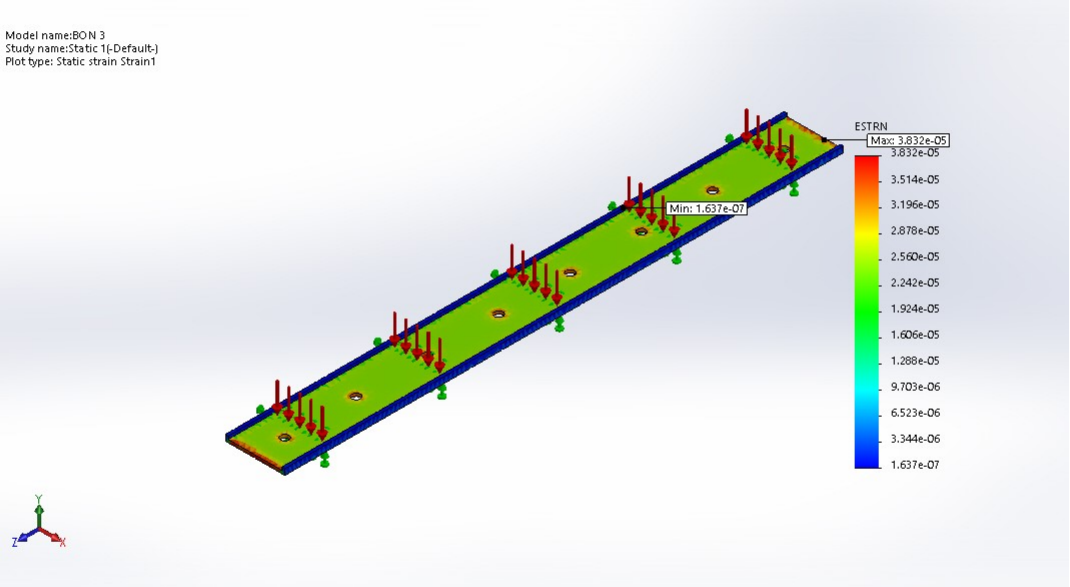


FIGURE V.40: Strain Plot of Lower Support

We notice from the plot a minimum strain of 1.637e-07 and a maximum strain of 3.832e-05.

V.3.8.7 Factor of Safety

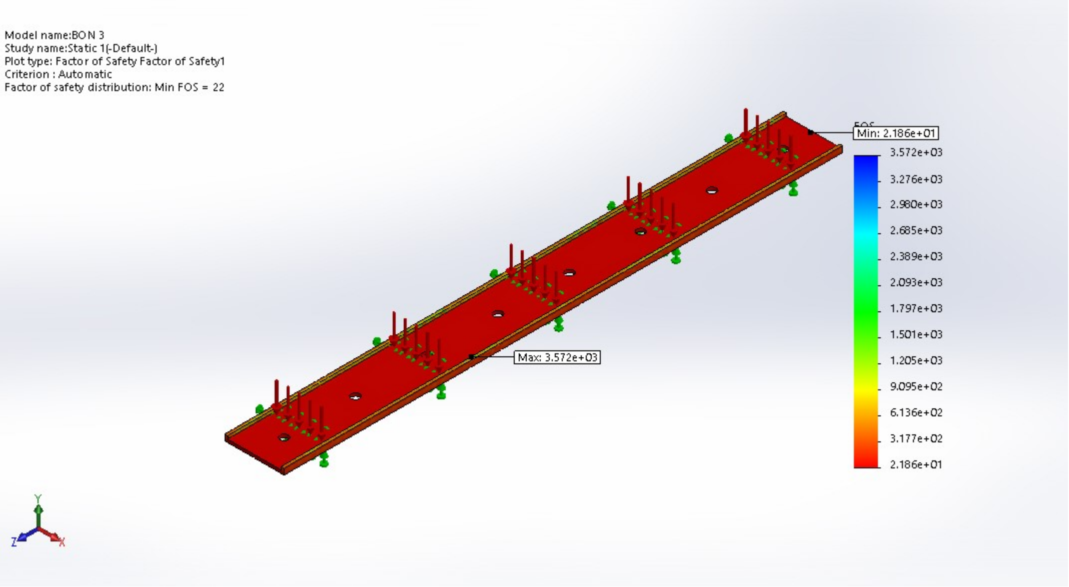


FIGURE V.41: Factor of Safety Plot of Lower Support

As shown in the picture above, the minimum FoS is 21.

Conclusion

The static simulation of the Lower Support: The yield strength of the material was found to be superior to the maximum stress observed, indicating that the support can withstand the applied load without exceeding its material's limit. The Factor of Safety (FoS) was calculated to be above the minimum requirement of 21, which is safe. Additionally, the displacement values indicated minor deformations at specific nodes, while the strain values remained within an acceptable range. These findings indicate that the support's structural performance meets the desired criteria and can safely withstand the applied loads during the RTM process.

V.3.9 Bottom Support

By applying a solid mesh of a Total number of Nodes of 29198, total number of Elements of 18417, and a Maximum Aspect Ratio of 8.1371, we find:

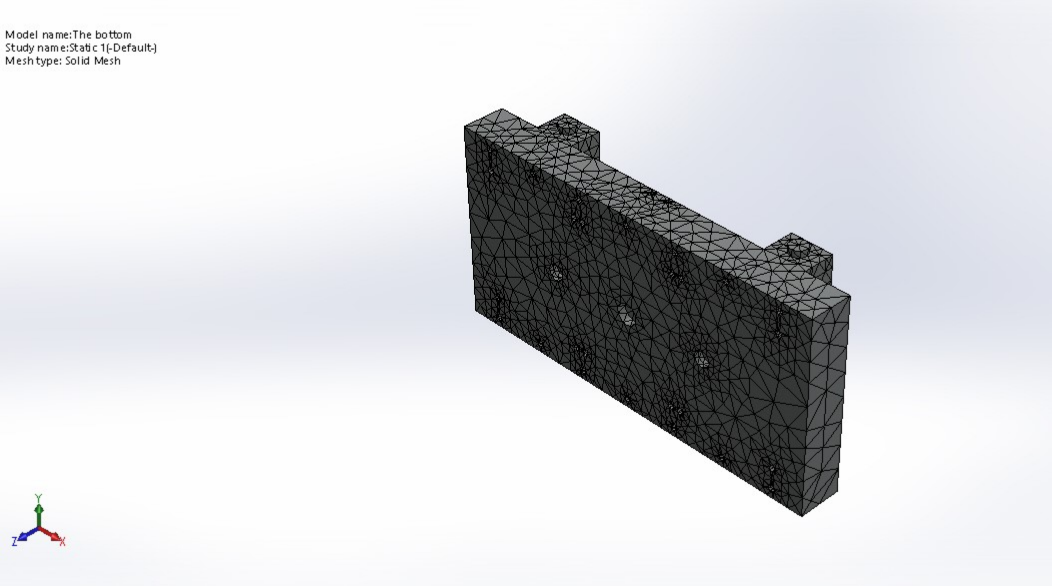


FIGURE V.42: Discretization of the Bottom Support

The bottom support is fixated on the the bottom frame. The pressure is applied on its upper face by the pressure multiplier (100 bars).

V.3.9.1 Volumetric Properties

Property	**Value**	**Unit**
Mass	374.18	kg
Volume	0.048	m^3
Density	7800	kg/m^3

TABLE V.24: Volumetric Properties of the Bottom Support

V.3.9.2 Material Properties

Property	Value	Unit
Yield strength	235	MPa
Tensile strength	360	MPa
Elastic modulus	210	GPa
Poisson’s ratio	0.28	

TABLE V.25: Material Properties of the Bottom Support

V.3.9.3 Reaction Force of the load

Sum Z
4.05183e+06 N

TABLE V.26: Reaction Force of the load

V.3.9.4 Stress Plot

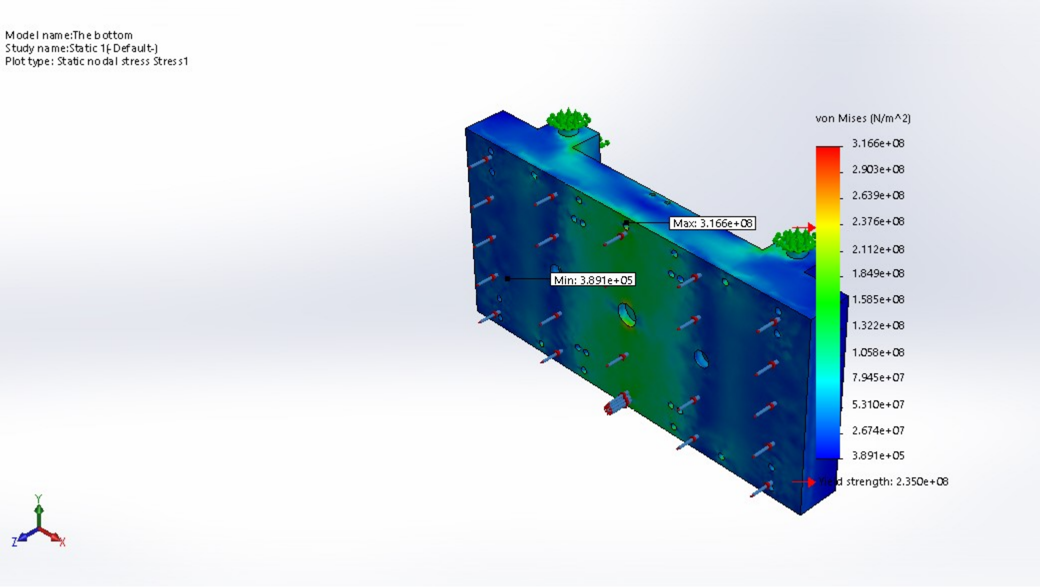


FIGURE V.43: Stress Plot of the Bottom Support

From the plot, we notice a minimum stress of 0.39 MPa and a maximum of 316.6 MPa.

V.3.9.5 Displacement Plot

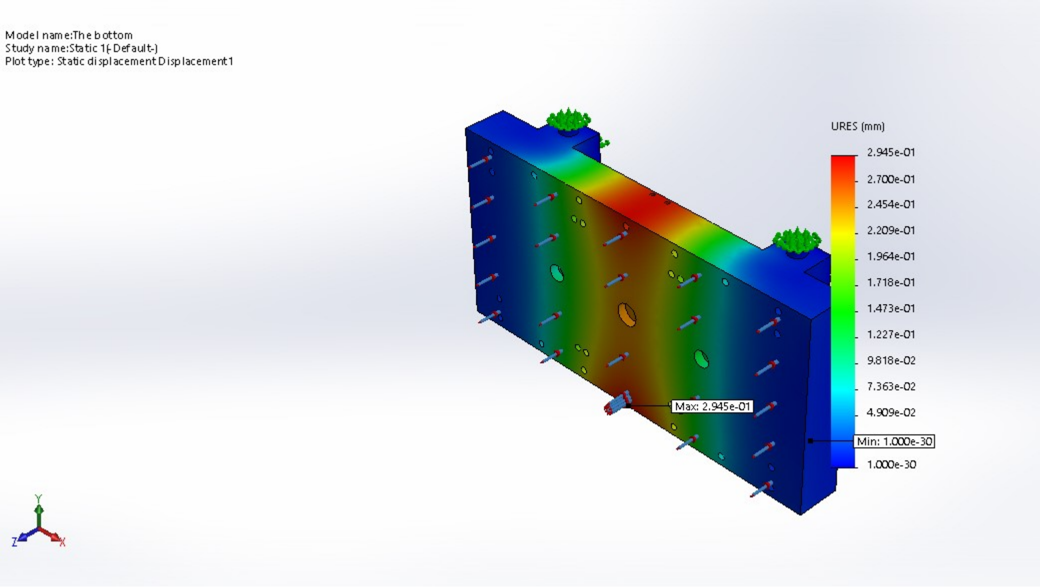


FIGURE V.44: Displacement Plot of the Bottom Support

From the plot, we notice that the minimal displacement is of 0 mm, and a maximum displacement of 0.295 mm.

V.3.9.6 Strain Plot

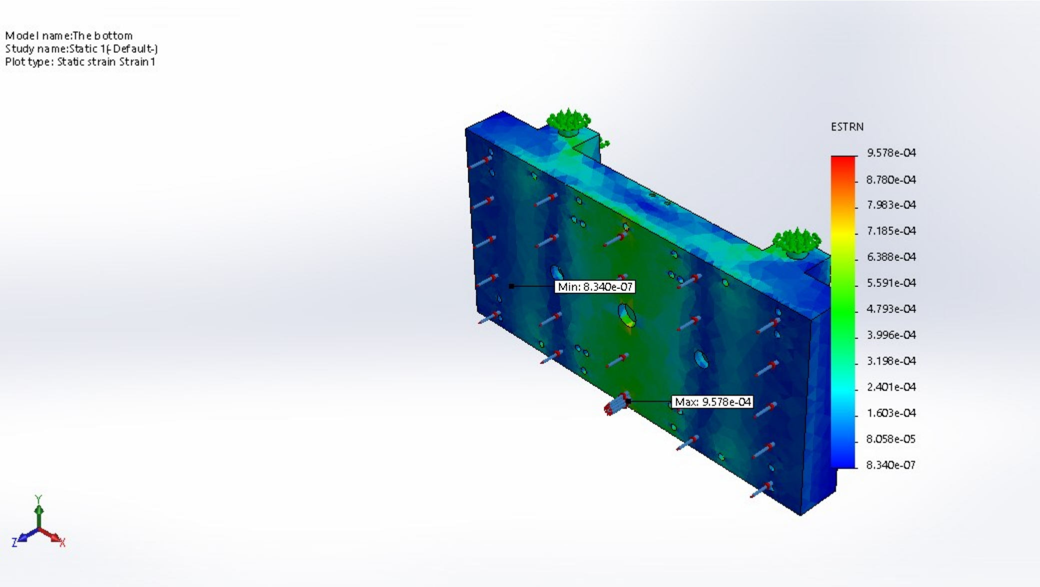


FIGURE V.45: Strain Plot of Bottom Support

We notice from the plot a minimum strain of 8.34e-07 and a maximum strain of 9.578 e-04.

V.3.9.7 Factor of Safety

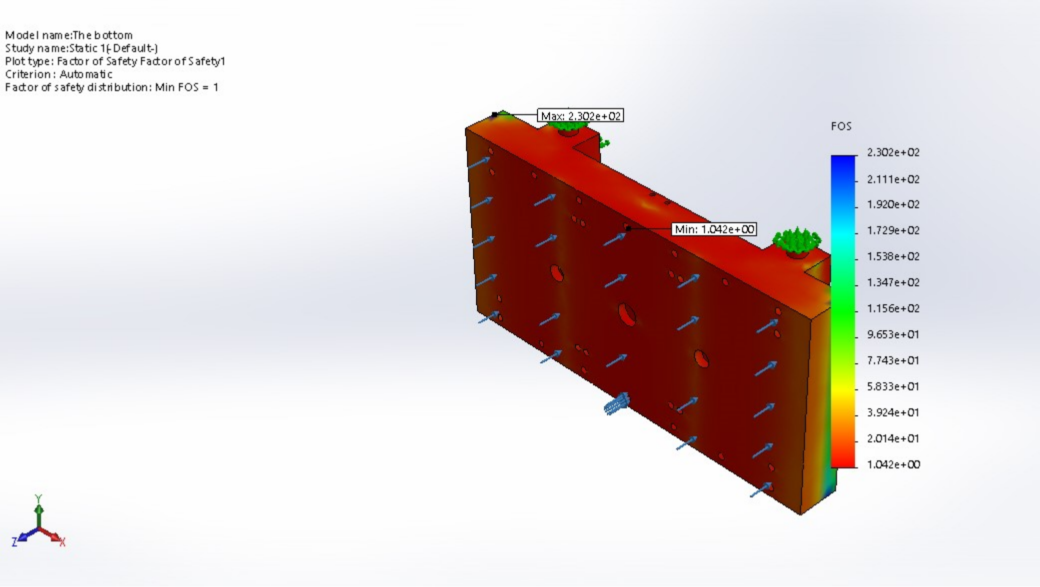


FIGURE V.46: Strain Plot of Bottom Support

As shown in the picture above, the minimum FoS is 1.042.

Conclusion

The static simulation of the Bottom Support: The yield strength of the material was found to be superior to the maximum stress observed, indicating that the plate can withstand the applied load without exceeding its material's limit. The Factor of Safety (FoS) was calculated to be above the minimum requirement of 1, which is safe. Additionally, the displacement values indicated minor deformations at specific nodes, while the strain values remained within an acceptable range. These findings indicate that the support's structural performance meets the desired criteria and can safely withstand the applied loads during the RTM process.

V.3.10 Lower Slide

By applying a solid mesh of a Total number of Nodes of 27910, Total number of Elements of 17179, and a Maximum Aspect Ratio of 3.9345, we find:

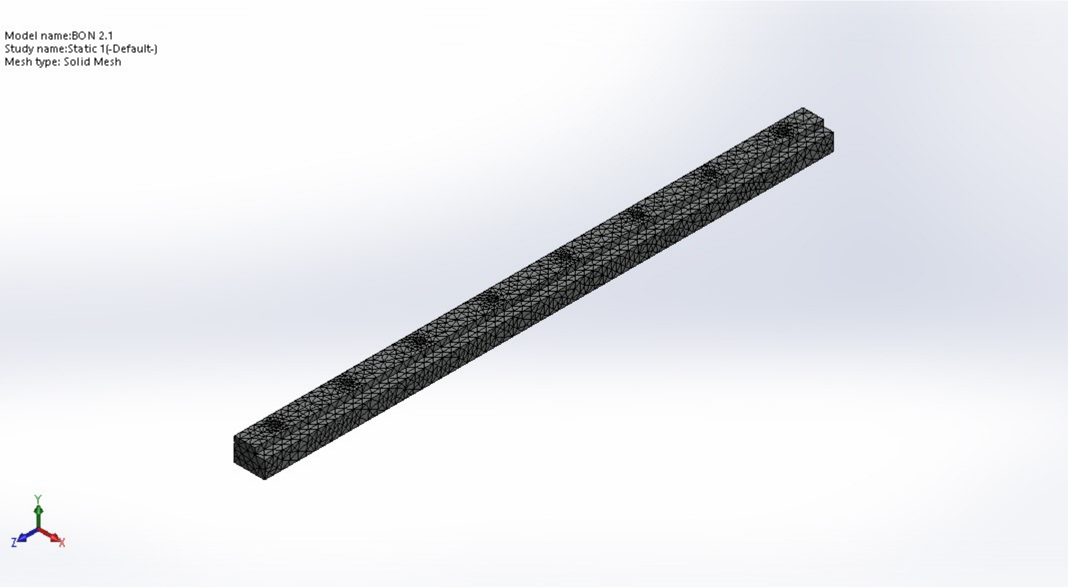


FIGURE V.47: Discretization of the Lower Slide

The Lower support is fixated on the bottom frame. The pressure is applied on its upper face by the pressure multiplier (100 bars).

V.3.10.1 Volumetric Properties

Property	**Value**	**Unit**
Mass	12.39	kg
Volume	1.59e-3	m^3
Density	7800	kg/m^3

TABLE V.27: Volumetric Properties of the Lower Slide

V.3.10.2 Material Properties

Property	Value	Unit
Yield strength	235	MPa
Tensile strength	360	MPa
Elastic modulus	210	GPa
Poisson's ratio	0.28	

TABLE V.28: Material Properties of the Lower Slide

V.3.10.3 Reaction Force of the load

Sum Y
-457692 N

TABLE V.29: Reaction Force of the load

V.3.10.4 Stress Plot

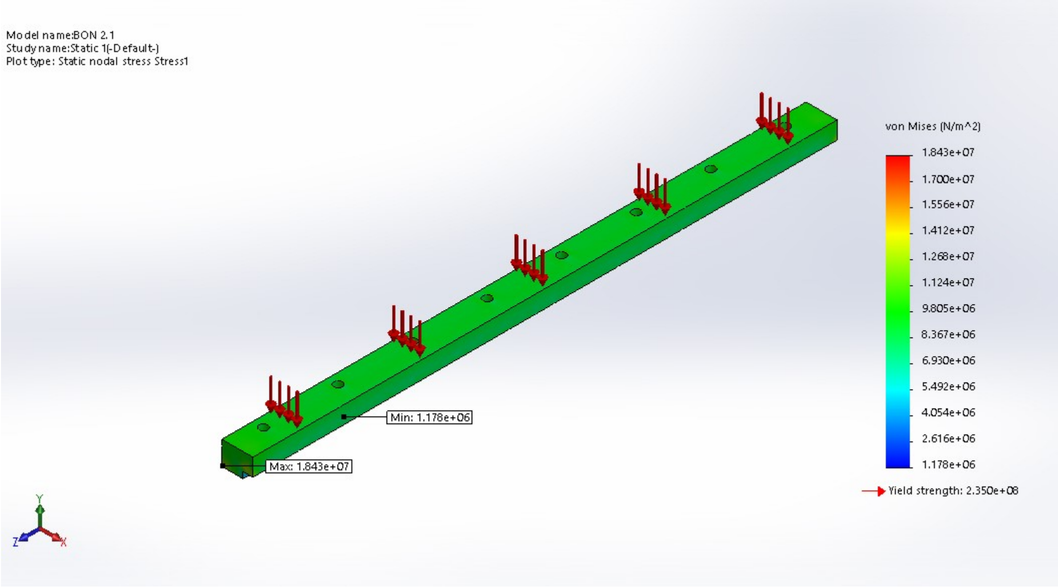


FIGURE V.48: Stress Plot of the Lower Slide

From the plot, we notice a minimum stress of 1.18 MPa and a maximum of 18.4 MPa.

V.3.10.5 Displacement Plot

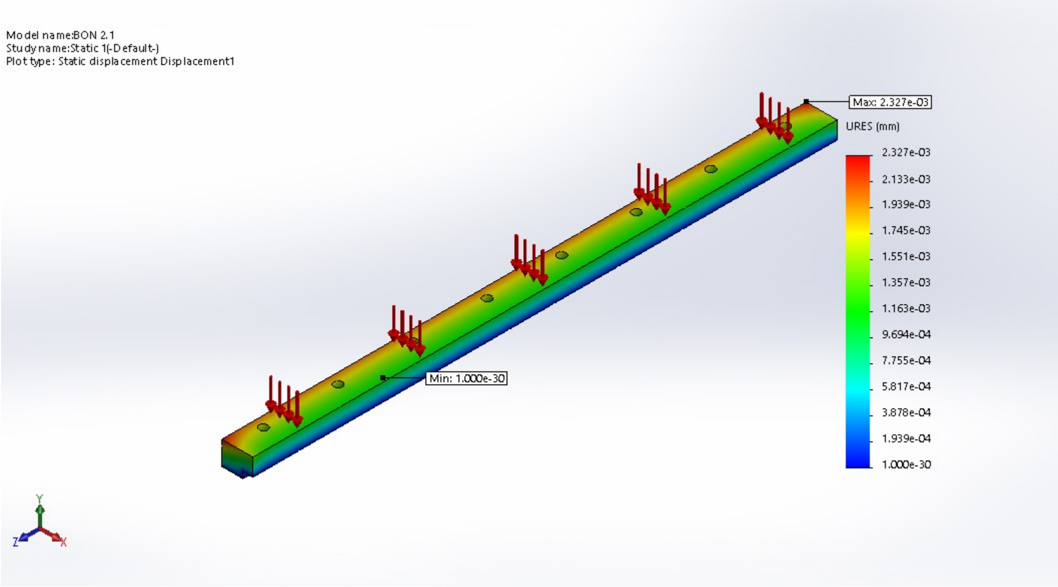


FIGURE V.49: Displacement Plot of Lower Slide

From the plot, we notice that the minimal displacement is of 0 mm, and a maximum displacement of 2.327e-03 mm.

V.3.10.6 Strain Plot

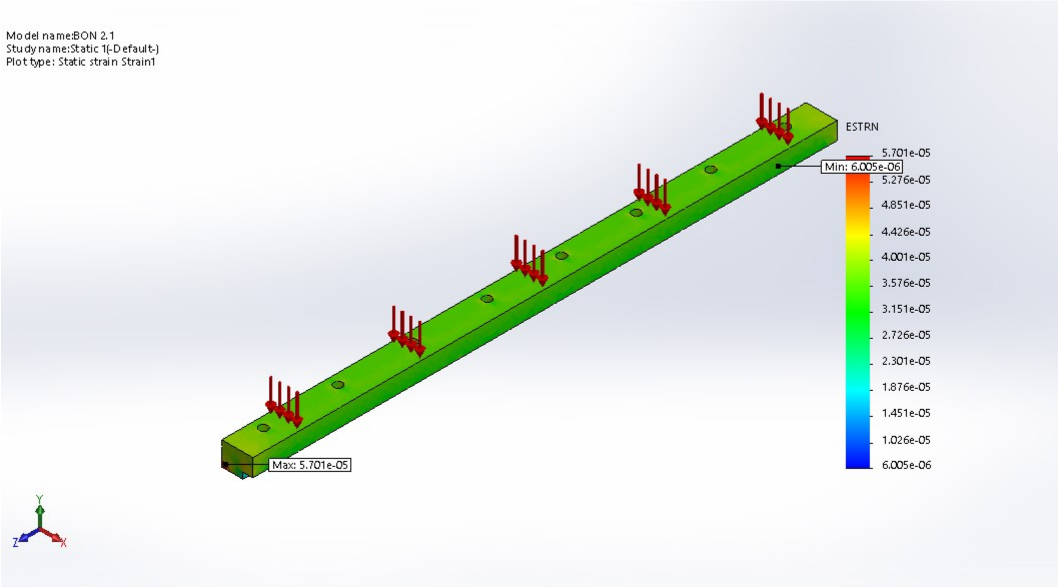


FIGURE V.50: Strain Plot of Lower Slide

We notice from the plot a minimum strain of 6e-06 and a maximum strain of 5.7e-05.

V.3.10.7 Factor of Safety

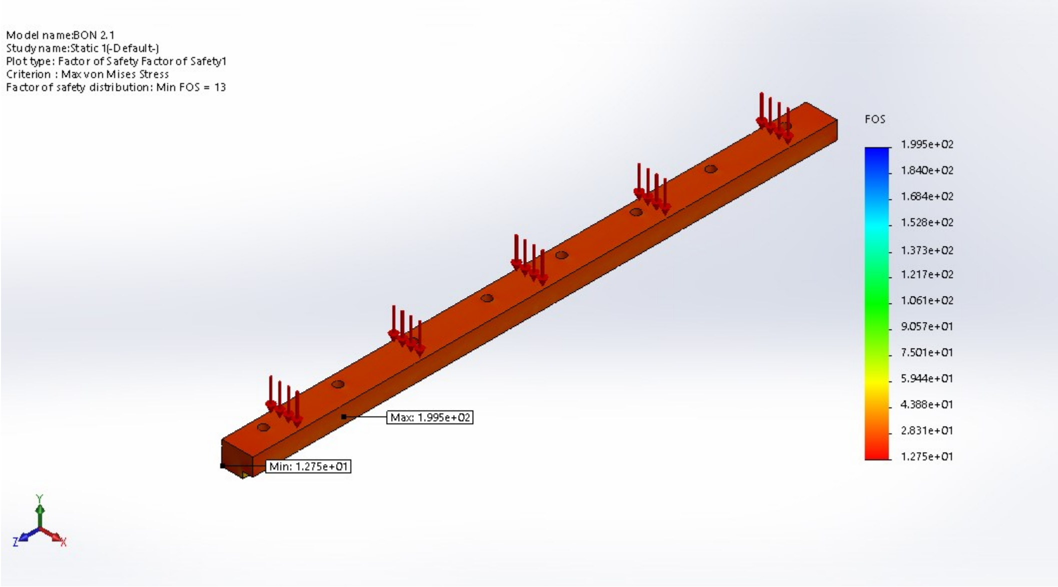


FIGURE V.51: Factor of Safety Plot of Lower Slide

As shown in the picture above, the minimum FoS is 12.75.

Conclusion

The static simulation of the Lower Slide: The yield strength of the material was found to be superior to the maximum stress observed, indicating that the support can withstand the applied load without exceeding its material's limit. The Factor of Safety (FoS) was calculated to be above the minimum requirement of 12.75, which is safe. Additionally, the displacement values indicated minor deformations at specific nodes, while the strain values remained within an acceptable range. These findings indicate that the support's structural performance meets the desired criteria and can safely withstand the applied loads during the RTM process.

V.3.11 Upper Slide

By applying a solid mesh of a Total number of Nodes of 18877, Total number of Elements of 11624, and a Maximum Aspect Ratio of 6.5272, we find:

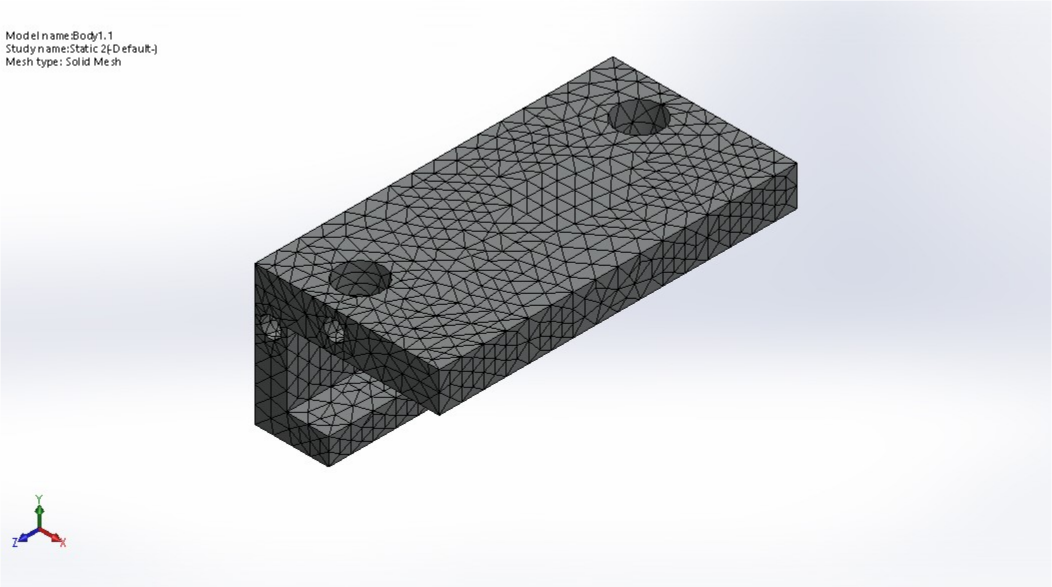


FIGURE V.52: Discretization of the Upper Slide

The bottom support is fixated on the the bottom frame. The pressure is applied on its upper face by the pressure multiplier (100 bars).

V.3.11.1 Volumetric Properties

Property	**Value**	**Unit**
Mass	1.71	kg
Volume	2.19e-4	m^3
Density	7800	kg/m^3

TABLE V.30: Volumetric Properties of the Upper Slide

V.3.11.2 Material Properties

Property	Value	Unit
Yield strength	235	MPa
Tensile strength	360	MPa
Elastic modulus	210	GPa
Poisson’s ratio	0.28	

TABLE V.31: Material Properties of the Upper Slide

V.3.11.3 Reaction Force of the load

Sum Y
90663 N

TABLE V.32: Reaction Force of the load

V.3.11.4 Stress Plot

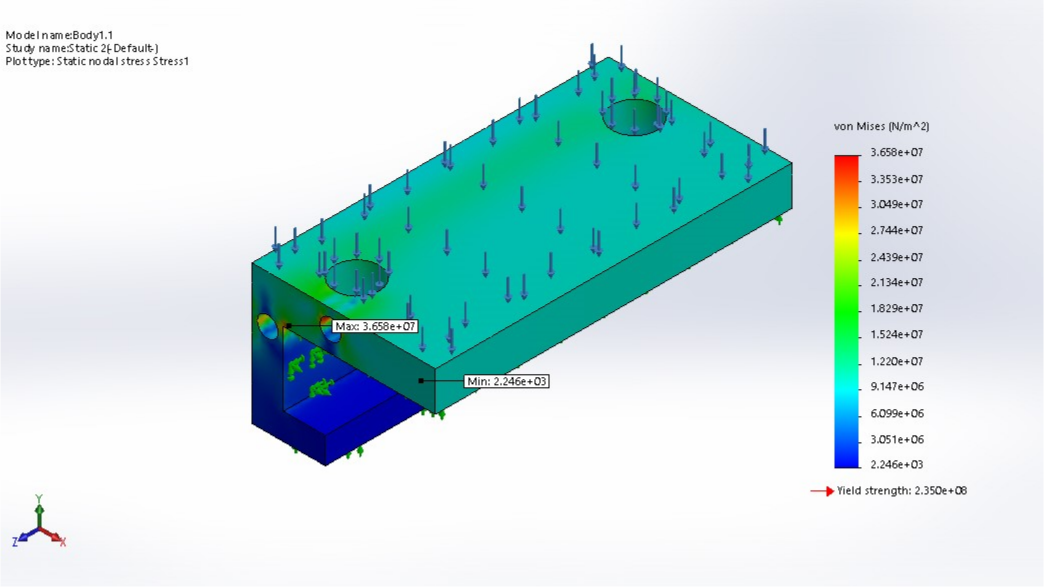


FIGURE V.53: Stress Plot of the Upper Slide

From the plot, we notice a minimum stress of 3.05e-04 MPa and a maximum of 36.58 MPa.

V.3.11.5 Displacement Plot

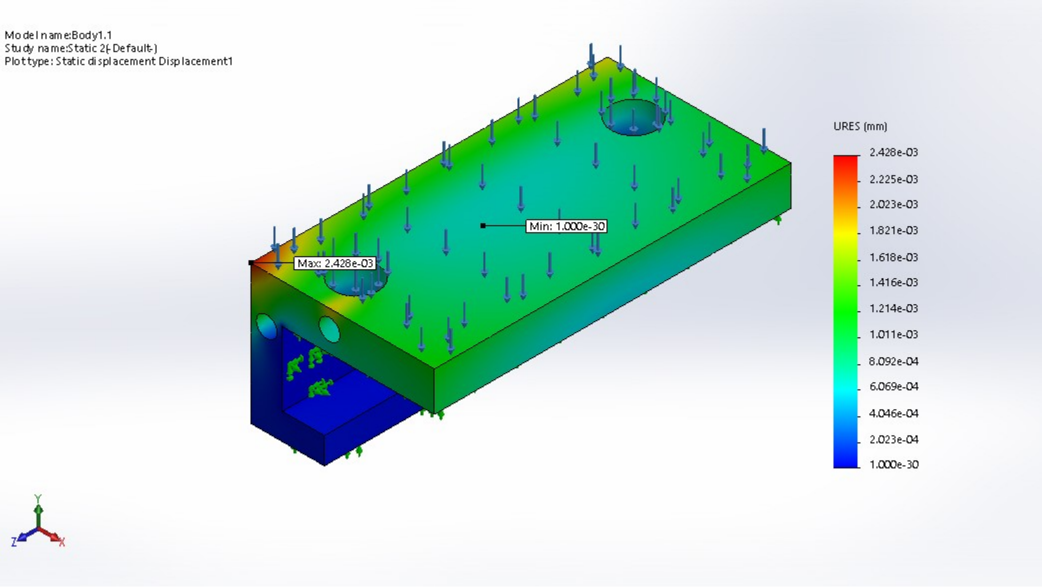


FIGURE V.54: Displacement Plot of the Upper Slide

From the plot, we notice that the minimal displacement is of 0 mm, and a maximum displacement of 2.428 e-03 mm.

V.3.11.6 Strain Plot

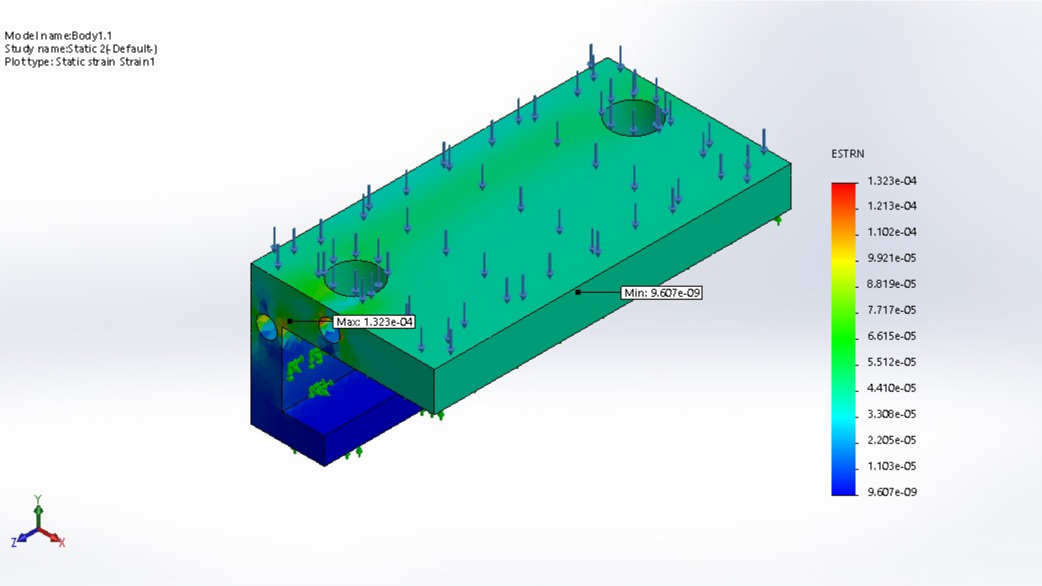


FIGURE V.55: Strain Plot of Upper Slide

We notice from the plot a minimum strain of 2.2 e-05 and a maximum strain of 1.32 e-04.

V.3.11.7 Factor of Safety

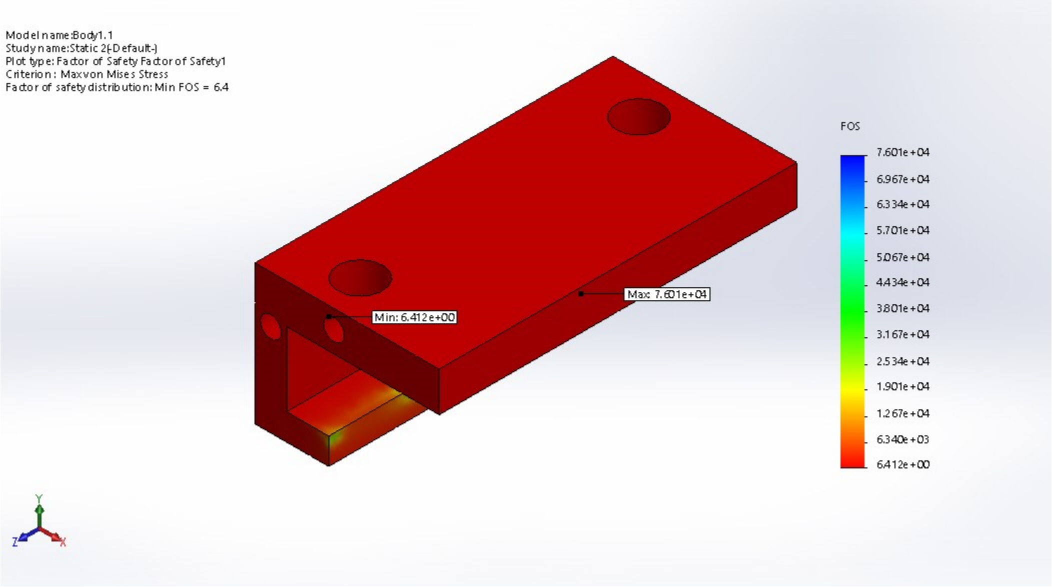


FIGURE V.56: Strain Plot of Upper Slide

As shown in the picture above, the minimum FoS is 6.4.

Conclusion

The static simulation of the Upper Slide: The yield strength of the material was found to be superior to the maximum stress observed, indicating that the plate can withstand the applied load without exceeding its material's limit. The Factor of Safety (FoS) was calculated to be above the minimum requirement of 6.4, which is safe. Additionally, the displacement values indicated minor deformations at specific nodes, while the strain values remained within an acceptable range. These findings indicate that the slide's structural performance meets the desired criteria and can safely withstand the applied loads during the RTM process.

CONCLUSION

In conclusion, this dissertation has comprehensively examined various aspects of the Resin Transfer Molding (RTM) process and its associated components. It explored the different stages of the RTM kinetic chain, with a particular focus on the utilization of innovative reinforcement material, specifically Date Palm Fibers. Additionally, the dissertation emphasized the significance of thermal systems in composite manufacturing and discussed various heating methods, heat transfer efficiency, and advancements in thermal management systems.

Furthermore, the dissertation presented insightful numerical simulations using SolidWorks Simulation, analyzing critical factors such as stress, displacement, strain, and factor of safety in the components of our RTM Machine. These simulations provided valuable insights into the structural behavior and performance of the machine.

It is important to note that the RTM machine discussed in this dissertation is currently incomplete, as it lacks an injection system. Incorporating an injection system is crucial for achieving optimal performance and ensuring consistent results across multiple layers. Moreover, to further enhance efficiency and outcomes, it is recommended to consider automating the machine.

This work significantly contributes to the existing knowledge and research in the field of composite manufacturing, particularly within the realm of RTM. It establishes a solid foundation for future advancements and improvements in the design, optimization, and automation of RTM processes, ultimately leading to more efficient and reliable composite manufacturing techniques.

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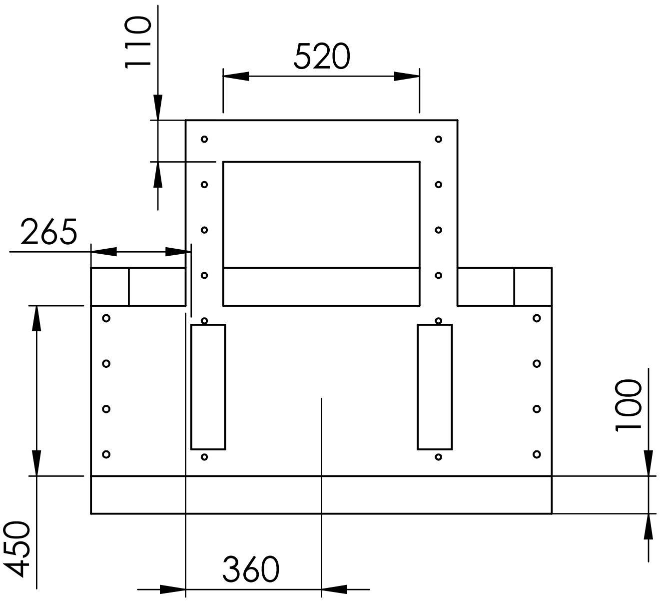
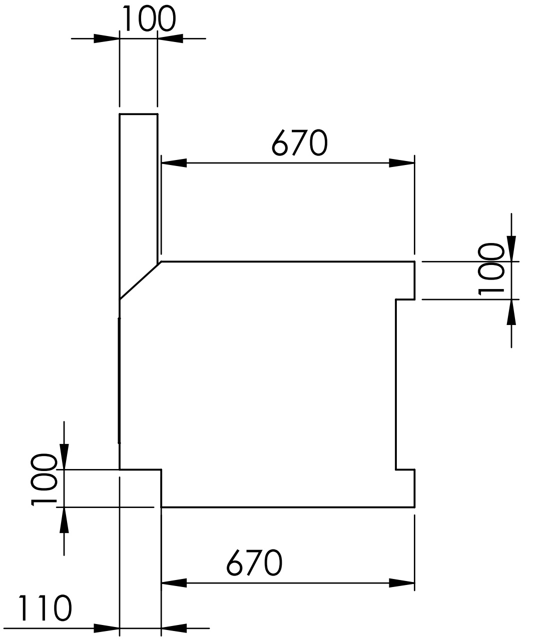
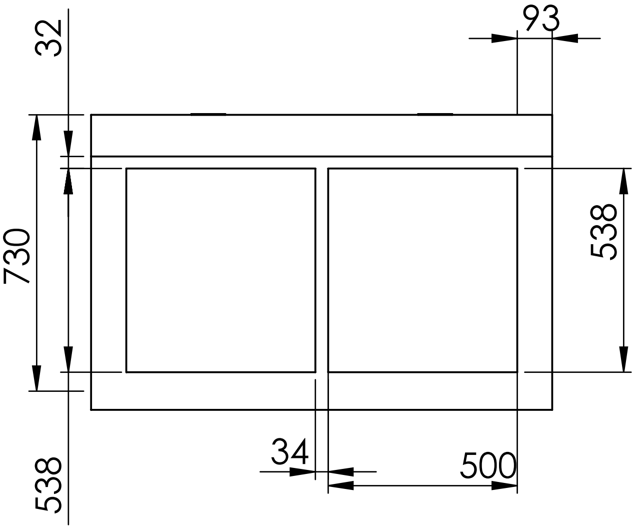
APPENDIX

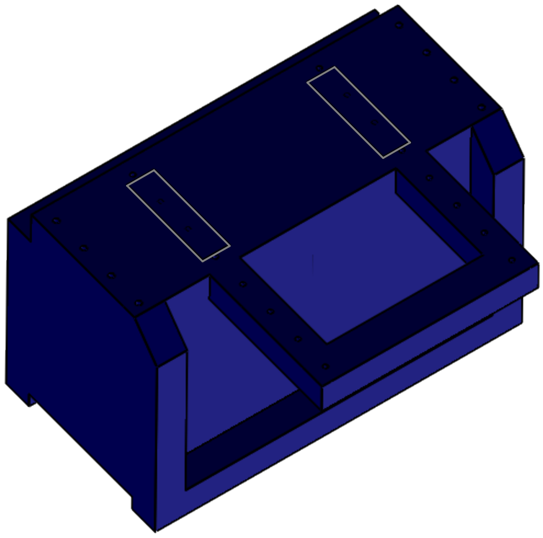
A

SOLIDWORKS TECHNICAL DRAWINGS









NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #1:** **Bottom Frame**	MECHANICAL ENGINEERING FACULTY
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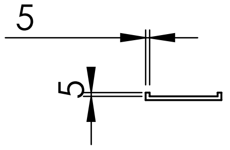
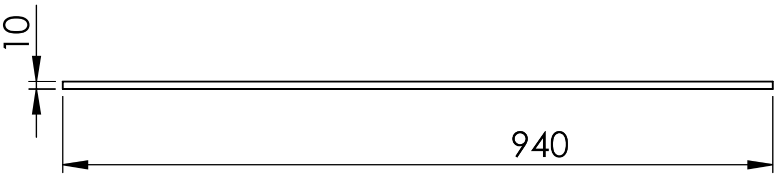
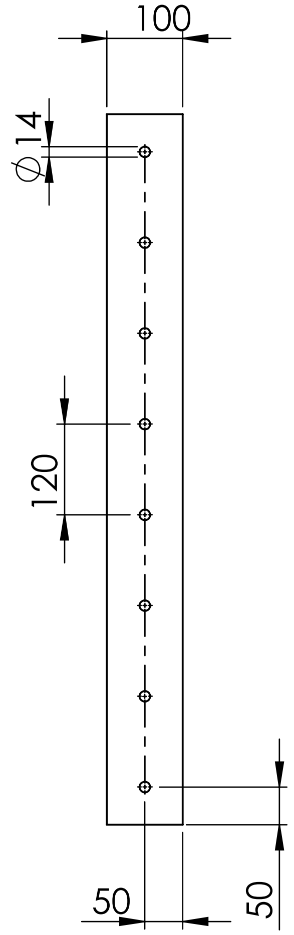
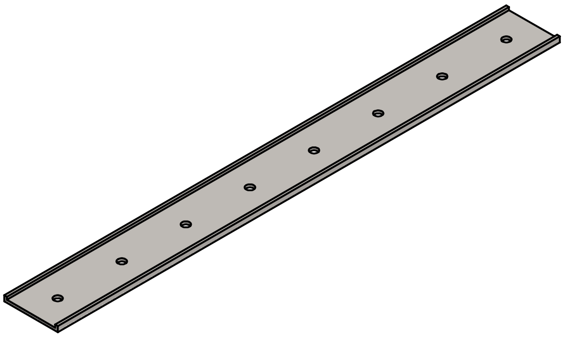
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	8/28/2023









NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #2:** **Lower Support**	MECHANICAL ENGINEERING FACULTY
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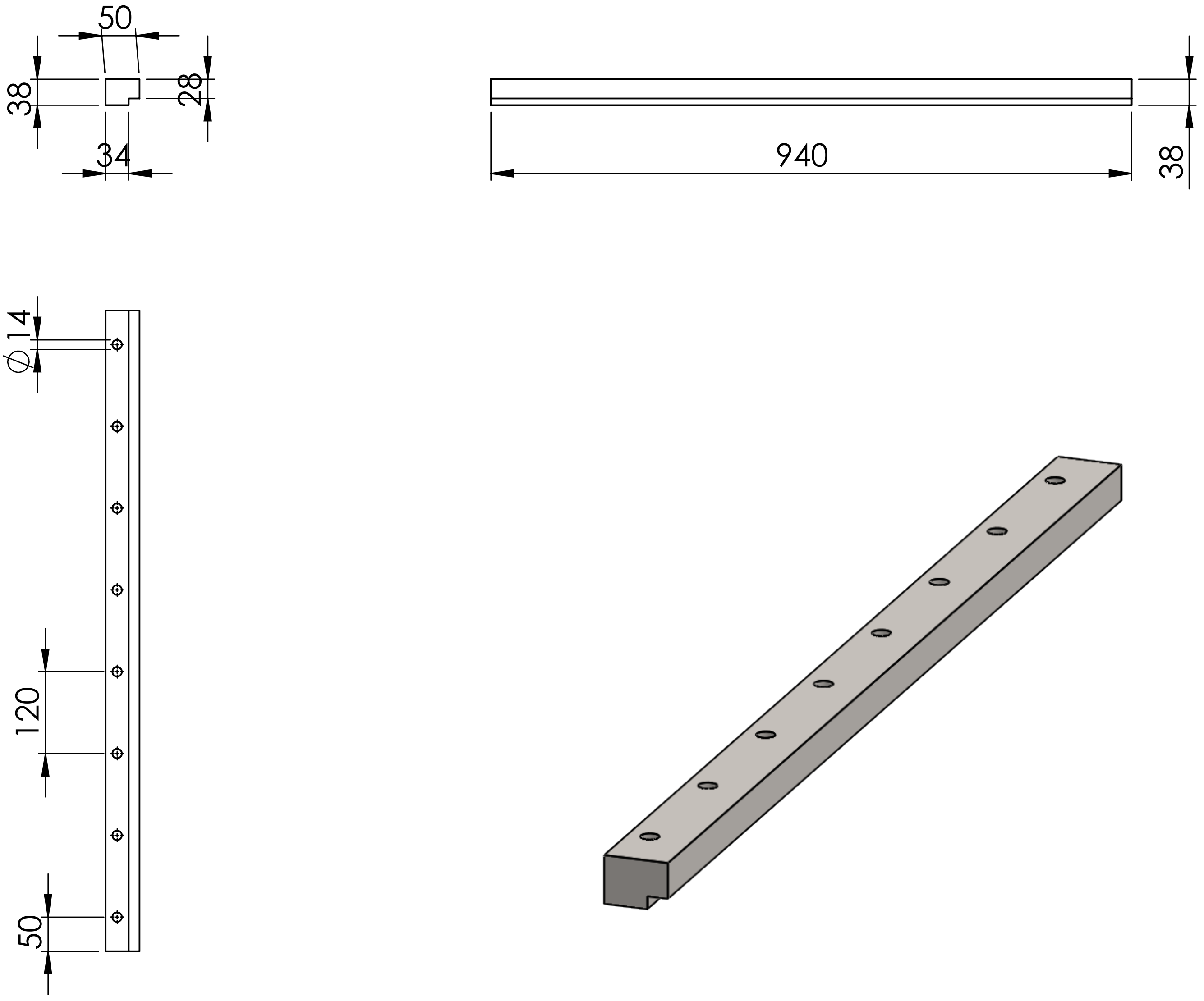
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023



NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #3:** **Lower Slide**	MECHANICAL ENGINEERING FACULTY
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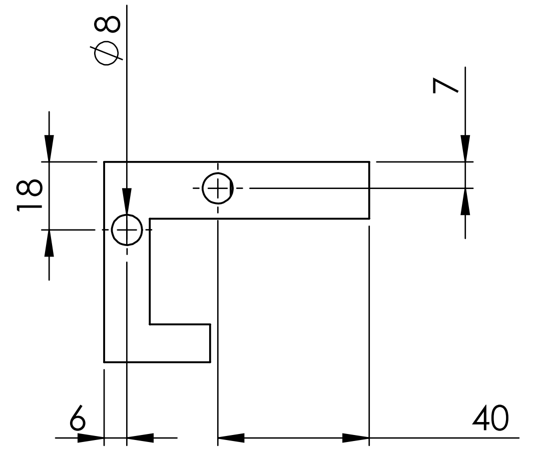
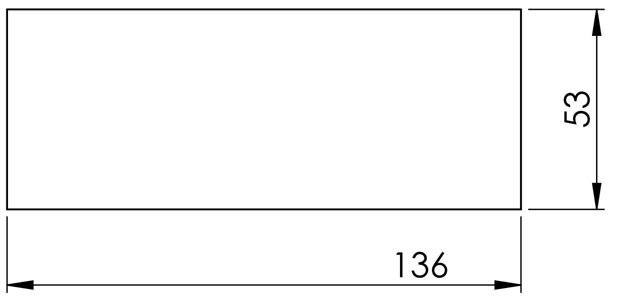
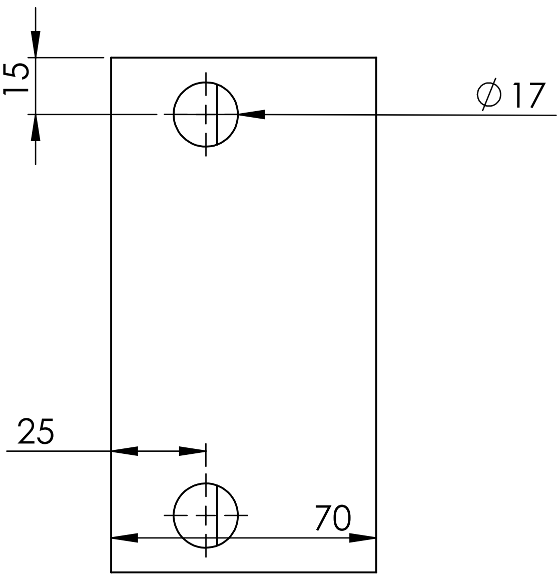
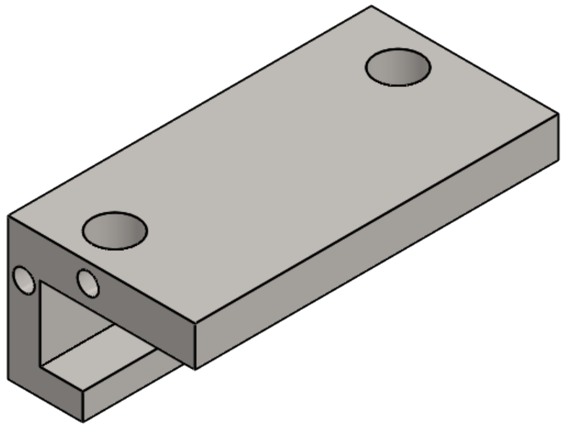
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023









NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #4: Upper Slide**	MECHANICAL ENGINEERING FACULTY
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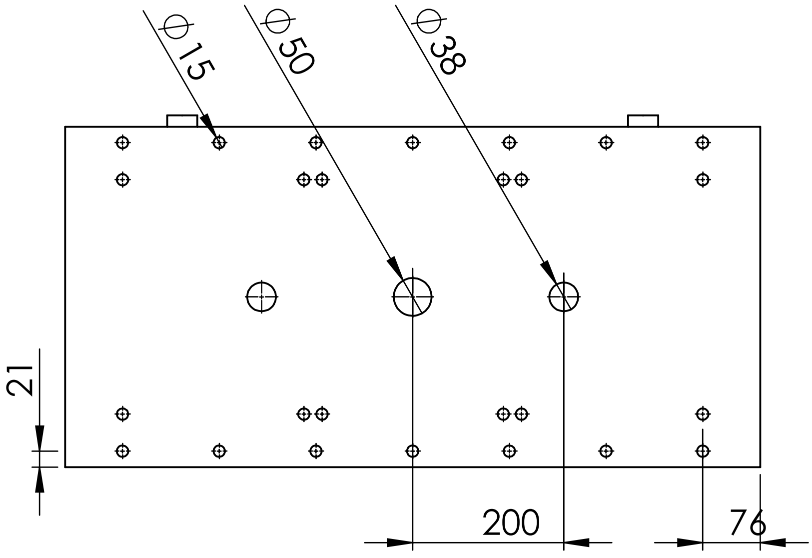
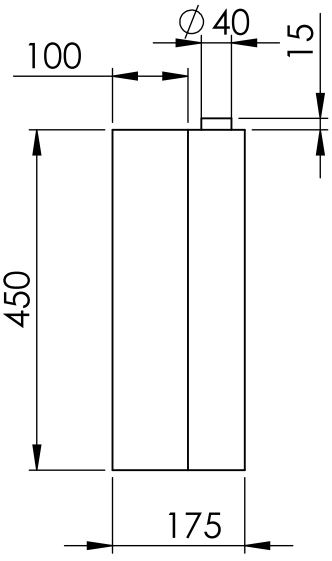
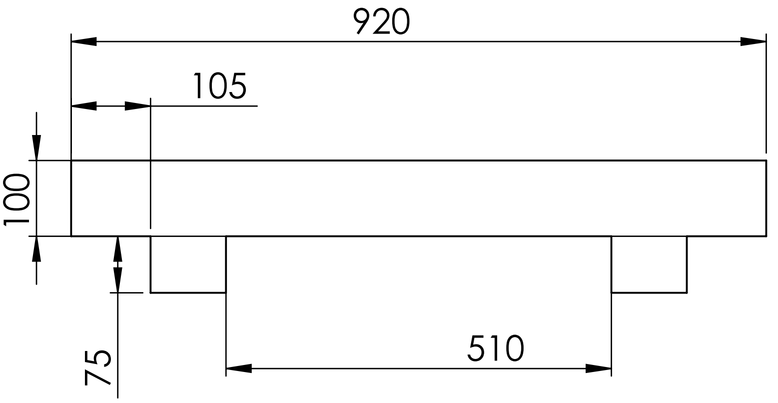
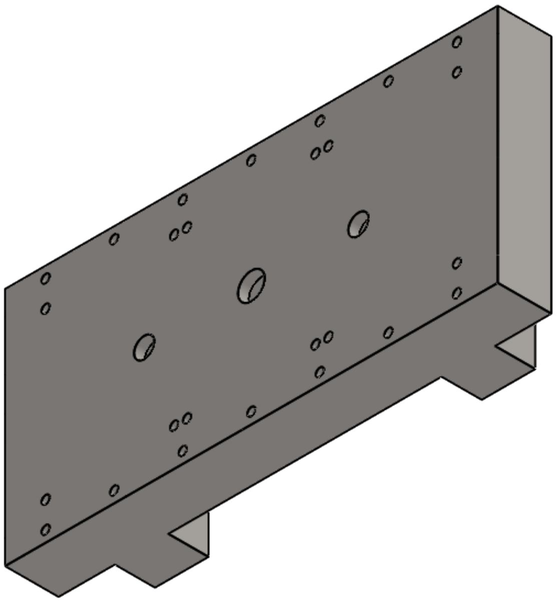
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023









NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #5:** **Bottom Support**	MECHANICAL ENGINEERING FACULTY
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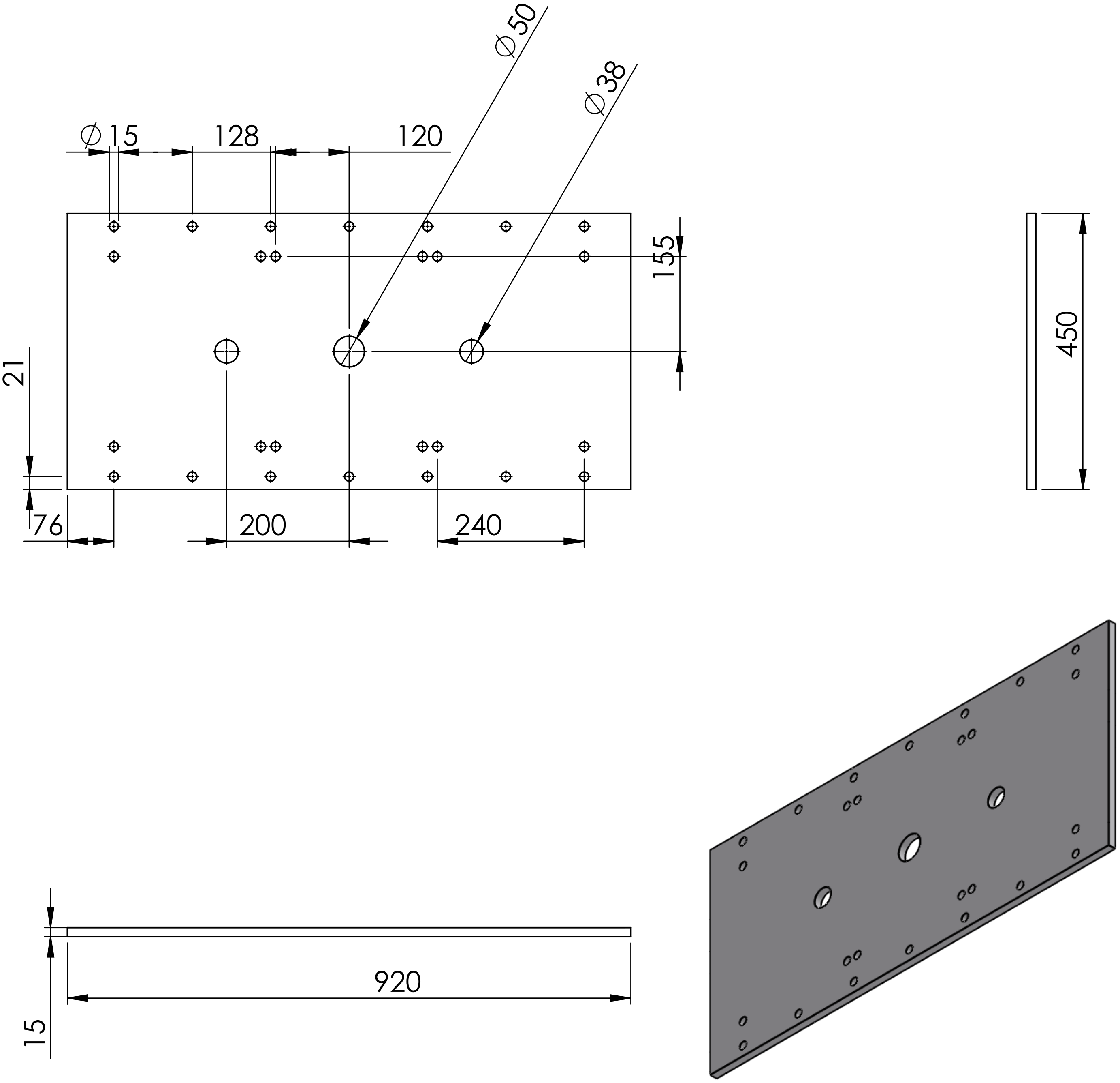
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	8/28/2023



NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #6: Heat Insulation Plate**	MECHANICAL ENGINEERING FACULTY
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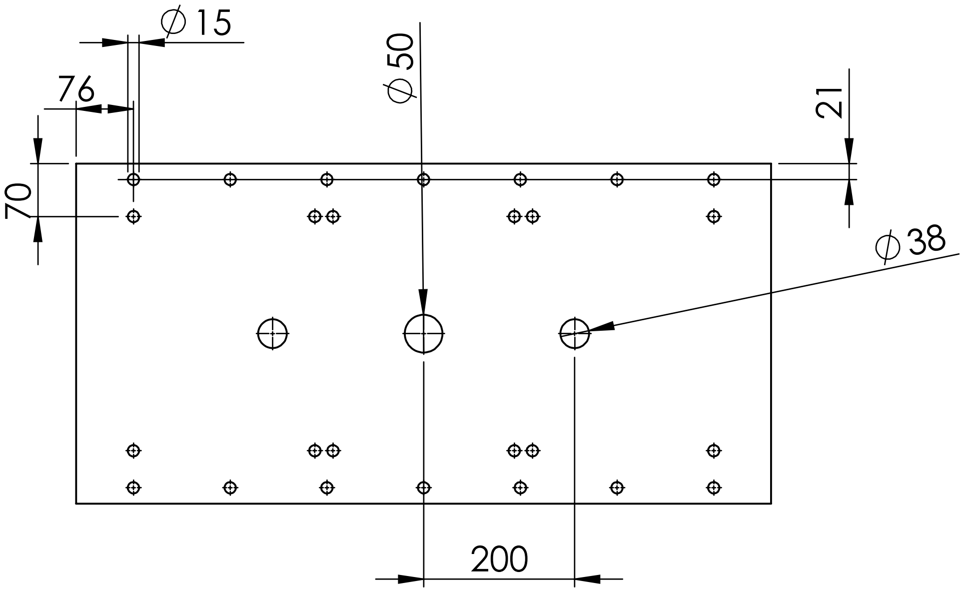
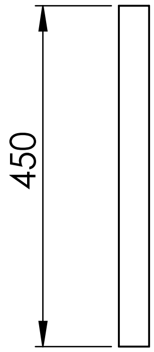
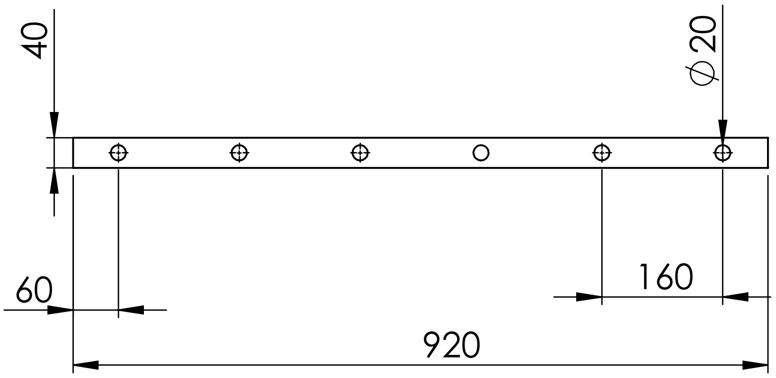
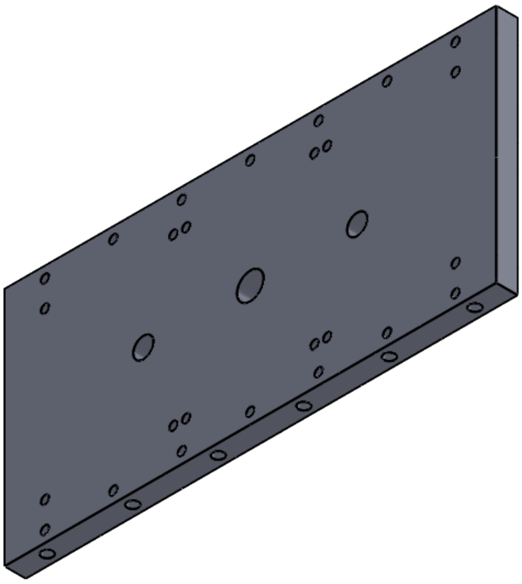
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023



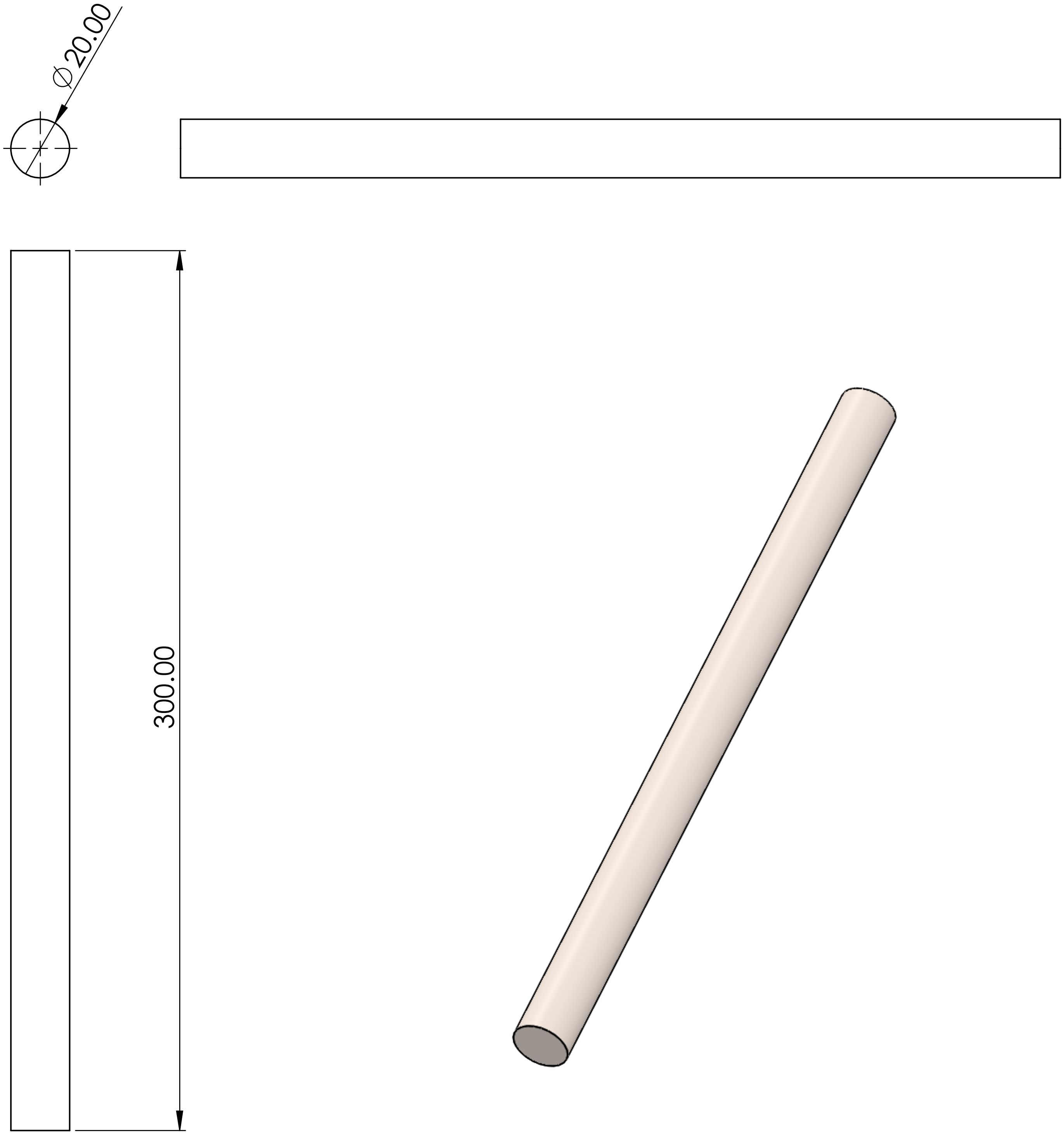






NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #7: Heating Plate**	MECHANICAL ENGINEERING FACULTY
1:10	**7075-T6 (SN)**			
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	8/28/2023



NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**			**RESISTOR**	MECHANICAL ENGINEERING FACULTY
1:2	**1.2343 (X38CrMoV5-1)**				
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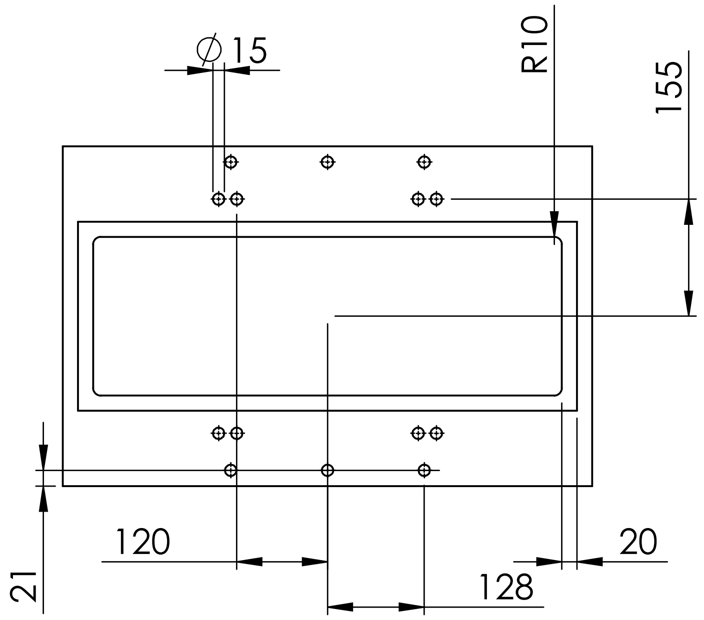
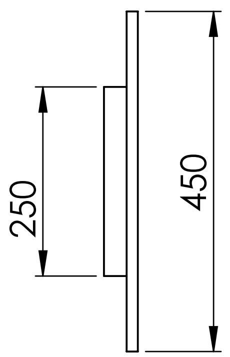
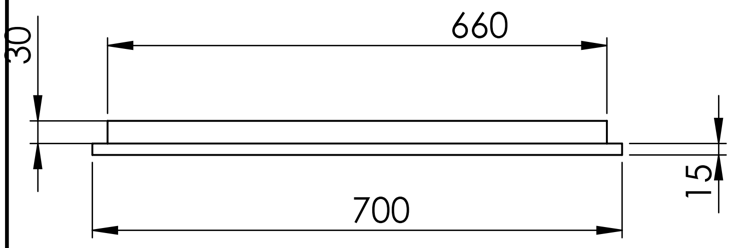
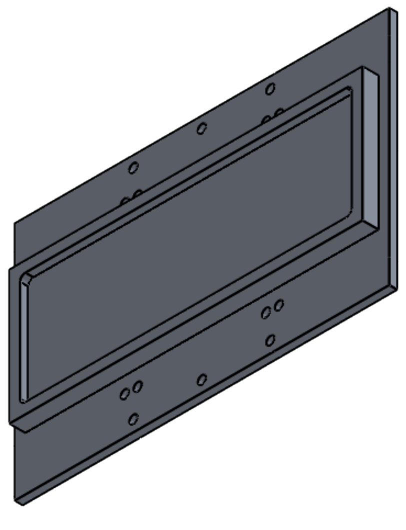
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE		**LOUNAOUSSI MEROUA**	7/13/2023









NATIONAL POLYTECHNIC SCHOOL

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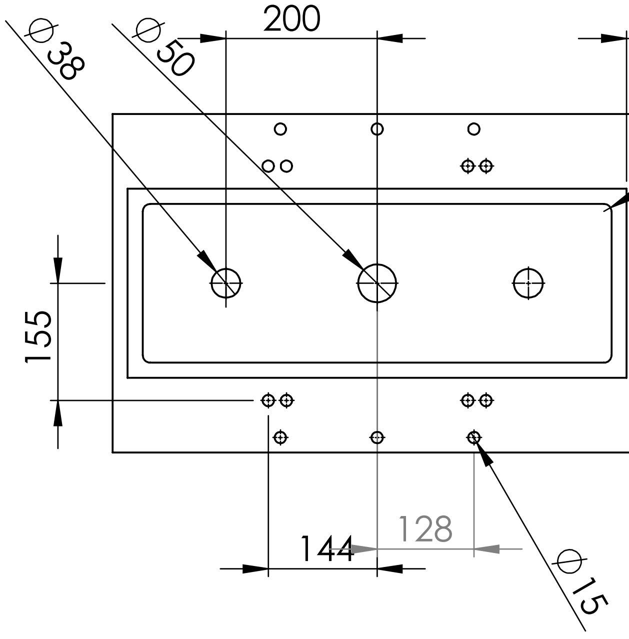
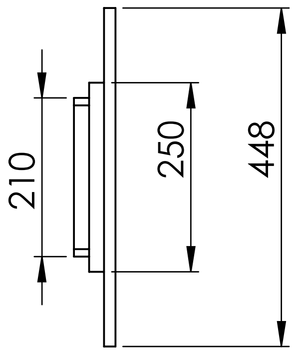
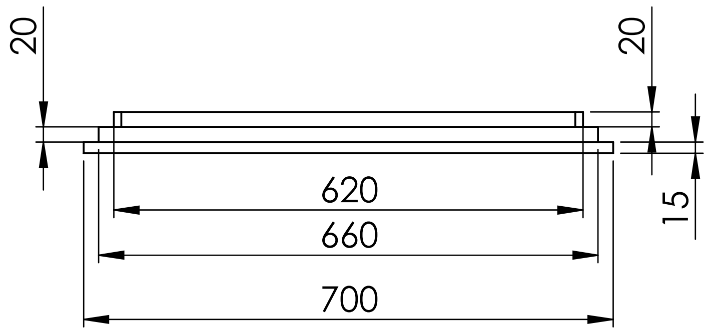
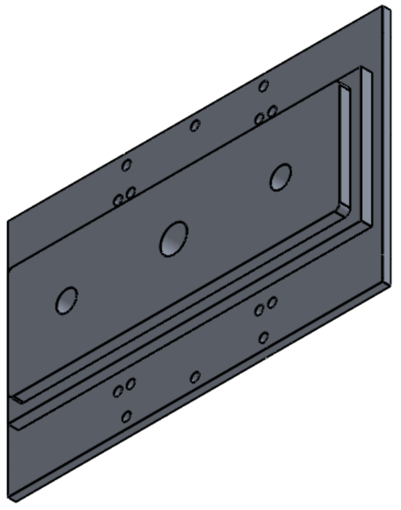
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	8/28/2023



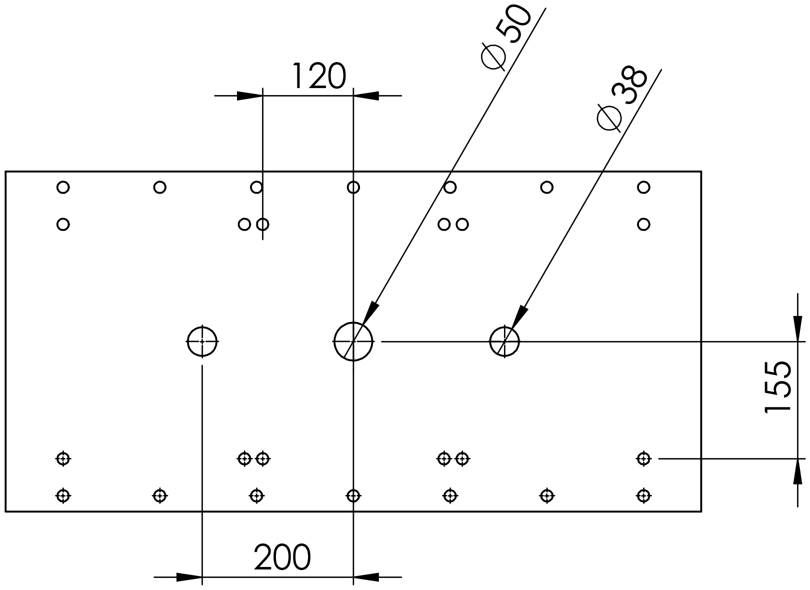


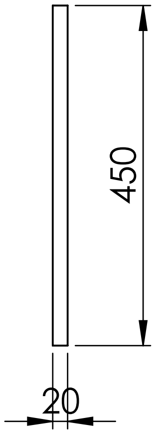


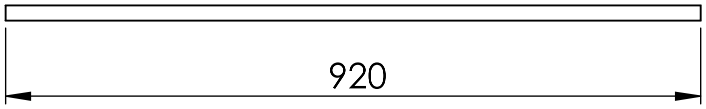


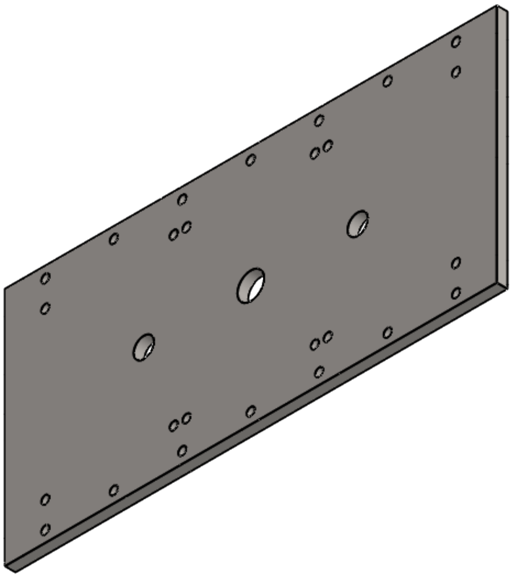
NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #10:** **Upper Mold**	MECHANICAL ENGINEERING FACULTY
1:10	**Alloy 7075 T6**			
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023



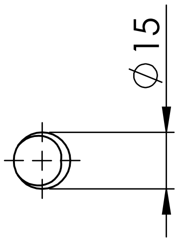


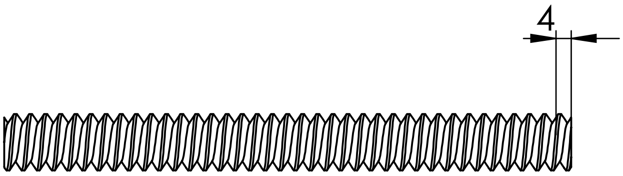


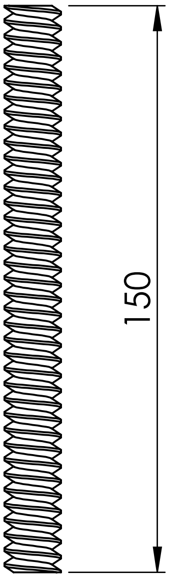


NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #11: Support plate**	MECHANICAL ENGINEERING FACULTY
1:10	**1.0037 (S578RJ)**			
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023

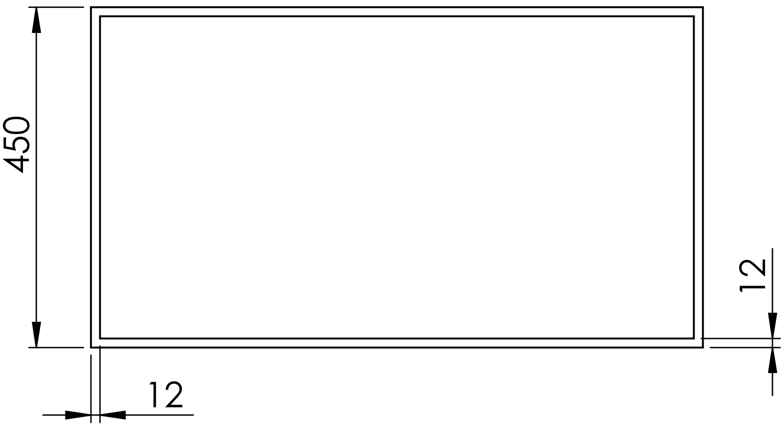


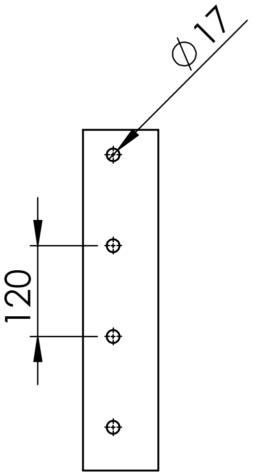


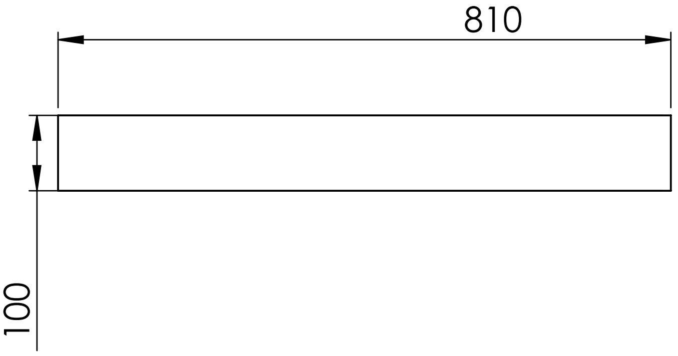


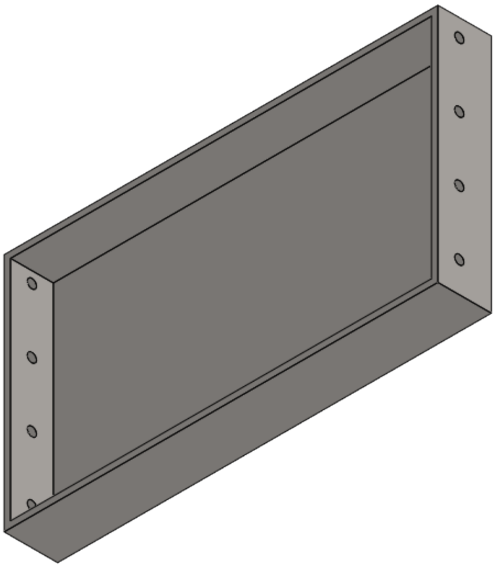
NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #12:** **Height Regulator Bolts**	MECHANICAL ENGINEERING FACULTY
1:2	**AST A36**			
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	8/28/2023



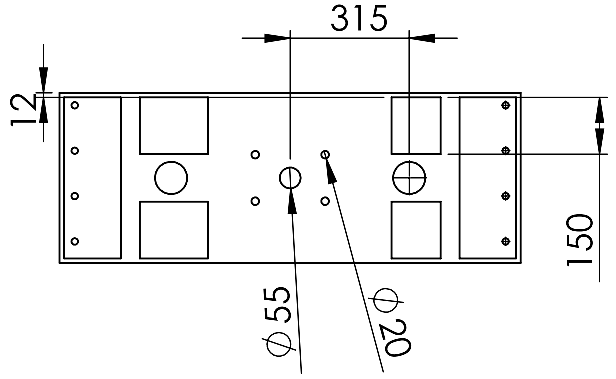


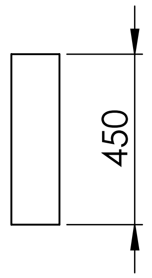


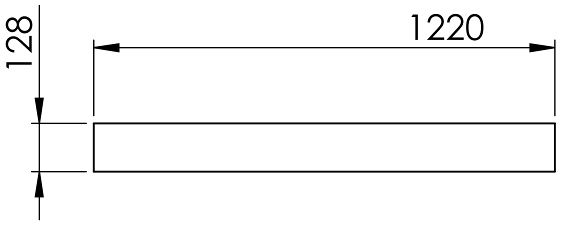


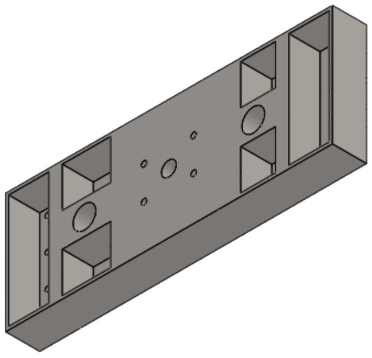
NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #13: Side Frame**	MECHANICAL ENGINEERING FACULTY
1:10	**1-0037 (S578RJ)**			
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023



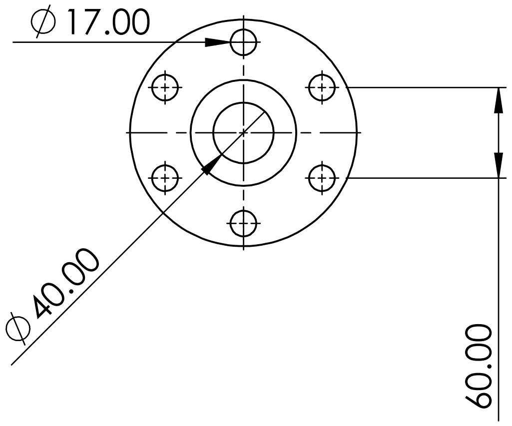


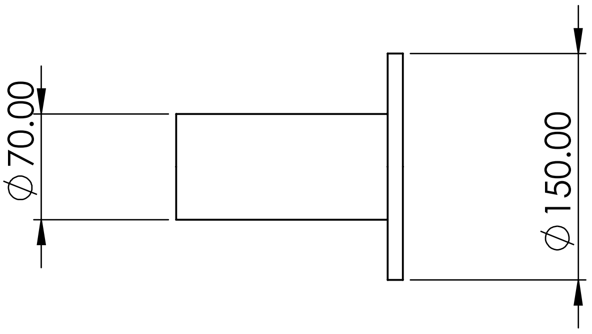


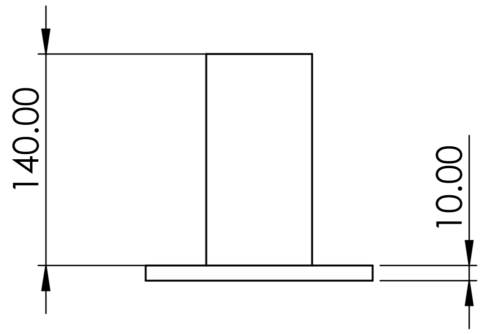


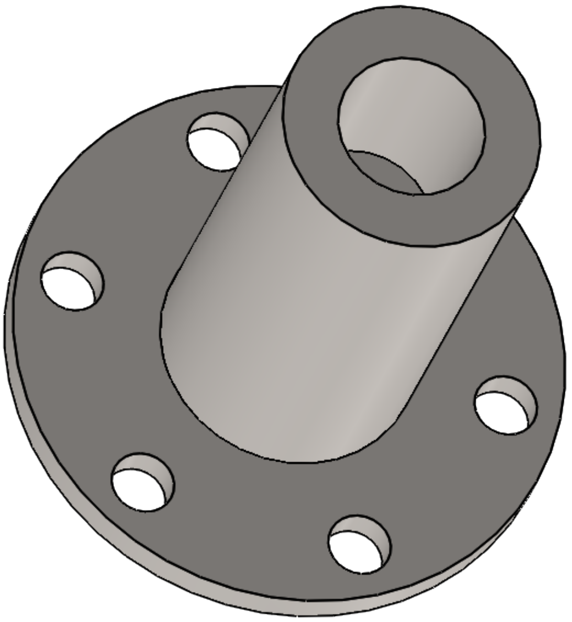
NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #14:** **Top Frame**	MECHANICAL ENGINEERING FACULTY
1:20	**1.0037 (S235J)**			
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023



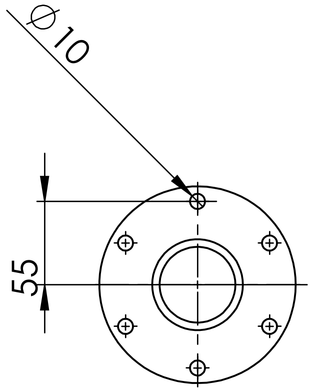


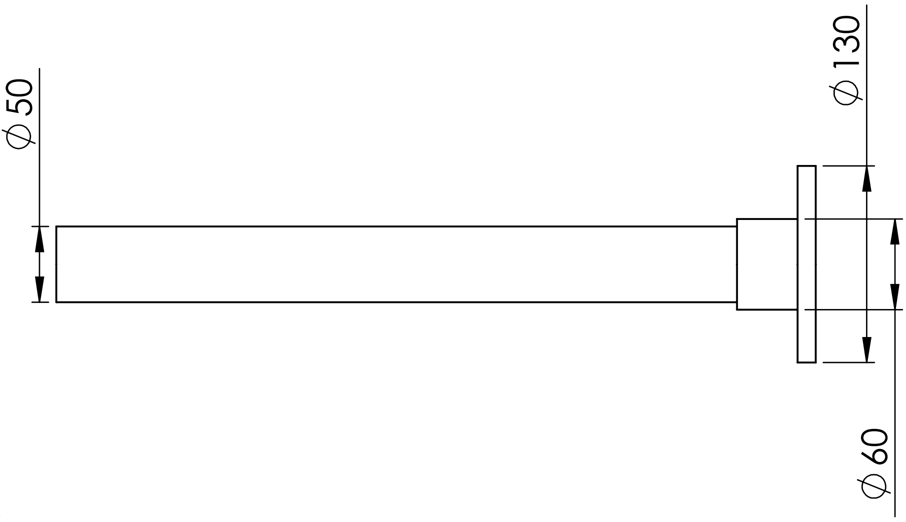


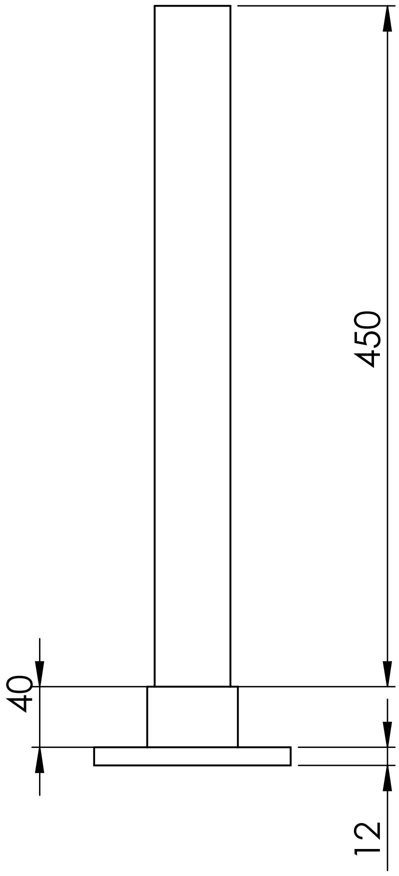


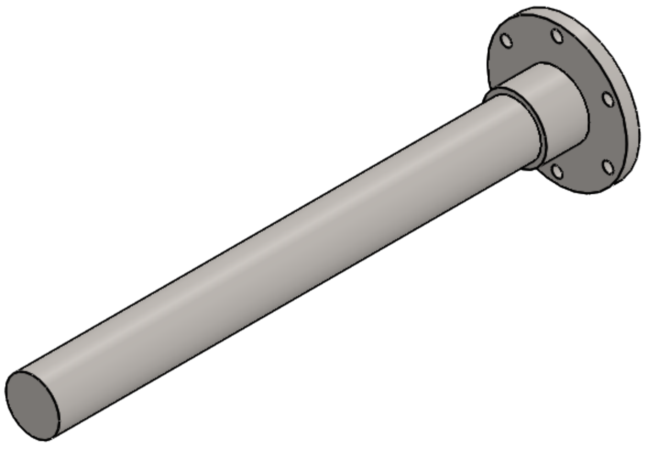
NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		Center Vertical Guidance Ring	MECHANICAL ENGINEERING FACULTY
1:5	**1.0037 (S578RJ)**			
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	7/12/2023



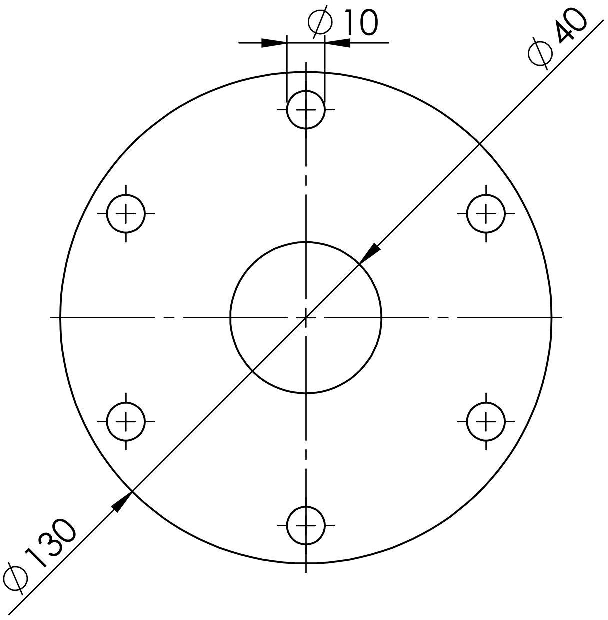


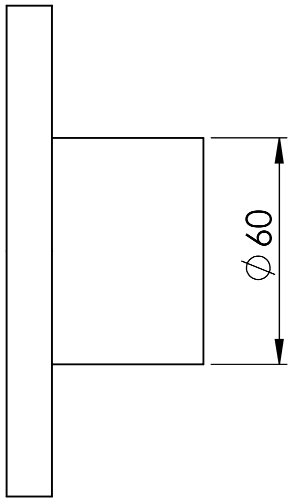


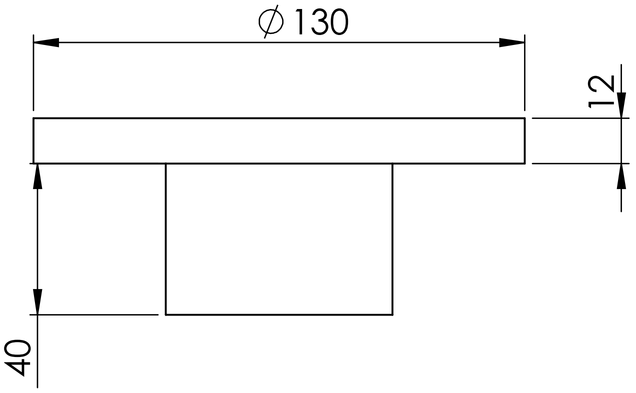


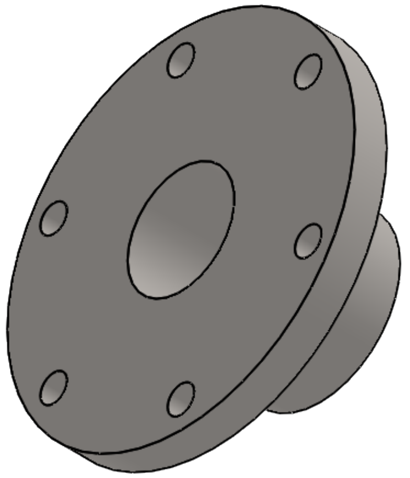
NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #16:** **Vertical Guidance Ring**	MECHANICAL ENGINEERING FACULTY
1:10	**1.0037 (S235JR)**			
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023



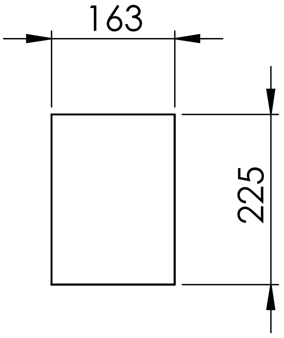


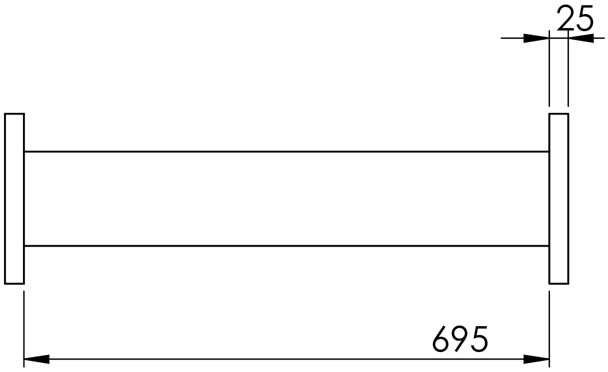


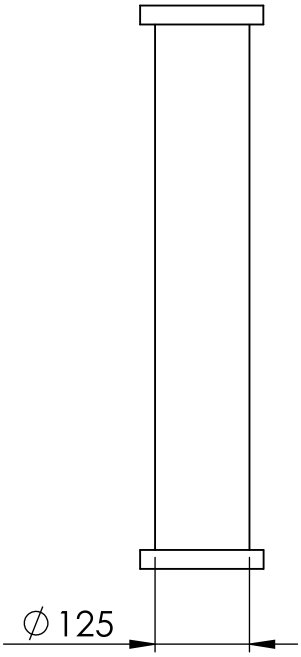


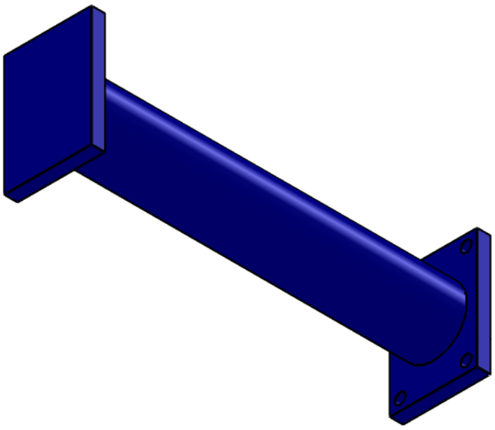
NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #17:** **Support Ring**	MECHANICAL ENGINEERING FACULTY
1:2	**1.0035(S578RJ)**			
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023



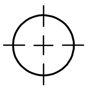


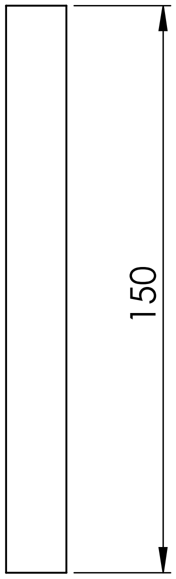


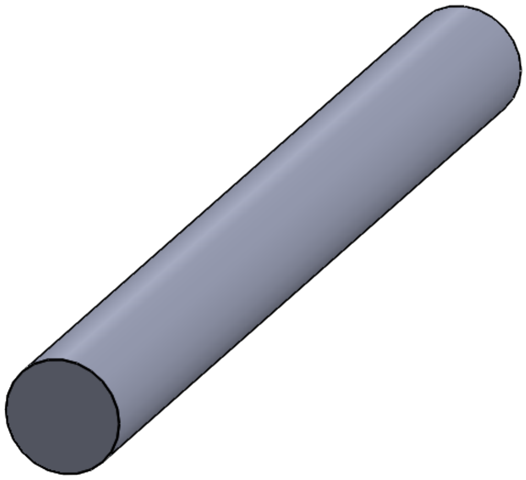


NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #18: Cylinder Body**	MECHANICAL ENGINEERING FACULTY
1:10	**1.0037 (S578RJ)**			
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	8/28/2023

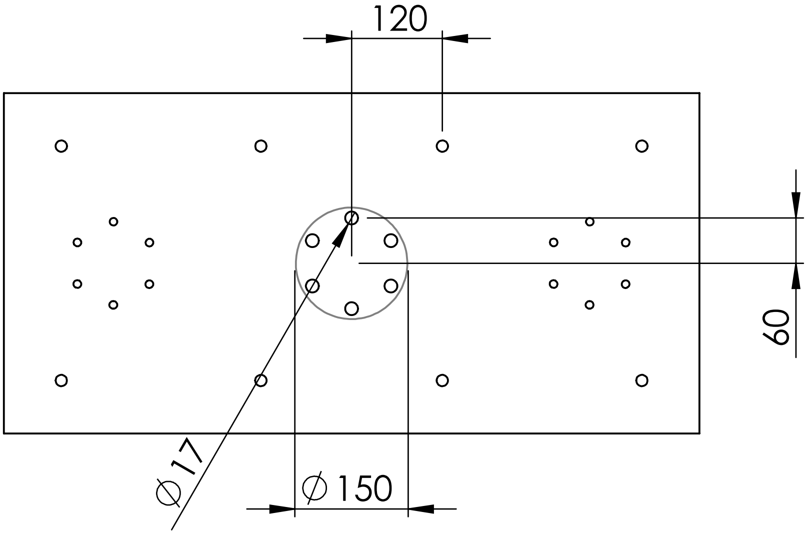


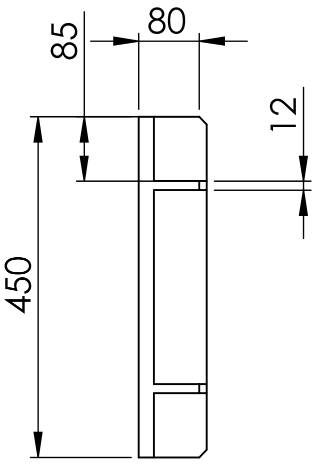


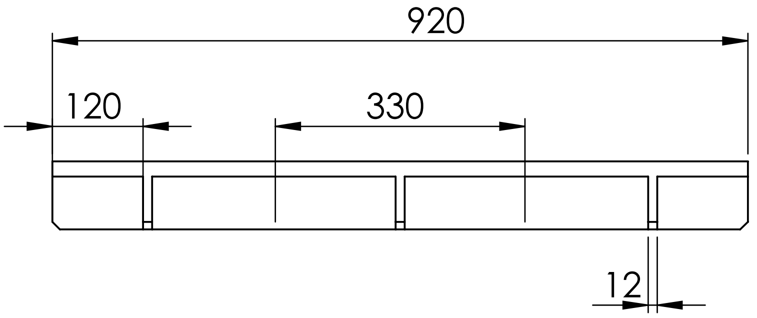


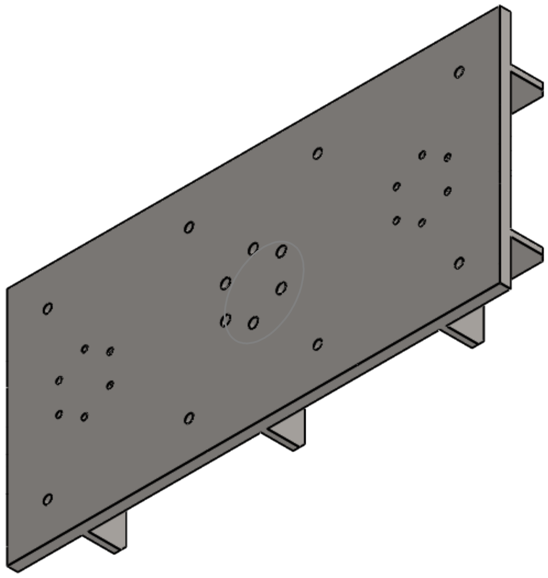
NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**PART #19:** **Piston**	MECHANICAL ENGINEERING FACULTY
1:2	**AST A36**			
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023



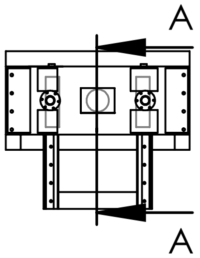


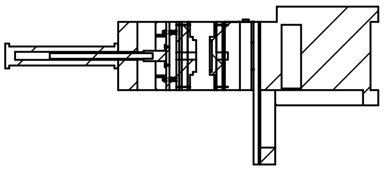




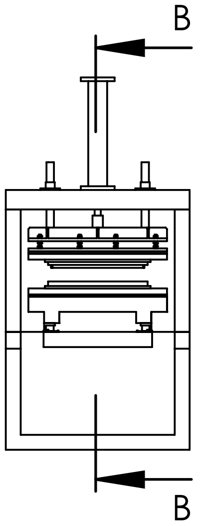
NATIONAL POLYTECHNIC SCHOOL

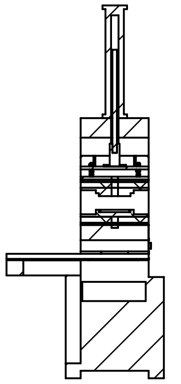
SCALE	**MATERIAL**		**PART #20:** **Top Support**	MECHANICAL ENGINEERING FACULTY
1:10				
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	9/4/2023



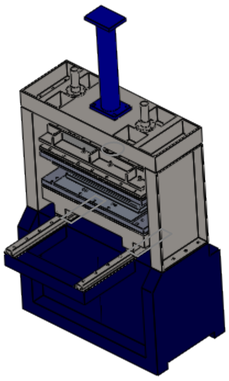


SECTION A-A





SECTION B-B



NATIONAL POLYTECHNIC SCHOOL

SCALE	**MATERIAL**		**RTM Machine**	MECHANICAL ENGINEERING FACULTY
1:50				
STUDENT	LOUNAOUSSI	MEROUA		
SUPERVISORS	RECHAK KARI	SAID DJAMAL EDDINE	**LOUNAOUSSI MEROUA**	7/12/2023