Designing a Self-healing Composite Material for Aerospace Structural Components

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Abstract –*The aerospace industry demands materials that exhibit incomparable durability and reliability under harsh functioning conditions. Composite materials have emerged as a promising solution due to their lightweight properties and high strength-to-weight ratio. However, these materials are susceptible to damage, which can compromise structural integrity and safety. To address this challenge, the concept of self-healing composite materials has garnered significant attention. This abstract presents a comprehensive overview of the ongoing research efforts aimed at designing self-healing composite materials for aerospace components. The primary objective is to investigate self-healing technologies in the aerospace industries. We explore various self-healing mechanisms, including microcapsule-based, vascular, and intrinsic healing, and their applicability to aerospace composites. The design process involves selecting compatible healing agents, encapsulation methods, and activation triggers while ensuring minimal weight gain and maintaining the material's mechanical properties.Furthermore, this abstract discusses the benefits and challenges of self- healing composites. Finally, to propose the potential application in aerospace industry and develop self- healing materials that are compatible with existing aerospace manufacturing and maintenance processes. In conclusion, the development of self-healing composite materials holds great promise for enhancing the performance, safety, and sustainability of aerospace components.*
Keywords: *Light-Weight, High Strength to Weight Ratio, Intrinsic Healing, Encapsulation Methods*

I INTRODUCTION

Self-healing composite materials represent a groundbreaking innovation in the field of aerospace engineering, offering remarkable potential to enhance the durability, reliability, and safety of critical aerospace components. In an industry where every ounce counts and structural integrity is paramount, the development of self-healing composites. The aerospace industry is known for its unrelenting pursuit of innovation and excellence, with a constant drive to improve the performance, safety, and sustainability of its components and structures. In this relentless quest, a groundbreaking technology has emerged as a potential game-changer: self-healing composite materials. These materials have the remarkable ability to autonomously detect and repair damage, offering a transformative solution to one of the most pressing challenges in aerospace engineering - maintaining the integrity of critical components under extreme conditions. Sites stands as a testament to human ingenuity and the relentless pursuit of excellence. These extraordinary materials possess the unique ability to autonomously detect and mend damage, presenting a transformative solution to a critical challenge faced by aerospace engineers worldwide - maintaining the structural integrity and longevity of essential components in the harsh conditions of flight.

A. Background

The aerospace industry is perpetually driven by a relentless pursuit of technological advancement and innovation. With a primary focus on enhancing the safety, performance, and longevity of aerospace components, engineers and researchers continually seek materials that can withstand the extreme conditions and stresses inherent to flight. Traditional composites have been instrumental in achieving lightweight structures and fuel efficiency, but they have limitations when it comes to damage tolerance and maintenance. In this context, the concept of self-healing composite materials has emerged as a groundbreaking solution to address these limitations. These materials are designed to mimic some of the remarkable regenerative abilities found in nature, such as the way our skin heals after an injury. By integrating self-healing capabilities into aerospace components, engineers envision a future where the need for costly and time-consuming repairs is significantly reduced, thus increasing operational efficiency and safety. The development of self-healing composite materials is deeply rooted in the interdisciplinary fields of materials science, chemistry, engineering, and nanotechnology. Researchers have drawn inspiration from various natural mechanisms, such as vascular systems in plants or clotting processes in the human body, to design composite materials that can autonomously detect and repair damage caused by environmental factors, fatigue, or impacts. These materials typically consist of microcapsules or vascular networks filled with healing agents, such as resins or polymers, that are strategically embedded within the composite matrix. When damage occurs, these healing agents are released, flow into the affected area, and undergo chemical reactions that restore the material's structural integrity. The development and application of self-healing composite materials hold the promise of significantly extending the service life of aerospace components, reducing maintenance costs, and enhancing overall safety and the schematic representation of incorporation of the self-healing composites in shown in Figure 1. As the aerospace industry seeks to push the boundaries of performance and efficiency, self-healing composite materials have emerged as a compelling solution to address the inherent challenges of maintaining structural integrity under extreme conditions. This background sets the stage for a deeper exploration of the principles, development, and potential applications of self-healing composites in aerospace components.

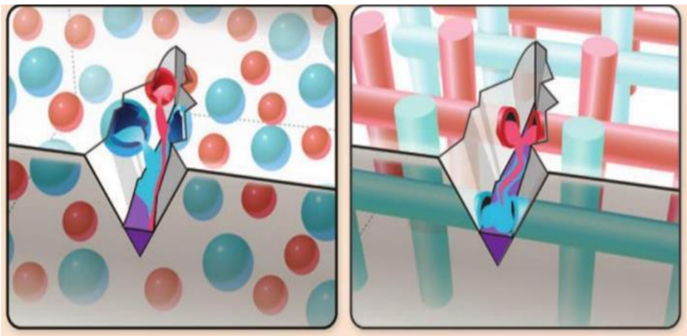

Figure 1 Schematics of Self-Healing Composites Incorporating

B. Design Considerations

Designing self-healing composite materials for the aerospace industry involves careful consideration of various factors to ensure their effectiveness, reliability, and suitability for aviation applications. Incorporate a reliable damage detection system that can identify cracks, impacts, or other forms of damage in real-time. This system can trigger the self-healing process when damage is detected. Choose an appropriate healing mechanism based on the type of damage expected in aerospace environments. Options may include microcapsules filled with healing agents, vascular networks, or shape-memory polymers. The healing mechanism should be compatible with the composite matrix. Ensure that the healing agent is compatible with the composite matrix material and does not degrade its structural integrity or performance. The healing agent should also be stable under aerospace operating conditions, such as temperature and pressure variations. Design an activation mechanism that releases the healing agent when damage occurs. This mechanism should be reliable and responsive to different types of damage, such as cracks or punctures. Distribute the healing agents or materials uniformly throughout the composite structure to ensure that they can reach damaged areas effectively. The distribution method should minimize any negative impact on the composite's mechanical properties. Self-healing mechanisms may involve temperature changes. Ensure that these temperature changes do not adversely affect the surrounding components or materials in the aerospace system. Minimize the added weight and mass of the self-healing system. Weight is a critical factor in aerospace design, so any increase in weight should be justified by the benefits of self-healing. Thoroughly test and validate the self-healing composite materials under realistic aerospace conditions, including vibration, pressure, temperature extremes, and radiation exposure. Ensure that the self-healing composites are compatible with other materials commonly used in aerospace applications, such as metals, ceramics, or other composites. Evaluate the long-term reliability of the self-healing system. Consider factors such as the lifespan of the healing agent, the frequency of inspections and maintenance, and the expected service life of the aerospace component. Design the self-healing composite materials with manufacturability in mind. Ensure that the manufacturing processes are scalable and cost- effective for aerospace production. Assess the environmental impact of the self-healing materials, including the disposal of any chemicals or materials used in the healing process. Ensure that the self-healing composite materials comply with relevant aerospace regulations and standards. This may involve extensive testing and certification processes. Conduct a thorough cost-benefit analysis to determine whether the benefits of self-healing composites, such as reduced maintenance costs and increased durability, outweigh the additional production and maintenance costs. Consider the scalability of the self-healing technology to ensure it can be applied to various aerospace components and structures of different sizes and complexities. Designing self-healing composite materials for the aerospace industry is a complex and interdisciplinary endeavor that requires collaboration between materials scientists, engineers, and aerospace experts. It also involves ongoing research and development to refine the technology and make it practical for real-world aerospace applications.

C. Advantages of Self-Healing Composites

Self-healing composites offer several advantages in the aerospace industry, where the reliability and performance of materials are of utmost importance. Self-healing composites can repair small cracks and damage without human intervention, which can significantly extend the lifespan of aerospace components. This is crucial for reducing maintenance costs and increasing the overall durability of aircraft. Self-healing materials can help prevent catastrophic failures by addressing damage as it occurs. This can improve safety for both passengers and crew, as well as reduce the risk of accidents caused by structural failures. Traditional composite materials often require frequent inspections and repairs, leading to significant downtime for aircraft. Self-healing composites can reduce the need for such inspections and maintenance, minimizing aircraft downtime and increasing operational efficiency. Weight is a critical factor in aerospace design, as it directly impacts fuel efficiency and overall performance. Self-healing composites can potentially replace heavier materials and conventional repair systems, resulting in weight savings. Although self-healing composites may initially be more expensive to produce than traditional materials, they can ultimately lead to cost savings over the life of an aircraft due to reduced maintenance and longer service life. Self-healing composites can help maintain the structural integrity of aerospace components, ensuring they perform as intended throughout their service life. This can lead to improved overall performance, especially in harsh environments or extreme conditions. Aerospace companies are increasingly focused on sustainability. Self-healing composites can help extend the life of aircraft components, reducing the need for replacements and minimizing the environmental impact associated with manufacturing and disposal. Aerospace components are exposed to a wide range of environmental factors, including temperature variations, moisture, and UV radiation. Self-healing composites can help mitigate the effects of these factors, maintaining their structural integrity over time. The adoption of self-healing composites in aerospace demonstrates the industry's commitment to innovation and the integration of cutting-edge technology, which can enhance the reputation of aerospace manufacturers. While self-healing composites offer numerous advantages, it's important to note that their widespread adoption in the aerospace industry may still be in the developmental or experimental stages as of my last knowledge update in September 2021. Researchers and engineers continue to work on refining these materials and overcoming challenges to make them a standard in aerospace applications.

D. Disadvantages of Self-Healing Composites Materials

While self-healing composites offer several advantages, they also come with certain disadvantages and challenges when considering their application in the aerospace industry. Complexity of Manufacturing: The production of self-healing composites can be more complex and expensive than traditional composites. Integrating the healing mechanisms and materials into the composite structure may require specialized manufacturing processes and equipment. Self-healing composites can be more expensive to produce initially due to the incorporation of healing agents and complex manufacturing processes. The higher upfront costs may pose a barrier to their widespread adoption in the aerospace industry. Depending on the self-healing mechanisms used, these composites may be heavier than traditional materials. Weight is a critical consideration in aerospace design, and any increase in weight can negatively impact fuel efficiency and overall performance. Self-healing composites are typically designed to repair small-scale damage, such as microcracks or small punctures. They may not be effective in repairing larger or more extensive damage, which could still require traditional repair methods. While self-healing composites reduce the need for some types of maintenance, they may require specialized inspections and maintenance procedures to ensure that the healing mechanisms are functioning correctly. This adds complexity to maintenance routines. The long-term reliability and durability of self-healing composites are still areas of active research and development. It can be challenging to predict how these materials will perform over extended periods of time, particularly in harsh aerospace environments. Integrating self-healing composites into existing aerospace structures and designs may require significant engineering and testing efforts. Compatibility with other materials and systems must be carefully considered. Some self-healing mechanisms may involve the use of chemicals or materials that could raise environmental concerns during manufacturing, use, or disposal. Aerospace companies need to consider the environmental impact of these materials. As of my last knowledge update in September 2021, self-healing composites were still in various stages of research and development. They may not be readily available for all aerospace applications, and further research and testing are needed to ensure their reliability and effectiveness. Aerospace companies must carefully weigh the benefits of self- healing composites, such as reduced maintenance costs and increased durability, against the higher initial costs of manufacturing and potential weight penalties. It's important to note that ongoing research and advancements in materials science and aerospace engineering may address some of these disadvantages over time. As the technology matures and becomes more practical and cost-effective, the disadvantages associated with self-healing composites may become less significant, potentially leading to broader adoption in the aerospace industry.

II LITERATURE SURVEY

In this section, literature available on developing a self-healing composite material for aerospace components has been reviewed. To achieve economic feasibility, fuel efficiency and cost reductions.

A. Review of Published Literature

[1] presented self-healing composites for aerospace applications exclaiming about all the numerous concepts that have proved to be remarkably efficient in polymer, ceramic and metal matrix, composites. These developments could pave the way to several applications, specifically in the fields of aerospace. These self- healing abilities are achieved by using microcapsules, vascular networks, dissolved thermoplastics and reversible interactions in the polymer matrix composites. Fiber matrix de-bonding, matrix microcracking and impact damage are major failure modes routinely encountered in the applications of composite materials. Furthermore, deployment and maintenance of composite materials pose a challenge

for critical structural parts, such as wings and fins. Hence, advanced materials and methodologies are essential to address these problems.

[2] presented research and development in self- healing composite material exclaims that self-healing materials are artificial or synthetically created substances that have the built in ability to automatically repair damage to themselves without any external diagnosis of the problem or human intervention. This article presents the current research and developments in self-healing composite materials. A detailed study is conducted on various types of self-healing composites with their self-healing mechanisms. The applications of self-healing materials in various fields including space sector is also discussed. Economics and Future outlooks for self-healing smart materials is highlighted at the end of the article. This research article will be useful to manufacturers, policy makers and researchers widely.

[3] presented self - healing materials and their applications that Self-healing materials are a class of smart materials which are inspired by biological systems. They have a structurally incorporated ability to repair damage caused by mechanical usage over time. A material that can intrinsically correct damage caused by normal usage could lower costs of different industrial processes through longer part lifetime, reduction of inefficiency as well as prevent costs incurred by material failure. They were first observed during roman times in mortars however their development began only at the close of the 20th century. It is a well-known fact that the initiators for structural failures include micro cracking and hidden damages. Repairing at remote locations is taxing and not easy or convenient. This is where self-healing materials have a great potential, thereby increasing the longevity of the structural materials. The property possessed by self-healing materials have a wide range of applications such as self-healing space crafts, satellites, used for geographical studies, GPS and in Automotive industries. Whenever a living organism experiences a superficial injury like a cut or a bruise, the defense system kicks in and forms a protective layer over it called a scab to begin the repair process. Self-healing materials are analogous to these systems. They have the ability to condition the mechanical damage incurred during any operation. There is tremendous growth in investments being made from both government and private industries.

[4] presented Development of self- healing composite materials: fabrication and micro- structural. Analysis which detailed about the healing properties and efficiency of polymeric materials based on thermally reversible Diels-Alder crosslinking have been previously discussed and demonstrated in the literature. In this work a modified RTM method for the fabrication of a self-healing composite material using this healable polymer matrix is described. The thermos- mechanical properties of the healable composite were investigated in order to select the temperature for the application of a suitable healing thermo-cycle. From these experiments two major conclusions can be drawn. First, the material clearly displays a drop of stiffness when the temperature approaches the glass transition temperature of the matrix polymer. This suggests that an ideal healing cycle should be conducted at temperatures which do not affect the structural performance of the material, particularly in cases where the healing is carried out while the component is subjected to external loads. Second, we were able to evaluate the material quality through the analysis of the X-ray reconstructed images and presence of distributed voids was observed to be less than 1.2%.

Reconstructed three dimensional images also demonstrated healing of microcracks within CFRP samples.

[5] presented self- healing nano composites for advancements and aerospace applications which explained about the comprehends the use of self-healing nanocomposites in the aerospace sector. The self-healing behavior of the nanocomposites depends on factors such as microphase separation, matrix–nanofiller interactions and inters- diffusion of polymer–nanofiller. The mechanism of self-healing has been found to operate via physical or chemical interactions. Future research must emphasize the design of new high-performance self-healing polymeric nanocomposites for aerospace structures. Self-healing nano composites are advanced materials that possess the ability to autonomously repair damage or cracks at the nanoscale without external intervention. These materials have gained significant attention in various industries, including aerospace, automotive, construction, and electronics, due to their potential to extend the lifespan and durability of products while reducing maintenance costs.

III PROBLEM STATEMENT, OBJECTIVES & SCOPE

A. Problem Statement

The aerospace industry relies heavily on advanced materials to ensure the structural integrity, safety, and performance of aircraft and spacecraft components. Composite materials, known for their lightweight and high-strength properties, have gained widespread use in aerospace applications. However, these materials are susceptible to damage from various sources, including impact, fatigue, and environmental factors. To address these challenges and improve the durability of aerospace components, there is a pressing need to develop reliable self-healing composite materials. Aerospace components, such as aircraft fuselages and wings, are subjected to mechanical stress and environmental conditions that can lead to damage, including cracks and delamination in composite materials. Ensuring the long-term structural integrity of these components is critical for safety and operational efficiency. The aerospace industry incurs significant costs in maintaining and repairing damaged components. Reducing maintenance costs by developing self-healing composites can lead to substantial economic benefits. Safety is paramount in the aerospace industry. Any compromise in the structural integrity of components can lead to catastrophic failures. Self-healing materials can enhance the reliability of aerospace systems and reduce the risk of failures. Aerospace components must perform reliably under extreme conditions, including high temperatures, low temperatures, and exposure to radiation. Developing self-healing composites that can function in such environments is a considerable challenge. Aircraft weight is a critical factor affecting fuel efficiency and overall performance. Self-healing materials should not add significant weight to the components, as this could negate the benefits gained from their use.

The aerospace industry operates on a large scale, requiring materials that can be manufactured consistently and in large quantities. Developing scalable manufacturing processes for self-healing composites is essential. New materials used in aerospace must undergo rigorous testing and certification processes to ensure they meet safety and performance standards. Developing self-healing composites that can meet these criteria is a significant hurdle.

B. Objectives

The main objective of this work are:

1. Investigate self-healing technologies in aerospace materials.
2. Design a Self-Healing material using CAD software. Analyze the benefits and limitations of self-healing composites.
3. Conduct simulation on self-healing material 3D design that are compatible with the existing aerospace manufacturing and maintenance processes.
4. Involve in multiple 3D prototyping and arrive in the most efficient, Beneficiary model.

C. Scope

Self-healing materials offer promising potential in the aerospace sector, primarily due to their ability to autonomously repair damage, which can enhance the longevity and safety of aerospace components. Increased Durability: Aerospace structures are subjected to various environmental factors such as extreme temperatures, pressure differentials, and mechanical stresses during flight. Self-healing materials can repair small cracks and damages that occur during operation, thereby increasing the durability and lifespan of aerospace components. Reduced Maintenance Costs: The autonomous repair capability of self-healing materials can reduce the need for frequent inspections and maintenance interventions, leading to cost savings for aerospace companies. This is particularly beneficial for components in remote or difficult-to-access areas of aircraft. Enhanced Safety: Self-healing materials can help prevent catastrophic failures by repairing damage before it compromises structural integrity. This is critical in ensuring the safety of passengers and crew, especially in high-stress environments like aerospace.

Weight Savings: Traditional repair methods often involve adding extra material or reinforcements, which can increase weight and fuel consumption. Self-healing materials offer a lightweight solution by autonomously repairing damage without the need for additional components, thus contributing to fuel efficiency and reducing emissions.

Versatile Applications: Self-healing materials can be incorporated into various aerospace components, including airframes, wings, engine components, and spacecraft structures. They can also be tailored to specific requirements, such as temperature resistance, flexibility, or strength, making them suitable for a wide range of applications.

Research and Development Opportunities: The development of self-healing materials for aerospace applications presents opportunities for research and innovation in material science, chemistry, and engineering. Advancements in this field could lead to the discovery of new materials with even better self- healing properties and performance characteristics. Challenges and Limitations: Despite their potential benefits, self-healing materials also pose challenges such as scalability, cost-effectiveness, and compatibility with existing manufacturing processes. Overcoming these challenges will require further research and collaboration between material scientists, engineers, and aerospace manufacturers.

IV METHODOLGY

A. Material Selection

Self-healing composite materials are fascinating innovations that can repair damage autonomously, extending their lifespan and functionality. Choosing the right material for self-healing applications involves considering several criteria to ensure optimal performance and functionality. Some key criteria to consider:

Self-Healing Mechanism: Understanding the mechanism by which the material heals itself is fundamental. Different materials employ various self- healing mechanisms, such as intrinsic reversible bonds, microvascular systems, or capsule-based systems. The chosen mechanism should align with the application requirements and environmental conditions.

Healing Efficiency: The material's ability to efficiently and effectively heal damage is crucial. Factors such as healing rate, healing capacity (size and frequency of healing events), and the extent of healing (degree of restoration of mechanical properties) should be evaluated.

Durability: The durability of the self-healing mechanism is essential to ensure long-term functionality. Materials should be capable of enduring multiple healing cycles without significant degradation in performance.

Compatibility: Compatibility between the healing agent, matrix, and other components of the composite is vital to ensure proper integration and functionality. Incompatible materials may lead to reduced healing efficiency or compromised mechanical properties.

Mechanical Properties: The mechanical properties of the self-healing material, including strength, stiffness, toughness, and fatigue resistance, should meet the requirements of the intended application. The incorporation of reinforcing materials may be necessary to enhance mechanical performance.

Environmental Stability: The material should be stable under relevant environmental conditions, including temperature variations, humidity, UV exposure, and chemical exposure. Environmental stability ensures the longevity and reliability of the self- healing functionality.

Processing Compatibility: Consideration should be given to the compatibility of the self-healing material with processing methods used for fabrication. Materials should be processable using common techniques such as moulding, extrusion, or additive manufacturing without compromising healing capabilities.

Cost: Cost considerations are important, especially for large-scale or commercial applications. The cost- effectiveness of the self-healing material, including raw material costs, processing costs, and potential savings from extended lifespan or reduced maintenance, should be evaluated.

Scale-up Potential: The feasibility of scaling up production of the self-healing material to meet commercial demands should be assessed. Scalability is essential for transitioning from laboratory-scale research to practical applications.

Safety and Health: The safety and health implications of using the self-healing material, including toxicity, handling requirements, and disposal considerations, should be evaluated to ensure compliance with regulations and standards.

Therefore, the materials used for this study by us will be Matrix: Epoxy Resin Microcapsules Due to its excellent adhesive properties, high strength and good chemical resistance and Reinforcement: Glass Fibers since it provides good strength as well as stiffness at a lower cost than carbon fiber. The properties of these materials are listed in the Table 1 and Table 2.

Table 1 Properties of Resin Epoxy

Properties	Values
Density	1160Kg/m^3
Young's modulus	3.78E+09 Pa
Poisson's ratio	0.35
temperature	22 C
Thermal conductivity	0.2 W/mK

Table 2 Properties of Glass Fibres

Properties	Values
Density	2500Kg/m^3
Young's modulus	9E+10 Pa
Poisson's ratio	0.22
temperature	22 C
Thermal conductivity	1.03W/mK

B. Designing of a Composite Material

Designing the geometry of a self-healing composite material in Solid Edge involves creating a detailed model of the composite structure using the software's modeling tools. Begin by defining the dimensions and layers of the composite material, considering factors such as the desired strength, stiffness, and overall performance. Using Solid Edge's features such as extrusions, sweeps, and blends, construct the geometry of the composite material, specifying the arrangement of glass fibers within the epoxy resin matrix. Pay attention to the distribution of fibers to optimize mechanical properties and ensure uniform reinforcement throughout the material. Incorporate features within the composite structure to accommodate the self-healing mechanism, such as channels or reservoirs where the healing agent can flow when damage occurs. Design these features to facilitate the effective distribution of the healing agent and promote efficient healing of the material. Iterate on the design as needed, making adjustments to improve performance and optimize the geometry for the specific application of the composite material. Throughout the design process, utilize Solid Edge's tools for 3D modeling and visualization to create a comprehensive representation of the self-healing composite material geometry. Top view of the microcapsule, epoxy resin and glass fibers are shown in Figure 2, 3 and 4 respectively. The 3D modeling representation of epoxy resin, glass fiber reinforcement and Microcapsules filled with Healing Agent is shown in Figure 5, 6 and 7 respectively.

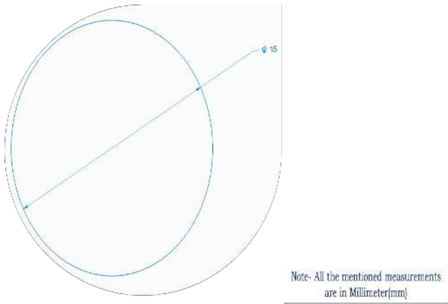

Figure 2 Top View of Microcapsules (Diameter-15 mm)

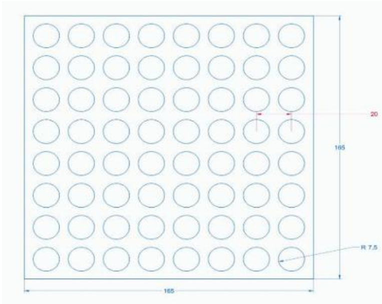

Figure 3 Top View of Epoxy Resin (Dimensions in mm)

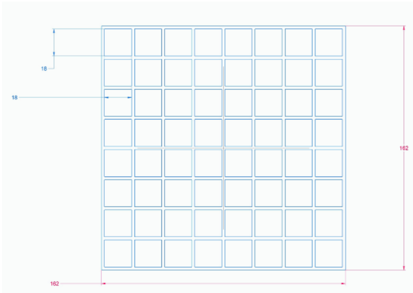

Figure 4 Top view of Glass fibers (dimensions in mm)

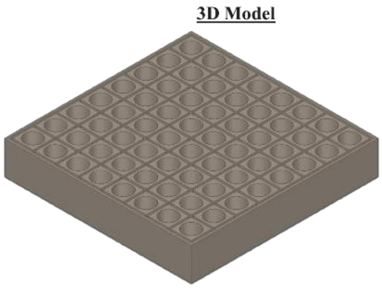

Figure 5 3D Modeling of Epoxy Resin

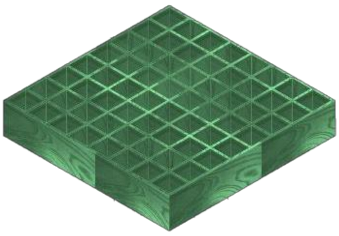

Figure 6 3D Modeling of Glass Fiber Reinforcement

Figure 7 3D Modeling of Microcapsules Filled with Healing Agent

Urea formaldehyde is a widely used healing agent in self-healing composites due to its excellent properties. In self-healing materials, such as polymers or composites, urea formaldehyde acts as a reservoir of healing agents that are released when damage occurs. When cracks or fractures appear in the material, the urea formaldehyde is triggered to react, filling in the gaps and restoring the material's integrity. The healing process involving urea formaldehyde typically involves the formation of polymeric networks within the damaged areas. These networks effectively seal off the cracks, preventing further propagation and restoring the mechanical properties of the material. Additionally, urea formaldehyde exhibits good adhesion to various substrates, ensuring that the healed regions remain bonded to the surrounding material. One of the key advantages of using urea formaldehyde as a healing agent is its relatively low cost and widespread availability. It can be easily incorporated into different types of composites, ranging from polymers to fiber- reinforced materials, making it suitable for various applications. Furthermore, urea formaldehyde-based healing systems can be tailored to specific requirements by adjusting the formulation and processing parameters, offering flexibility in design and performance optimization.

C. Analysis of a Self- Healing Composite Material

The analysis of self-healing composite materials, comprising epoxy resin and glass fibres, using ANSYS software offers a comprehensive understanding of their mechanical behaviour and healing capabilities. ANSYS enables engineers to simulate various loading conditions and assess how these materials respond to external stresses, such as bending or impact. Through finite element analysis (FEA), ANSYS can predict stress distribution, deformation patterns, and potential failure modes within the composite structure. In the case of self-healing composites, ANSYS facilitates the evaluation of healing mechanisms, such as microcapsules containing healing agents dispersed within the resin matrix. By modelling the release and flow of these healing agents under different conditions, engineers can assess the effectiveness of the healing process in restoring the structural integrity of the material after damage. Furthermore, ANSYS allows for the optimization of composite designs to enhance self- healing properties while maintaining mechanical performance. The scaled down 3D model and meshing of the composite material with healing agent is represented in Figures 8 and 9 respectively. By iteratively testing different configurations and material compositions, engineers can identify the most efficient combination of epoxy resin, glass fibres, and healing agents to achieve desired levels of durability and resilience.

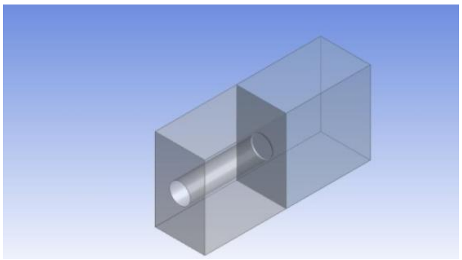

Figure 8 Scaled Down 3D Model of the Composite Material with Healing Agent

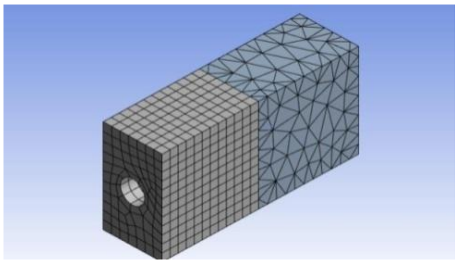

Figure 9 Meshing of Scaled Down 3D Model of the Composite Material with Healing Agent

Meshing a self-healing composite material composed of epoxy resin and glass fibres in ANSYS involves several key steps. Initially, you need to prepare the geometry, ensuring it's clean and error-free. Then, to configure mesh settings, specifying parameters like element size and type to accurately capture the material's behaviour. Since composites often have heterogeneous properties, adjusting mesh sizing for different regions, such as resin and fibre areas, is essential. Next, assign material properties for epoxy resin and glass fibres using ANSYS's material libraries. It's crucial to select properties that reflect the self- healing capabilities of the material if available. Once materials are defined, generate the mesh, employing techniques like swept meshing for fibres and tetrahedral meshing for resin regions. Quality mesh ensures accurate representation of geometry and material behaviour. With the mesh in place, set boundary conditions and loads according to your analysis requirements, such as constraints and forces. Then, configure the analysis type and solver settings before initiating the solution process. Post-processing involves analysing results, visualizing stress/strain distributions, and assessing the material's performance. ANSYS offers various tools for post-processing, aiding in result interpretation.

V RESULTS AND DISCUSSION

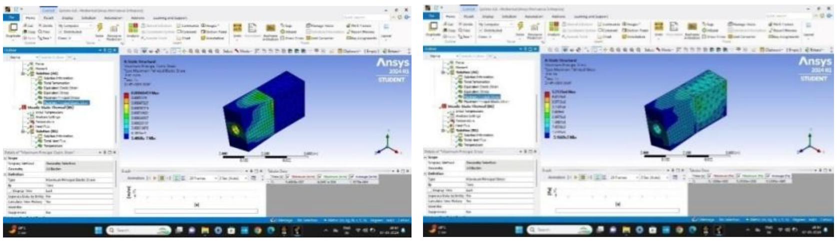

Figure 10 Static Structural Analysis using ANSYS

Figure 10 shows the Static Structural Analysis using ANSYS and from results it is identified a Maximum Principal Elastic Strain of 1.1579×10−41.1579×10−4. This strain value signifies the highest level of deformation experienced by the material under the applied loads. The small magnitude of this strain suggests that the material is experiencing minimal elongation or deformation. In the context of our analysis, this strain level is within acceptable limits and does not raise immediate concerns regarding structural performance. Further investigation into other aspects of the analysis will be conducted to comprehensively evaluate the behavior of the structure under varying conditions. The static structural analysis conducted in ANSYS resulted in the determination of the maximum principal stress within the analyzed structure, measured at 5.3295 × 10^5 Pascals (Pa). The maximum principal stress represents the highest magnitude of stress experienced by the material in the structure under the applied loading conditions. This stress value is crucial for assessing the structural integrity and safety of the component, as it indicates the level of mechanical stress that could potentially cause failure or deformation

We conducted a static structural analysis using ANSYS, powerful finite element analysis software. One of the critical outcomes of this analysis was the determination of the Equivalent (von-Mises) stress within our model. The von-Mises stress is a scalar value used to represent the complex stress state at a particular point in a material, combining the effects of normal and shear stresses. The specific Equivalent (von-Mises) stress obtained from our analysis was 9.4195e+005 Pa (or 941,950 Pa). This stress value signifies the equivalent uniform stress that would produce the same effect, in terms of deformation, as the actual stress state in our structure. In simpler terms, it quantifies the maximum effective stress experienced by the material, accounting for all components of stress—tension, compression, and shear. The analysis conducted in ANSYS revealed an Equivalent Elastic Strain value of 1.5732e-004. Equivalent Elastic Strain refers to the deformation or elongation experienced by a material under an applied load, which in this case corresponds to a strain value of 0.00015732. This strain value indicates the relative amount of deformation in the material due to the applied mechanical forces, such as tension, compression, or bending. The specific value of 1.5732e-004 (or 0.00015732) indicates a deformation that is within the elastic limit of the material, meaning that upon removal of the applied load, the material is expected to return to its original shape and size. This analysis result provides valuable insights into the structural performance and integrity of the component under study, aiding in the design optimization and ensuring that the material operates within safe deformation limits under anticipated operational conditions.

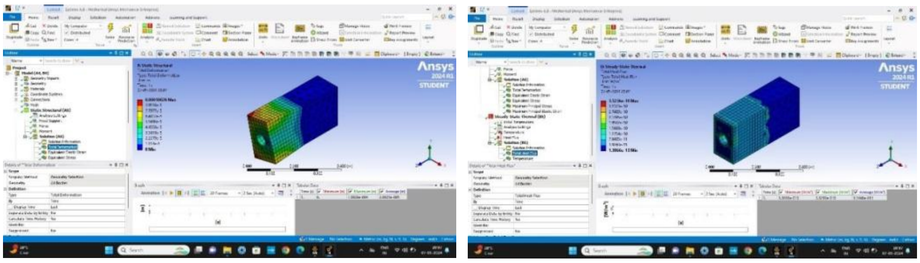

Figure 11 Steady State Thermal Analysis

The total heat flux represents the amount of heat energy passing through a unit area per unit time in a steady state thermal analysis and it is shown in Figure 11. In this context, a heat flux of $3.3468\times10-11$ W/m^2 means that for every square meter of the analyzed surface, $3.3468\times10-11$watts of thermal energy is transferred per second. This extremely low value indicates a very minimal heat transfer rate across the surface under investigation. The heat flux value is particularly significant in understanding the thermal behavior and performance of the system or component being analyzed. In practical terms, such a low heat flux suggests either a very small temperature difference driving the heat transfer or a material with extremely low thermal conductivity.

After conducting static structural analysis using Ansys, the total deformation observed in the model was determined to be $2.6925\times10-5$ meters. This deformation value represents the overall displacement experienced by the structure under the applied loads. It indicates how much each point on the model has moved or deformed from its original position due to the applied forces and boundary conditions in the analysis. The obtained temperature distribution of 22 degrees Celsius validates the effectiveness of our simulation approach and informs subsequent design decisions.

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