Smart Composite Structures used as an Actuators

A Thesis submitted by

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DEDICATION

This thesis is dedicated to

Our Parents, Siblings, and Teachers.

For the absolute affection and support during that time I spent away from home. For their guidance and time which they spent on me to improve my skills. With whom efforts, prayers, and dedications we'reable to stand, have support to walk and features to fly.

CERTIFICATE

This case study carried out and written by **Ehtisham Ghalib (19-NTU-PE-1008)** and **M. Aftab Alam (19-NTU-PE-1016)** under the direction of their supervisor, **Dr. Zakariya Zubair**, and approved by all the members of the Project Committee of the department, has been presented to and accepted by the Chairman, Department of Materials and Dean, School of Engineering & Technology in fulfillment of the requirement of degree Bachelor of Science in Polymer Engineering.

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Student Declaration

We declare that this dissertation "**Smart Composite Structures used as an Actuators**" is the result of our own except as cited in references. This dissertation has not been accepted for any degree and is not concurrently given in candidature of any other degree.

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List of Abbreviations

SMP (Shape Memory Polymer)

SMM (Shape Memory Materials)

SMPC (Shape Memory Polymer Composite)

GFRP (Glass fiber polymer reinforced composites)

CFRP (Carbon Fiber Polymer Reinforced Composites)

DSC (Differential scanning calorimetry)

DMA (Dynamic mechanical analysis)

ILSS (Interlaminar Shear strength)

Tg (Glass Transition Temperature)

Sustainable Development Goal (SDG#9)

Figure 1 Industry, Innovation, and Infrastructure

Industry, Innovation, and Infrastructure

The Sustainable Development Goals include things like developing inclusive and sustainable development, creating environmentally friendly architecture, and fostering innovation. 9. This SDG addresses three essential aspects of sustainable development: infrastructure, industry, and innovation. Infrastructure provides the essential physical systems and structures needed for a neighborhood or company to operate. Industrialization encourages economic growth, creates job opportunities, and reduces income poverty. New talent development is encouraged through innovation, which also improves the technological capabilities of many industrial sectors. Thanks to inclusive and sustainable industrial expansion, which also provides the technological tools necessary for industrialization that is ecologically benign, all people's living standards may increase fast and steadily. Applications and Our Project will contribute to This Objective.

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ABSTRACT

Glass fiber reinforced composites have significant promise for the creation of functional composites by leveraging the capabilities of epoxy resin and composite design shape memory behaviour and polymer shape memory behaviour. The purpose of this research is to use experimental measurements to examine the shape memory behaviour of a thermally active Glass composite. For interpreting the properties DSC and DMA of the samples were preformed to analyze the recovery behaviour of composite with external stimuli of temperature This accomplishment may lead to the use of multilayer SMP composites as thermally active actuators.

Keywords:

SMP, SMPC, Shape recovery, Electrical actuation, Thermal actuation, Investigation of rigid fabric composite.

Chapter 1

1.1 Introduction

SMPs are a type of materials that recover their original shape after being deformed by any external stimulus like heat, light, or moisture. SMPs are a type of intelligent substance that can recognize changes in their surroundings and respond predictably to them.

A polymer chain's ability to switch between two states a high-temperature or "soft" state and a low-temperature or "hard" state is what gives SMPs their shape memory function. A temporary shape can be fixed by heating an SMP while it is bent. The polymer chains are then locked onto the new shape as the SMP is cooled. The material can then be warmed up to put the chains back in their original state and shape.

SMPs are a novel and fascinating class of materials that have the potential to change the structure and operation of many systems and devices.[1]

1.2 Stimulus methods of SMPs

Shape memory polymers (SMPs) are substances which change shape when influenced by an external stimulus like pH or temperature. The choice of stimulus technique has great influence in performance and reaction of the SMP. There are many stimulus methods to produce the shape-memory behaviour in SMPs as.[3] Thermal Stimuli, light Stimuli, pH Stimuli.

1.3 Structural categorization of SMPs

Shape memory polymers (SMPs) classified as intelligent material which return to original shape in response to a specific stimulus. SMPs can be classed in a number of ways based on various traits. [2] [1]

1.4 Thermoplastic Shape Memory Polymers

These are form memory polymers (SMPs) that exhibit shape memory activity when exposed to temperature stimuli (SMPs). Thermoplastic SMPs have remarkable properties, which include outstanding processability, exceptional shape memory performance, and great mechanical strength.[4], [5]

1.4.1 Trigger Temperature:

The trigger temperature for thermoplastic SMPs is often higher than the polymer matrix's T_g (Glass Transition temperature). The glass transition temperature is Range at which polymer goes from rubbery to glass sate, allowing the polymer chains to move more freely and triggering the shape memory effect. [4], [5]

1.5 Shape Recovery:

The temporary crosslinks are dismantled with rise of temperature to the trigger point, allowing chains to migrate and take on their original structure. Crosslink density, molecular weight, and processing conditions, among other things, can have an impact on how thermoplastic SMPs recover their shape.

1.6 Synthesis of Thermosetting SMPs:

To make thermosetting SMPs, chemical processes are performed to crosslink polymer chains. The processes for creating thermosetting SMPs are numerous and include:

Epoxy-based crosslinking, the method used the most frequently, involves the reaction of an epoxy resin with a curing agent. The chemical interaction between thiol groups and double bonds between carbon atoms is known as thiol-ene click chemistry. additional methods, including Michael addition, Diels-Alder reaction, and radical polymerization.[6], [7]

1.7 Recent Scientific Studies on Thermosetting SMPs:

Recent scientific studies have focused on the development and application of thermosetting SMPs. Here are some concrete examples:

The effects of adding sulfonic acid-functionalized graphene oxide to thiol-ene crosslinked poly(-caprolactone) SMPs were examined in "Enhanced Shape-Memory Performance of Thiol-Ene Crosslinked Poly(-caprolactone) with Sulfonic Acid-Functionalized Graphene Oxide," Liang et al. (2020). The results show that adding graphene oxide raised the crosslinking amount, which improved the SMPs' ability to store shapes.

Zhang et al 2020.'s work on the synthesis of a bioinspired shape-memory polyurethane (PU) with dynamic covalent bonds was titled "Bioinspired Shape-Memory Polyurethane with Dynamic Covalent Bonds." Because of its exceptional shape-memory performance and mechanical qualities, the PU was a potential material for biomedical applications.

Wang et al. (2021) developed thermoset shape-memory polymers utilising polyurethane and epoxy as the building blocks in their paper titled "Thermoset Polyurethane with Epoxy." polyurethane improved mechanical capabilities of epoxy-based SMPs while maintaining their shape-memory qualities.

1.8 OWSME (One-way Shape Memory Effect)

The following are some crucial elements of OWSME: The substance is heated over its T_g and then bent to a temporary shape in order to programmed an SMP to display OWSME. After that, cooled less then T_g, "locking in" transient form. The phase occurs when SMP is heated over Tg once more. The material is capable of regaining its previous shape while in the rubbery state. When a material needs to be temporarily deformed before resuming its original shape in reaction to outside inputs, OWSME might be helpful. In biomedical devices like stents, which can be momentarily compressed for implantation into the body before restoring their original shape once there, SMPs with OWSME, for example, can be used. OWSME may also be limited in circumstances that call for repetitive or more intricate deformations of the material. Then, in this case, the two-way form memory effect comes into play.

1.9 TWSME (Two-way Shape Memory Effect)

SMPs takes on a more complex form in TWSME: In order to train an SMP to display TWSME, the material is first heated over its T_g and twisted into a temporary shape. The material is then cooled below T_g to "lock in" the temporary shape. The substance is then bent into a second temporary shape while being heated over T_g once more. The material is then once more cooled below T_g to "lock in" the second temporary shape. When the SMP is heated over T_g once more, when a material needs to be deformed more than once or in a more sophisticated way, TWSME can be useful. SMPs with TWSME, for instance, might be utilised to create materials that can change shape or for robotics. TWSME may have limitations in applications requiring a high level of precision since the programming and recovery procedures may be more involved with TWSME than with OWSME. The TWSME's multiple programming stages can also cause the material's mechanical characteristics to deteriorate.

SMPs can display both OWSME and TWSME, each has unique benefits and restrictions in a range of applications. Additional study and development in this field could result in creative and original uses for SMPs and their shape.[8], [9]

1.10 SMPCs composites and on their different types

SMPs often lack the necessary mechanical qualities for these applications. Shape-memory polymer composites (SMPs) can be reinforced with fibers or particles to get around this restriction (SMPCs). Fiber- and particle-reinforced SMPCs are the two primary subcategories of SMPCs.

1.10.1 Particle-Reinforced SMPCs:

Particle-reinforced SMPCs are composite materials where the polymer matrix's mechanical strength has been boosted by the addition of particles. To enhance SMPCs, many particle kinds can be employed, such as small alloy-based particles the mechanical properties of the resulting SMPC can be enhanced by adding these SMPs to a polymer matrix. These composites' behaviour depends on a variety of parameters, including the concentration, size, and structure of the SMPs. Comprised of inorganic granules: To create particle reinforced SMPCs, inorganic particles like glass beads, silica nanoparticles, or carbon nanotubes can be combined with a polymer matrix.

1.10.2 Fiber-Reinforced SMPCs:

In fiber-reinforced SMPCs, fibres are added to the polymer matrix to enhance its mechanical properties. There are several types of fiber reinforced SMPCs, to make these composites, continuous fibres like carbon or glass fibres are mixed with the polymer matrix. The fibres may be oriented in a certain way to enhance the final composite's mechanical characteristics. Aerospace and automotive applications typically use SMPCs with continuous fiber reinforcing.[1], [10]

Chapter 2

2.1 Literature Review

Significant study has been done on shape memory materials ever since the 1960s, when the form memory phenomenon in metal alloys was discovered (SMMs). SMMs can be used in disciplines like biomedical, aerospace engineering, civil engineering thanks to this special feature.

Early research on SMMs mostly concentrated on metal alloys, especially those containing copper. It was demonstrated that these materials had shape memory due to a reversible martensitic transformation, which is a change from high to low temperature phases. When heated above transition temperature into the high-temperature phase, a material that has been distorted in the low-temperature phase can restore its previous shape.

It was found that polymers and ceramics also exhibited the shape memory effect as the field of SMM research expanded. Polymer-based SMMs have attracted a lot of interest for use in stents, scaffolds, and drug delivery systems because of their biocompatibility and adaptability. Ceramics have also been researched for usage in high-temperature products including brake pads and aircraft parts.

One of the biggest challenges in the creation of SMMs has been comprehending the underlying mechanics that result in the shape memory effect. X-ray diffraction, electron microscopy with heat analysis in order to understand the microstructural changes that occur during deformation and recovery.

The development of novel SMMs with enhanced properties has been a major area of research in addition to figuring out the basic mechanics creating of materials with specialized transition temperatures, enhanced mechanical characteristics, and the capacity to react to a variety of outside stimuli.

The development of SMM has led to a wide range of applications across many sectors. Orthopedic implants, sutures, and stents that may change shape in response to body temperature are made using SMMs in biomedical engineering. In order to improve fuel efficiency, morphing wing designs that can change their shape while in flight are being investigated in the aerospace industry. In civil engineering, SMMs are used to design adaptable structures that can change the way they look in response to shifting environmental conditions.

Background research on SMMs has been motivated by the need to understand the mechanics underlying the shape memory effect and to develop innovative materials with improved characteristics. As a result, several applications have been created in numerous other disciplines, and there is yet room for the creation of even more ground-breaking and revolutionary applications in the future. As our understanding of SMMs continues to expand, we might expect to see a lot of more intriguing advancements in the years to come.[1], [2]

In reaction to external stimuli, a subclass of materials called stimulus-responsive shape memory polymers. Major objectives of introduction are to provide a thorough understanding of SMPs and to highlight recent advancements in SMP research. All of the SMPs that have been developed are based on different switching methodologies. These processes can also be triggered by thermal, electrical, magnetic, pH, solvent, and light cues, among other things. The switching mechanism to be utilised will be determined by the precise application requirements and the necessary environmental conditions for the SMP to operate.

The review of the developments in SMP research in this chapter emphasizes the discovery of novel materials, understanding the fundamental principles governing shape memory behaviour, and looking into new applications. In order to increase the performance of SMPs in terms of shape memory, significant progress has been made, including raising the material's stability and durability as well as boosting shape recovery ratios and the shape fixity.

Shape memory polyurethane (SMPU), a particular SMP, is described. SMPU is recognized due to its outstanding advantages over other SMPs in terms of applications. Due to its wide range of adaptive characteristics, including as mechanical strength, flexibility, biocompatibility, and chemical resistance, polyurethanes are suitable for biomedical, and high-performance industries like automotive and aerospace.

This chapter serves as an introduction to the study of SMPs and establishes the framework for further research into their unique properties and applications. It prepares the reader for the in-depth examination of the specifics of stimuli-responsive shape memory polymers, including their manufacture, characterization, processing approaches, and applications in diverse industries, that will take place in later chapters.

In the study you presented, you used experimental data to investigate how thermally active 3D multilayer composites behave in terms of shape memory. The aim is to examine how polymer shape memory properties can be combined with 3D reinforced preforms to produce useful composites.

The researchers began by making multilayer shape memory polymer (SMP) composite samples as a basis for their analysis. These samples come with a carbon fiber active layer. A crucial characteristic of these composites is their capacity to produce internal heat via the Joule effect on the active carbon layer. In other words, the carbon fibers are subjected to an electrical current that causes heat and activates SME.

Researchers use a big bending test approach to electrically actuate test the multilayer SMP composite samples. This requires the application of controlled sample bending and measurement of the reactions.

The excellent demonstration of the multilayer SMP composites' shape memory behaviour and consistently responsive actuation response paves the way for their potential usage as electroactive actuators. These actuators may convert electrical energy into mechanical motion in response to electrical inputs, enabling controlled and programmed shape changes.

The combination of 3D woven design and SMP properties of polymers offers a variety of advantages for the production of functional composites. By utilising the benefits of 3D reinforcement with reversible SME, the composites can be used in a range of applications, including actuation systems, smart structures, and adaptive materials.

Overall, the study highlights the potential of multilayer SMP composites, which invites further research and development in this area.[1]– [3], [6]– [10]

In comparison to any other human-made actuator, EAP (Electroactive Polymer) nearly resemble human and other biological natural muscles; for this reason, they have been given the name "artificial muscles." Early in the field's development, materials that produced low actuation strain attracted little attention because of this.

A number of Electroactive materials have appeared which show substantial change in response to electrical stimulus. They were able to produce and demonstrate a variety of fascinating and innovative mechanisms, such as robot aquatic muscle.

Tissue engineering and microfluidic devices are two examples of novel uses. Numerous engineers and scientists working in a variety of fields are being drawn in by the remarkable improvements in their actuation strain. Since these materials may be utilised to create intelligent robots and other systems that are inspired by living things, they are very appealing for biomimetic applications.

More and more EAP-actuated mechanisms with broad application potential are being developed. This chapter examines the current level of knowledge, difficulties, and possible uses of EAP materials.

Living systems utilize intricate sensing mechanisms, actuating and regulating mechanisms, and feedback control systems to adapt their structure and functionality to fluctuations in nature. Therefore, nature may be thought of as the ideal example a scientist can have in mind when designing novel materials and applications; the overarching objective is to build materials with dynamic and programmable qualities that match the active microenvironment that happens in nature.

When the environment changes slightly, smart polymers or stimuli-responsive polymers experience reversible, significant physical or chemical changes in their characteristics. Depending on the physical state of the chains, they can react to a single or multiple stimulus like temperature, pH, electric or magnetic fields, light intensity, biological molecules, etc. that cause macroscopic responses in the material like swelling, collapse, or solution-to-gel transitions.

Smart linear macromolecules that have been solubilized will change from a monophasic to a biphasic state close to the transition conditions, giving birth to reversible sol-gel states. When a network transitions from a collapsed to an enlarged state, smart cross-linked networks go through chain reorganization. Responsive interfaces are provided by smart surfaces, which alter their hydrophilicity in response to an external stimulus.

All of these modifications may be utilised to create smart devices for a variety of uses, such as minimally invasive injection systems, pulsatile drug delivery systems, or novel substrates for cultured cells or tissue engineering applications.

Polymers have been one of the most amazing materials in recent years for biomedical applications due to their great biocompatibility and degradation. The versatility and functions of polymers, which allow them to develop from bioactive hydrogels to recyclable polymers, are an additional distinctive quality of these materials. Along with it, it encompasses a wide range of production processes, including electro-spinning, 3D printing, extrusion, casting, and micro fluidity.

To expand the functions and variety of characteristics of polymers, new nanocomposites can be created by strengthening particles into a matrix of polymers. For purposes including medication delivery, the engineering of tissues, and healing wounds, polymer composites are therefore now the subject of extensive research.

In this context, the development of electroactive smart polymers that can transport electrons under certain electric fields opens up a wider range of technical applications, including those for sensors and robotics.

Due of the electro mechanical characteristics of electroactive polymers, researchers have recently been drawn to them. Since these kinds of actuators have advantages beyond just being lightweight and simple to make, some dielectric polymers may be able to deliver higher rates of strain. Particularly for medical uses like pumps and micro values, this strain level is employed. The Figure 2 shows the applications of SMPs

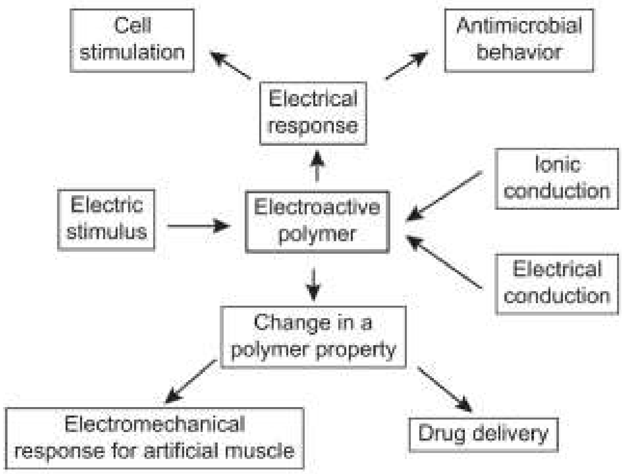

Figure 2 SMP Applications

2.2 Applications of SMPs:

Potential applications for thermosetting SMPs include Thermosetting SMPs can be used to create implantable devices that can adjust to changes in body temperature or other inputs. They can be used to create drug-delivery systems that can release drugs in response to a specific trigger or to create stents that fit the shapes of blood arteries. Aerospace applications, such as morphing airfoils or wing structures that may change shape in reaction to temperature or airflow fluctuations, can use thermosetting SMPs.

2.2.1 Epoxy as SMPs

Epoxy is a versatile thermosets polymer that has been widely employed in a variety of industries, including aerospace, automotive, construction, and electronics. Epoxy has recently attracted increasing interest as a shape-memory polymer (SMP) due to its exceptional mechanical properties and strong heat stability. In this essay, we will look into epoxy's features as an SMP, current scholarly investigation, and potential applications.[3], [8], [9]

2.2.2 Properties of Epoxy as an SMP:

Epoxy possesses outstanding shape-memory properties that allow it to quickly change shape in reaction to a stimulus like heat, light, or moisture before quickly returning to its original shape. Epoxy has excellent mechanical strength, making it suitable for a variety of structural applications. The figure 3 shows the Typical Properties of Epoxy

Epoxide Value	ASTM D 1652-04	5.15 - 5.40
Density @25°C	ASTM D 1475-98	1.16 g/ml
Water content	ASTM E 203-01	0.05 % max.
ECH content	TEC-AS-P-023	10 ppm max.
Non-volatile content	ASTM D 1259-06	100 %
Flash point	ASTM D 93	252 °C

Figure 3 Typical Properties of Epoxy

Epoxy is readily processed into a wide range of shapes and sizes using a variety of techniques, including injection moulding, extrusion, and 3D printing. [1], [10]

2.2.3 Thermal shape memory behavior

The SMP is heated over its glass transition temperature to produce thermal shape memory behaviour (T_g). Indicators of this kind of behaviour include when SMP is heated over T_g, a phase shift from a glassy to a rubbery state takes place. Rubbery materials can be easily molded into a short-term shape. Even after cooling below T_g, the SMP retains its transitory structure. When heated over T_g again, the SMP takes on its original, unchanged shape once more. [8], [9] The Figure 4 shows morphing structures made of SMPs

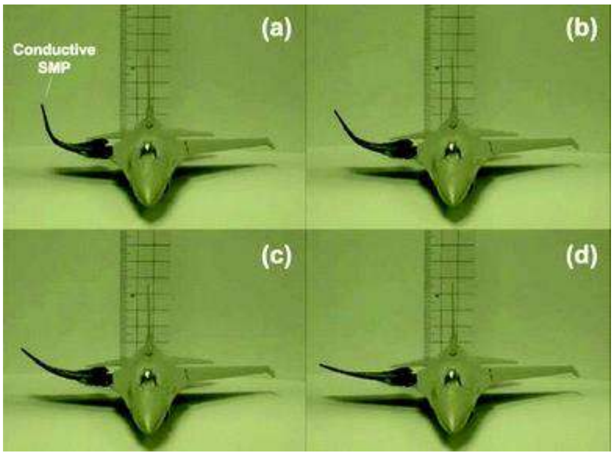

Figure 4 Morphing Structure in Fighter Jet Wing

2.3 Research gap

Rigid fabric shape memory polymer composite materials:

Characterization and Optimization of Shape Memory Properties despite significant advancements in the development of shape memory polymer (SMP) composite materials, particularly in flexible and soft matrices, there is a research gap regarding the characterization and optimization of shape memory properties in stiff fabric SMP composites. The incorporation of shape memory effect in stiff fabric composites has not been adequately addressed in the majority of current studies because of the inherent shape memory properties of flexible matrices.

2.4 Research Objectives

Building Rigid Fabric Composite Structures: Design and Construction the main objective of the work is to design and fabricate stiff fabric composite structures that can benefit from the potential for actuation of shape memory polymers.

SMP Composites with thermally active Properties: Design and Production the second objective is to produce thermally active SMP composites. This will enable the application of electrical stimulation to trigger temperature and the impact of form memory.

Chapter 3

3.1 Materials and Experimental Setup

Material selection: Glass fabric and carbon fibers are typically two reinforcing materials, epoxy resin and hardener for SMPs. Think about things like mechanical characteristics, shape memory behaviour, and compatibility with glass fibers. Also consider the glass transition temperature (T_g). Glass fiber selection: **200 GSM** glass woven cloth is used to support the SMP composite. To customize the mechanical properties and improve the performance of the composite, consider the fiber diameter, length, and orientation. The Following Figures 5, 6, 7 show the Materials used in Experimentation

Figure 5 Matrix

Figure 7 Carbon Fiber

Figure 6 Glass Fabric

3.2 Method for Composite fabrication:

Technique hand lay-up was used. Layers of the glass fiber reinforced SMP composite were prepared and trimmed to a size of 4 cm (approximately 1.57 in) x 12 cm (about 4.72 in). Usually, the SMP matrix is impregnated into glass fibers prepared and trimmed to a size of 4 cm (approximately 1.57 in) x 12 cm (about 4.72 in). Usually, the SMP matrix is impregnated into glass fibers. Hand lay-up can be used to ensure proper fiber distribution and resin infiltration. The Figure 8, 9 shows fabrication process of composite

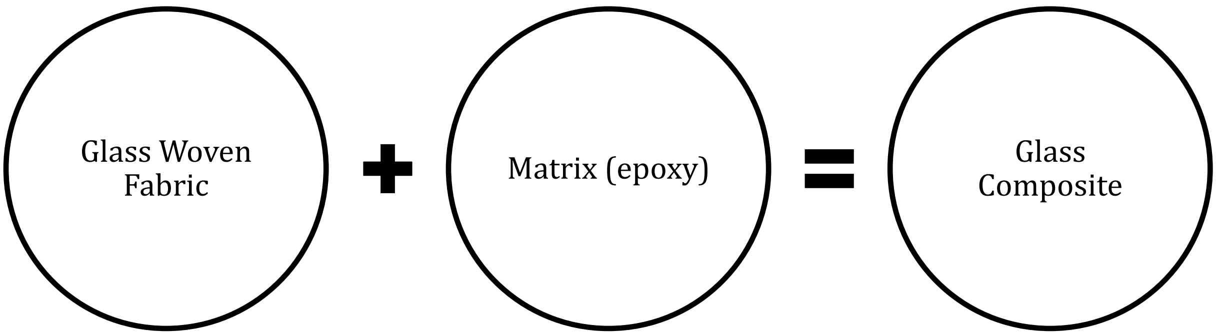

Figure 8 Fabrication Process

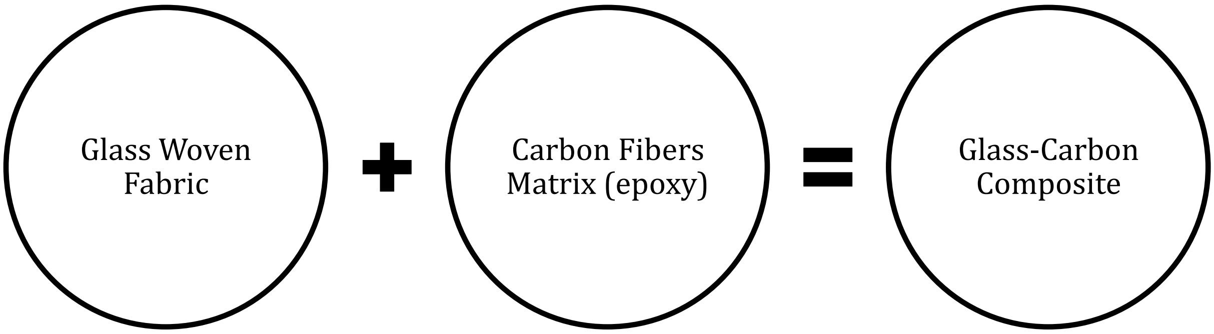

Figure 9 Fabrication Process II

Glass fabric is cut into suitable dimensions for the single, double, and triple layer composite. Layers are staked on each other and mixture of 70% epoxy and 30% hardener is applied on them with the help of roller by using hand-layup method all the samples are cured for 24 hours so that epoxy and glass layers are bonded with each other.

The Figure 10, 11 shows Method and Samples Prepared by that method of Hand lay-up

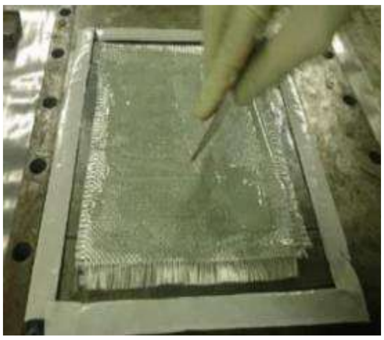

Figure 10 Hand Layup Method

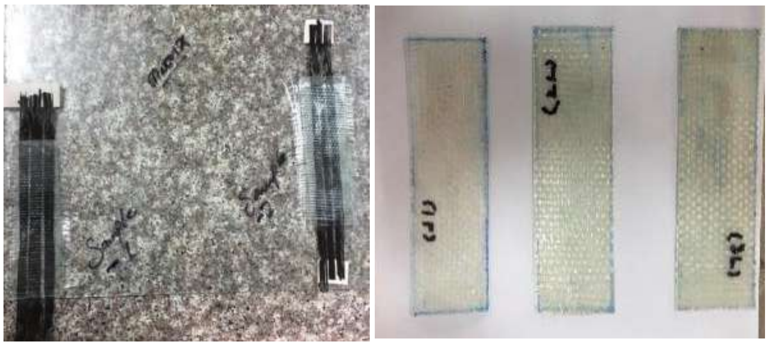

Figure 11 Samples of Composite

Shape memory cycle

When exposed to an external stimulus, such as Joule heating, light, magnetism, or moisture, the shape memory cycle for SMPs can restore its original shapes after significant deformation. The Figure 12 shows Shape Memory Cycle

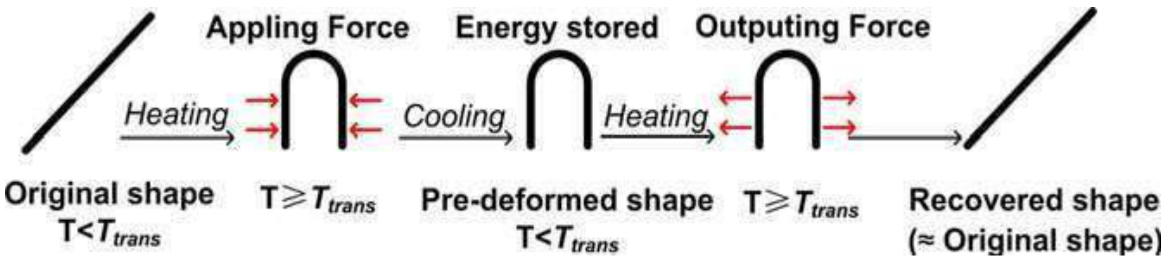

Figure 12 Shape Memory Cycle

Fabrication of the SMPs into an original shape. Heating the SMP above the thermal transition temperature (T_{trans}). Deformation of the SMP by applying an external force – cooling well below $T_{trans.}$ Removal of the constraint to obtain a temporary pre-deformed shape and heating of the pre-deformed SMP again above T_{trans} that results in the recovery of the SMP towards its original shape called as recovered shape. The figure 13 shows the Shape Deformation Apparatus.

Figure 13 Shape Deformation Apparatus

3.3 Characterizations for Investigation:

3.3.1 DSC (Differential Scanning Calorimetry)

DSC works by detecting the differential in heat flow while a sample and a reference material are heated or cooled under controlled conditions. This makes it possible to identify endothermic and exothermic reactions taking place inside the SMP sample.

Mechanism of DSC Glass Transition Temperature (T_g) of SMPs, for the behaviour of shape memory and programming temperatures of the material, can be found via DSC. The melting temperature T_m, at which the crystalline parts of polymer change from a solid to a liquid state, found using DSC if the SMP is semi-crystalline polymer.

Figure 14 DSC (Differential Scanning Calorimetry)

3.3.2 DMA (Dynamic mechanical analysis)

The basic idea behind DMA is to change the temperature across a specified range while applying a little oscillatory stress or strain to the SMP sample.

Mechanism of DMA We measure and examine the mechanical response of the sample, particularly its storage modulus (E'), loss modulus (E''), and damping characteristics. Depending on the particular research goals and the geometry of the SMP specimen, DMA is frequently carried out in either the tensile or the bending modes.

Storage Modulus (E') is measurement of a material's stiffness or elastic response is its storage modulus. Loss Modulus (E'') is connected to the material's damping characteristics, represents the energy lost as heat under cyclic loading. The glass transition temperature T_g of SMPs may be precisely determined via DMA. A key temperature range known as the glass transition is where a material changes from a stiff, glassy condition to a more flexible, rubbery state. DMA exposes the complex modulus (E*) and loss factor (tan) of SMPs, as well as other viscoelastic characteristics. The material's capacity to store and release energy during deformation and shape recovery is described by these properties.

Figure 15 DMA (Dynamic mechanical analysis)

3.3.3 ILSS (Interlaminar shear strength)

A crucial mechanical property test known as interlaminar shear strength (ILSS) is used to evaluate the shear resistance of composite materials along a plane parallel to the layers or plies of the composite laminate. Material Characterization: Since different composite materials have variable shear strength qualities, ILSS testing gives useful information for material selection.

The composite's ultimate mechanical characteristics may change as a result of the curing procedure. The Figure 16 Shows the ILSS Machine.

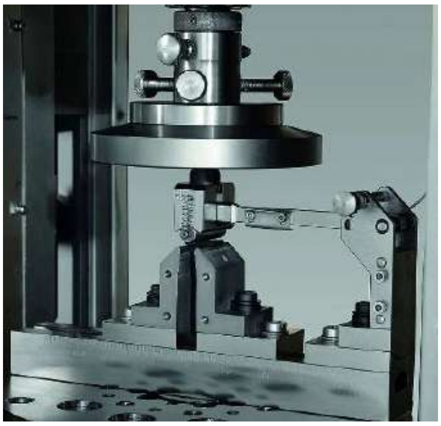

Figure 16 ILSS (Interlaminar shear strength)

3.4 Synthesis of Shape Memory Polymer Composites

In order to create shape memory polymer composites, shape memory polymers (SMPs) are added to composite materials. 200 GSM glass fabric was used for reinforcement. To create the SMP matrix, the matrix mixture is composed of 30% hardener and 70% epoxy resin.[1], [2]. The "shape deforming temperature" is the temperature at which a polymer is subjected to a particular strain and given a temporary shape. This temperature is very important because it affects the SMP's overall performance. It could be higher, lower, or equal to T_g. The temperature ranges are 45, 65, and 85 degrees Celsius. A warped SMP is fixed in its temporary shape at this operating temperature.

It is assumed that the fixing temperature will be 45°C below the T_g for the glassy SMPs. Although the crystallization temperature, which is lower than the transition temperature, is the fixing temperature for semi-crystalline SMPs, these materials are frequently chilled to a temperature that is 40°C below the transition temperature. The recovery temperature is the temperature at which a permanent shape can be recovered. Transformation, switching, or responsive temperature are some other names for it. The temperature at which deformation occurs during the first stage of the SM cycle is T_g, which is typically 20°C higher than this. The Figure 17-18 show the mold and mold fixing.

Figure 18 Mold for Shape Fixing **Figure 17 Shape Fixing**

Shape fixity: An SMP's capacity to maintain the strain that was applied to the sample during the deformation stage after cooling and unloading is characterised by this property. The fixed displacement (dF) to maximum displacement ratio (RF) is calculated (d_{max}) The equation shows the shape fixity ratio as Shown in Equation 1 expressed below.

$$\text{Shape fixity ratio, } R_f = \left[\frac{\varepsilon_u(N)}{\varepsilon_m}\right] \times 100\%$$ ------------------ Equation 1

3.5 Shape recovery:

Shape recovery describes an SMP's capacity to undo the strain that was generated during the deformation process after cooling and unloading, then warming to the rubbery state. There are two ways to define it. The first method involves dividing the retrieved displacement by the fixed displacement.

45°C single layer:

The Figure 19 shows shape Recovery of Single Layer Glass composite is observed in 40 seconds with the interval of 10 seconds

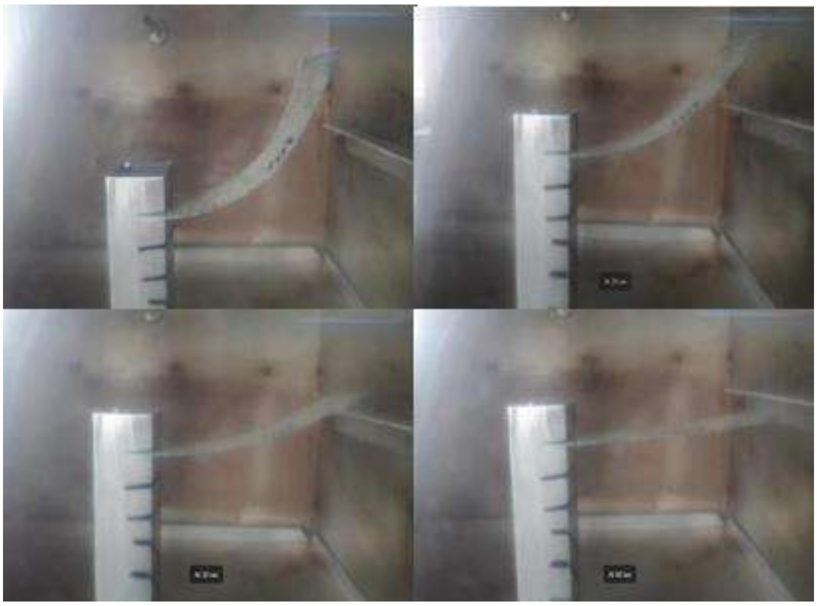

Figure 19 Shape Recovery of Single Layer Glass composite in 40 seconds

Double layer at 45°C:

The Figure 20 shows shape Recovery of Double Layer Glass composite is observed in 115 seconds with the interval of 20 seconds

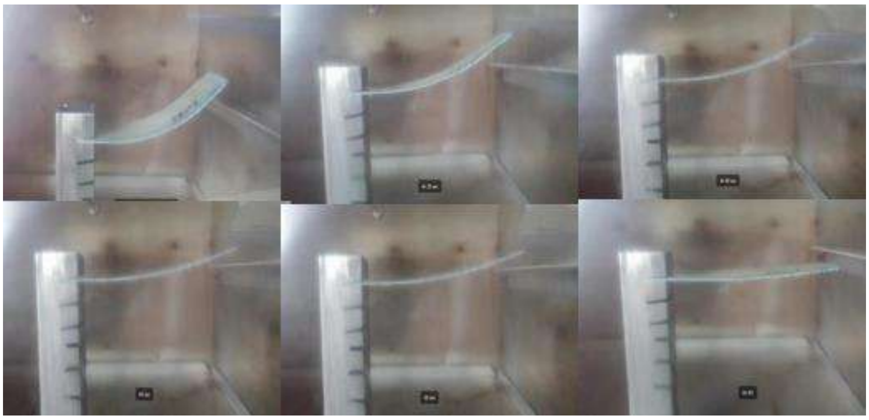

Figure 20 Shape Recovery of Double Layer Glass composite in 115 seconds

Triple layer at 45°C:

The Figure 21 shows shape Recovery of Triple Layer Glass composite is observed in 120 seconds with the interval of 40 seconds

Figure 21 Shape Recovery of Triple Layer Glass composite in 120 seconds

Single layer at 65°C:

The Figure 22 shows shape Recovery of Single Layer Glass composite is observed in 20 seconds with the interval of 10 seconds

Figure 22 Shape Recovery of Single Layer Glass composite in 20 seconds

Double layer at 65°C:

The Figure 23 shows shape Recovery of Double Layer Glass composite is observed in 40 seconds with the interval of 20 seconds

Figure 23 Shape Recovery of Double Layer Glass composite in 40 seconds

Triple layer at 65°C:

The Figure 24 shows shape Recovery of Triple Layer Glass composite is observed in 100 seconds with the interval of 20 seconds

Figure 24 Shape Recovery of Triple Layer Glass composite in 100 seconds

Single layer at 85°C:

The Figure 25 shows shape Recovery of Single Layer Glass composite is observed in 10 seconds with the interval of 2 seconds

Figure 25 Shape Recovery of Single Layer Glass composite in 10 seconds

Double layer at 85°C:

The Figure 26 shows shape Recovery of Double Layer Glass composite is observed in 20 seconds with the interval of 5 seconds

Figure 26 shape Recovery of Double Layer Glass composite in 20 seconds

Triple layer at 85°C:

The Figure 27 shows shape Recovery of Triple Layer Glass composite is observed in 35 seconds with the interval of 10 seconds

Figure 27 Shows shape Recovery of Triple Layer Glass composite in 35 seconds

Chapter 4

4.1 Results and Discussion

4.1.1 Shape recovery Time

The Time it takes for a polymer matrix glass composite to regain its original shape following deformation is referred to as the shape recovery time. It may differ based on the type of polymer used, the reinforcing used. The figure 28 shows Shape Recover time of three composite samples prepared.

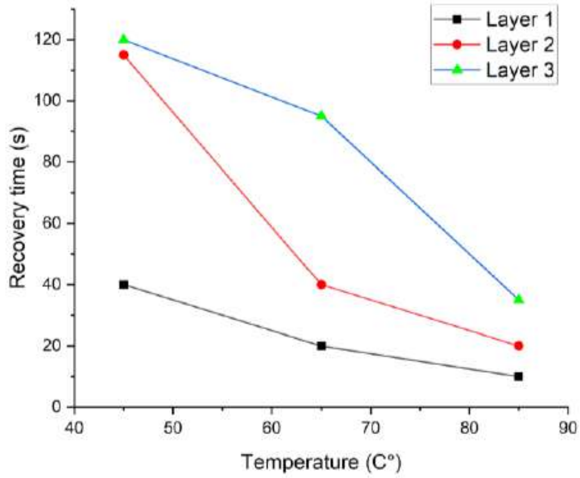

Figure 28 Shape Recover time of Three composite samples prepared L1, L2, L3 wrt to the Temperature given in controlled environment

4.1.2 Speed of Recovery

Velocity of recovery is a measurement of how fast the composite regains its original shape after being deformed. Connected with shape memory materials, "remember" their original shape and revert to it under specific circumstances, such as temperature fluctuations. The figure 29 shows Recover speed of three composite samples prepared calculated by following formula of speed. $\mathbf{v} = \frac{s}{t}$ -------- Equation 2

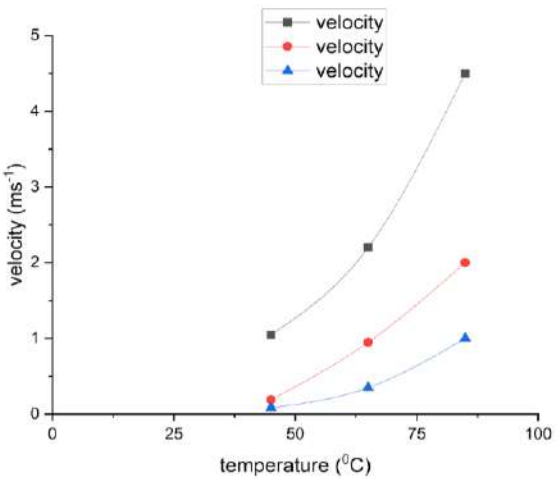

Figure 29 Recover speed of Three composite samples prepared L1, L2, L3 wrt to the Temperature given in controlled environment

4.1.3 Shape fixity ratio.

The degree to which a polymer matrix glass composite maintains its distorted shape following stress is determined by its shape fixity ratio. Higher values denote greater form preservation, and the value is a dimensionless number between 0 and 1.

When the stress is released, a composite with a high shape fixity ratio will likely continue to preserve its distorted shape, but one with a low value would likely do so more quickly. Figure 30 shows Shape fixity (%) ratio of three composite samples prepared

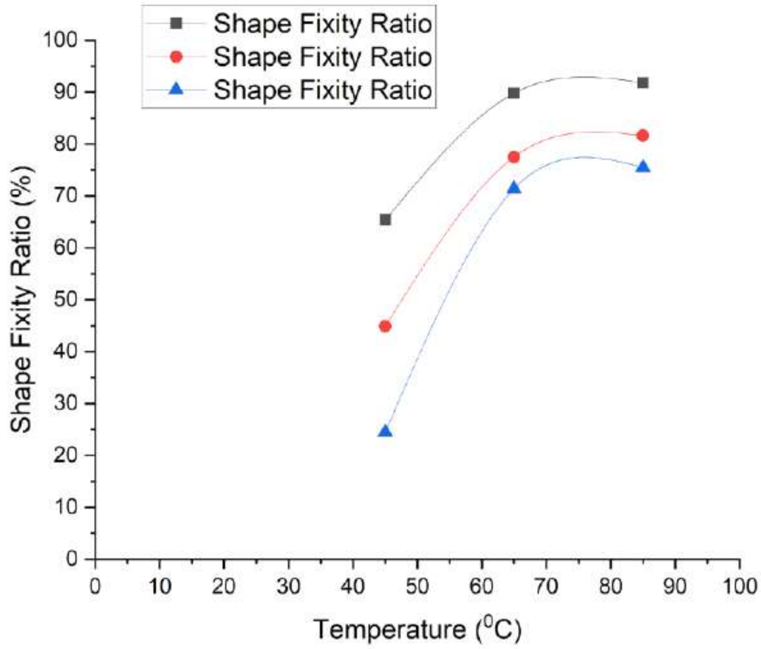

Figure 30 Shape fixity (%) ratio of Three composite samples prepared L1, L2, L3 wrt to the Temperature given in controlled environment

4.1.4 DSC (Differential Scanning Calorimetry)

DSC offers details on the heat flow connected to the SMPs' thermal transitions. The heat absorbed or emitted during these transitions is seen by the region beneath the endothermic or exothermic peaks in the DSC curve. This measurement can be used to determine how much energy goes into shape memory processes and gauge how effective the shape memory effect is. The $T_{g\ is}$ 65.37 ºC for Composite and 63.37 ºC for Resin. The Figure 31 shows DSC Graph Describes the Tg of the Composite of Epoxy and Glass Fiber Composite and the resin itself.

Graphical Presentation of Result:

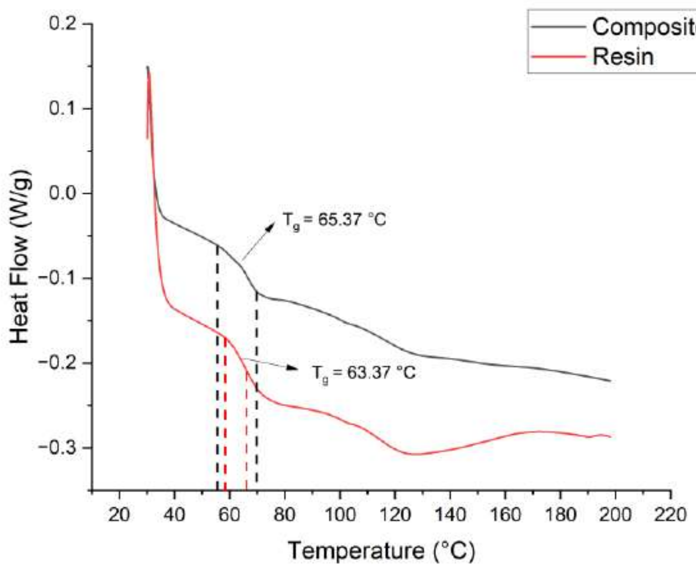

Figure 31 DSC Graph Describes the Tg of the Composite of Epoxy and Glass Fiber Composite and the resin itself.

4.1.5 DMA (Dynamic mechanical analysis)

Shape memory polymer viscoelastic characteristics and behaviour are characterised using the potent technique known as dynamic mechanical analysis (DMA) (SMPs).

Storage Modulus (E'): The shift of the material from a glassy state to a rubbery state can be seen by using DMA to measure how the storage modulus of the SMP changes with temperature. The figure 32 shows DMA Graph (Storage Modulus) the curves of L1, L2, L3 are presented in the graph

Graphical Presentation of Results:

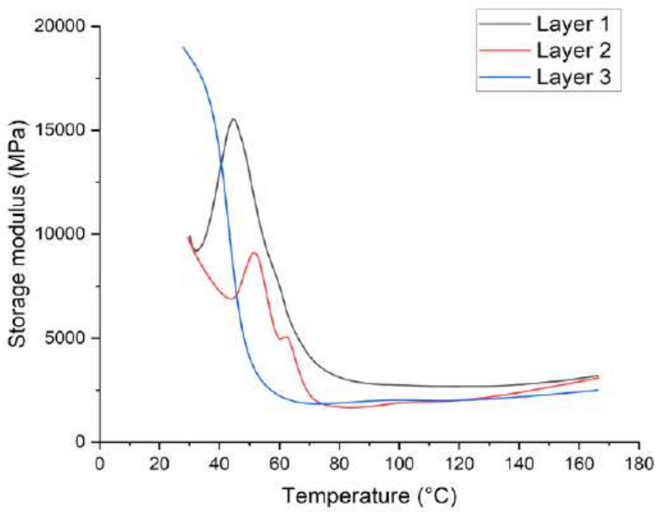

Figure 32 DMA Graph (Storage Modulus) the curves of L1, L2, L3 are presented in the above graph

Loss Modulus (E"): The loss modulus, which is connected to the material's damping characteristics, represents the energy lost as heat under cyclic loading. The figure 33 DMA Graph (loss Modulus) the curves of L1, L2, L3 are presented in the graph

Graphical Presentation

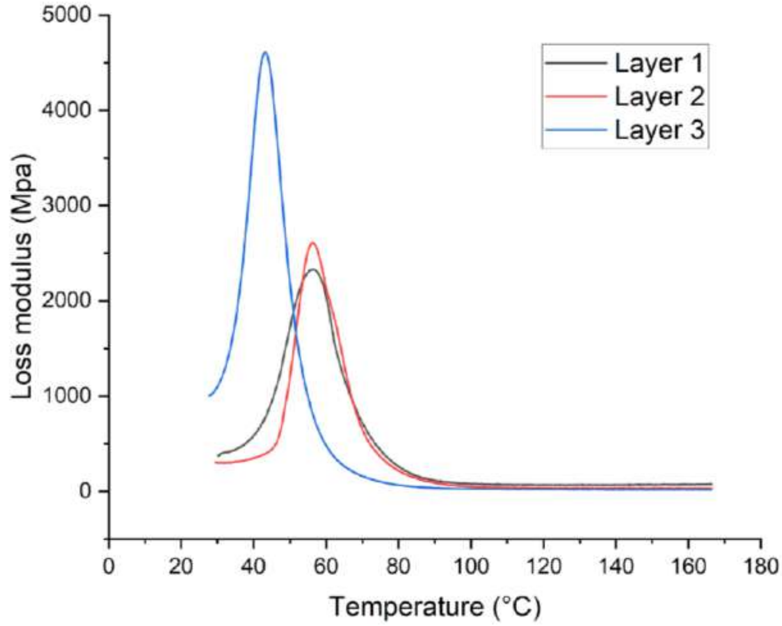

Figure 33 DMA Graph (Loss Modulus) the curves of L1, L2, L3 are presented in the above graph

Tan delta: The indicator of the specimen's elastic behaviour is the storage modulus, which might be either E' or G'. The tan delta, also known as damping, is the ratio of loss to storage. It is a measurement of a material's energy loss. The figure 34 shows DMA Graph (Tan Delta) the curves of L1, L2, L3 are presented in the graph

Graphical Presentation

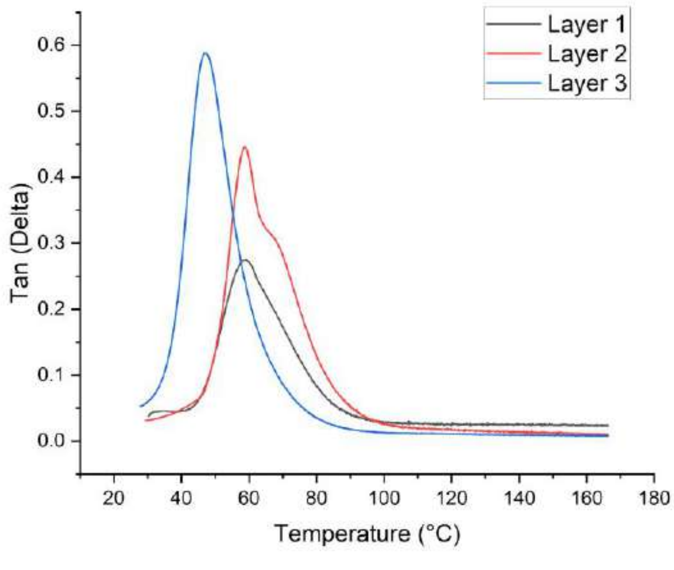

Figure 34 DMA Graph (Tan Delta) the curves of L1, L2, L3 are presented in the above graph

4.1.6 ILSS (Interlaminar shear strength)

This test aids in determining the composite material's resistance to shearing pressures that are applied perpendicular to the layers of the laminate. ILSS is a crucial factor. In evaluating and developing composite materials, the ILSS test has various uses. The figure shows 35 ILSS (Interlaminar shear strength)

Graphical Presentation:

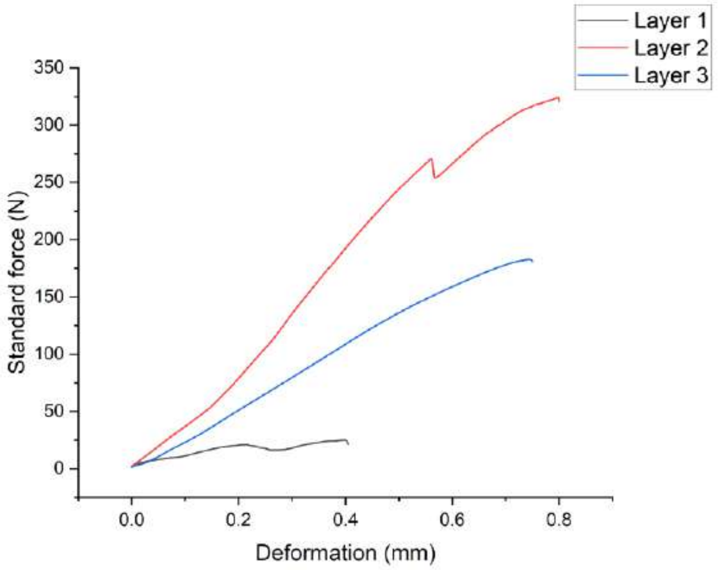

Figure 35 ILSS (Interlaminar shear strength)

Chapter 5

5.1 Conclusions:

Issues SMPs and their composites are currently facing have been addressed in this work, including the large activated displacement, recovery to original position at a temperature lower than the deforming temperature, large recovery force, recovery to original position even under load, The large activated displacement, recovery to original position at a temperature lower than the deforming temperature, large recovery force, recovery to original position even under load.

Because high stiffness lowers initial fixity, the composite with the highest rigidity has the lowest initial fixity. The more rigid design has a smaller overall recovery displacement because there is less free displacement during recovery. Due to the decreased blocking force of the stronger structure, it is discovered that the composite with the most asymmetries has better actuation qualities than the other composites. It is found that when unconstrained recovery is carried out for a recovery temperature (TR) lower than TD, the composite plate is not entirely deprogrammed during multi-step recovery. Until TR equal to TD is specified, the SME is still included in the composite. It tends to be pushed downward, near the initial fixity, by SME. SMPs return to their initial position and cool to a fixity that is relatively close to their initial fixity when TR is equal to 80°C. This shows that original fixity was recovered after heating at TR equal to 80°C. The fixity associated with this cooling will be lower than the fixity associated with the cooling at 80°C, but it will still return to the starting fixity as it cools. The shape memory behaviour of Rigid Glass fiber fabric which we investigated shoed use its potential and how further research can lead use to its SMP enhancement.

5.2 References

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