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AN EXPERIMENTAL INVESTIGATION ON GLASS EPOXY RESIN AND CARBON EPOXY RESINS FOR AEROSPACE APPLICATIONS

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ABSTRACT

With a 10:1 resin to hardener ratio, the goal of this research is to create laminates employing glass and carbon fiber. The study looks at the processes involved in designing tufted structures for aircraft, including material selection, manufacturing processes, and mechanical testing. Tufting technology enhances interlaminar resistance to delamination, according to the results. Tensile strength is maximum for the EWM laminate without tufting, and compression and bending strength are highest for glass fiber tufted at a 45-degree angle.

Keywords: Resin, laminates, glass, carbon fiber, tufted structures, aircraft, and compression strength

1. INTRODUCTION

Composite materials (CM) are becoming more and more important in a variety of industries, from construction and sports to automotive and aerospace. These materials have combined the benefits of several parts to produce the best material with improved qualities, revolutionizing the area of materials engineering in the process. The purpose of this introduction is to give a general awareness of CM including information on their composition, production methods, and wide range of technological uses. A CM is created by combining 2 or 3 different materials, each with special qualities of its own, to create a new material with enhanced properties. elements that make up a substance.[1]To provide support and transfer stresses between the phases of reinforcement, the matrix material encircles and binds the reinforcing materials.

Conversely, the mechanical characteristics of the composite, like its strength, stiffness, and durability, are enhanced by the reinforcement materials. Depending on the desired qualities of the finished product, the matrix materials used in composites can include ceramics, CBM(carbon-based materials), epoxy, metals, polymers, polyester and VE(vinyl ester) among the polymers that are frequently utilized as matrix materials because of their superior corrosion resistance, ease of processing, and lower density. [2] MMCs(Metal matrix composites) provide enhanced strength and good thermal conductivity by using metals such as magnesium, titanium, or aluminium as the matrix. Ceramics such as alumina or silicon carbide are used as the matrix in CMCs (ceramic matrix composites), which offer remarkable resilience to high temperatures and thermal stability. [3] In composites, fiber or particle components are usually used as reinforcement. Fibrous reinforcements, such as carbon fiber, aramid, and fiberglass, are commonly utilized because of their remarkable strength-weight proportions and outstanding stability.

Improved wear strength, thermal stability, and electrical conductivity are offered by particulate reinforcements. Alumina, silicon carbide, and graphene are a few examples of them.[4].The particular needs of the composite, such as the required, electrical, mechanical and thermal qualities, determine which reinforcement material is best. In summary, a class of materials known as composite materials combines the benefits of several components to produce a superior material with improved qualities.[5] They are composed of a matrix material that binds and envelops the reinforcement elements to transfer stresses and offer support. Polymers, metals, or ceramics can be used as the matrix materials, while fibrous or particulate materials can be used as the reinforcement materials.[6]Composite materials are widely employed in many different sectors and applications due to their greater stability, toughness, and miscellaneous required features, which are made possible by the unique mix of reinforcing and matrix components. We shall go into more detail on the qualities, uses, and manufacturing processes of composite materials in the sections that follow. An intriguing and creative advancement in the realm of advanced materials is represented by tufted composite materials. These materials create a high-performance, multipurpose material by fusing the advantages of typical composite structures with the special qualities of tufting technology.

The purpose of this introduction is to give a thorough review of tufted composite materials, covering their features, applications, manufacturing methods, composition, and possible future advances.[7]A particular kind of composite material known as tufted composite material combines tufting, a technique frequently employed in the textile sector. To produce a pattern or design, tufting entails inserting yarn or fiber into a backing material. To create a three dimensional reinforcement structure, reinforcing fibers or threads are embedded into a matrix material by tufting in the context of composites. The ability to precisely adjust the orientation, density, and positioning of fibers during the tufting process results in improved mechanical qualities and customized performance characteristics.

The two main components of the majority of tufted composite materials are the matrix and the tufted reinforcement. Depending on the qualities and intended uses, the matrix material may be polymer, metal, ceramic, or a combination of these. Because of their versatility, polymers like epoxy, polyester, or thermoplastic resins are frequently employed as matrix materials.[8]High-strength fibers or yarns, including aramid, glass, or carbon fiber, make up the tufted reinforcement and provide the material better mechanical qualities. Tufted composite materials are made by a multi-step process.

The design and setup of the tufting pattern come first, then the selection of the suitable matrix and reinforcing materials. Using specialized tufting equipment, the reinforcing fiber is inserted into the matrix material during the tufting process. Following tufting, the material goes through consolidation or curing procedures to guarantee that the reinforcement and matrix are properly bonded.[9]To get the desired result, more post-processing procedures including trimming, finishing, and surface treatments may be used. Tufted composite materials have several benefits and characteristics. The ability to precisely manage the positioning of fibers during the tufting process produces customized reinforcing patterns and enhanced load-bearing capacities.

In comparison to conventional two-dimensional laminated composites, the three-dimensional tufted structure improves mechanical qualities including strength, stiffness, and impact resistance. Additionally, tufted composites have better damage tolerance, fatigue resistance, and delamination resistance. Furthermore, certain characteristics like electrical conductivity, acoustic damping, or thermal insulation can be built into tufted composite materials. Tufted composite materials have a wide range of growing uses.[10]

2. LITERATURE SURVEY

A carbon fiber/epoxy T-stiffener-to-skin adding was reinforced via thickness, increasing pull-off resistance under quasi-static and impact loading action. A finite element model successfully reproduced the cracking growth in un-reinforced and 3D reinforced joints.[11] The whole work presents a fully handled with resin infusion experimental setup, addressing challenges in reliability and repeatability. It @vides preliminary experimental data on laminate permeability, full field thickness variations, in-mould resin pressures, flow advancement, and inflow resin flow volume rate.[12]The study examines the impact of tufting on the mechanical characteristics of non-crimped fabric composites. It reveals that tufting lowers in-plane toughness and stability about 10% in the axial direction, but significantly advances delamination defense in the normal and shear directions.

[13]Tufts moderately influence in-plane properties, but compression and tension response vary significantly. Disc punched tests gives greater energy consumption but smaller failure load for tufted works. Damage maps from cyclic loading experiments reveal significant differences between load cases and layup. The study explores the impact of through-thickness stufted fibers on sandwich structures' compression and bending properties, aiming to improve performance, interlaminar strength, and damage tolerance. Experiments involved compression and 3P bending tests on various sandwich panels.[14]A fine component model was developed to assess the impact of tufting gaps on admixing behaviour under point curving, focusing on the performance through-thickness fiber injection. This research examines heavy-speed Mode- I delayering characterization of C Non-Crimp Fabric compounds employing physical and force calibration, as well as mathematical or analytical study, to restrict errors because of the dynamic test's nature and impact. Numerical simulations show UD laminates also experience this effect, limiting test validity to weighting velocities less than 3 m/s. Optical

examination noticed that rate effects at crack formation, harder for tufted interaction. To eliminate mixed mode impacts, load both arms simultaneously.

[15]The aerospace industry requires thicker, more complex composite parts, and traditional multi-layered reinforcements are used. Recently, 3D fabrics have been developed using tufting technology, allowing user control over tufting parameters. This study analyzes tufted 3D fabric performance in hemispherical stamping and compares preforming behaviors with multi-layered forming samples.

The study found that tufting yarns significantly impact material draw-in, inter-play sliding, and winkling during forming, and their orientations can lead to mis-alignment defer in strong in plane shear zones.[16]The paper provides practical guidelines for manufacturing composite parts reinforced by tufting, reviewing the need for through-thickness reinforcement in high performance carbon fiber structures. It discusses the tufting process, its effects on preform fiber architecture, and potential applications, including tuft insertion and loop management. The manufacturing process may face critical issues such as thread insertion, loop formation, fabric fiber layout changes, or local volume fraction changes.

[17]The study presents a continuous work specimen for tufts bridging mode- I delayer, describing progressive debonding from the embedding laminate. It uses a fracture mechanics approach and experimental data to identify stiffness, strength, and toughness properties. The mode I bridging law is applied to a meso-scale cohesive spectrum generation, predicting the behaviour to delayer of tufted twin cantilever beam coupons, validated through experimental data.[18]A study tested small-scale tufted sandwich structures to determine if manufacturing variations affect energy absorption during crushing. Results showed that a single tuft affected the small-scale effect, while tufting parameters affected damage behavior and resin column response. Increased tufting increased energy absorption.

[19]The study focuses on improving mechanical performance of 3D compound work specimens strengthened by tufting , transport, and energy industries. It details the tufting process, equipment configuration, and resin transfer moulding technology is employed to fabricate complex work specimens. Tensile tests reveal that tuft length significantly impacts the mechanical characteristics of tufted compounds, suggesting that controlling tuft length is crucial for optimizing the tufting process and improving the mechanical behaviour of integrated thick reinforcement sand compounds.

[20]The article presents experimental Model analysis of a layered woven GFRP specimen with tufting reinforcement, evaluating the effects of idle tuft and loop-less profiles on fracture resistance. The cohesive model's traction separation relations are derived from strain calibration and force-separation co-relations, revealing that tuft failure is significantly influenced by tufting pattern and geometry.

[21]The study investigates the shock and after shock characteristics of woven carbon fiber compounds using tufting, analyzing density, angle, and damage tolerance ultrasonic C-Scan and CAI techniques.[22]The study investigates the impact of tuft geometry and tufting geometry on Mode I interlaminar cracks in GFRP. Idle tufting profile increases fracture resistance by 3.5-6 times, while a 5mm squared tufting pattern isolates individual tuft contribution. Experiments reveal tuft geometry significantly impacts delamination mechanisms in tufted composites, with 65% rised fight for loop-less specimens compared to idle work-piece due to increased energy necessary for tuft pullout. [23]

3. METHODS and MATERIALS

The process involved designing a mould using CATIA V5 software for laminates, manufacturing them using a hand-lay-up method, and calculating the weight percentage for each laminate after it was ready. This involved several steps to ensure quality and durability. Test laminates to ensure quality, performance, and industry standards. Common tests include tensile, compression, bending, and interlaminar shear test. Comparing results with different laminates is done. Results are presented logically and a report is prepared based on findings.

3.1. Epoxy Resin

Epoxy resins are reactive prepolymers and polymers that contain oxide groups. They can be cross-linked with co-reactants like poly functional amines, acids, phenols, alcohols, and thiols, forming thermoset structures called staying or gelation. Curing can induce residual stress.

Figure 1 Brush

Figure 2 Epoxy Resin

Figure 3 Moudling Machine

Figure 4 Teflon Sheet

3.2 E-Glass fiber

Glass fiber is a thermally insulating material made from extremely fine glass fibers, trapping small air cells for a low-density, air-filled glass wool family.

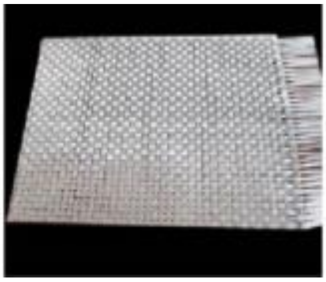


Figure 5 Glass Fibre

Figure 6 Thread

3.3 Tufting threads

Tufting threads are specialized fibers used in composite manufacturing for strength, durability, and cost-effectiveness. They are used in industries like aerospace, automotive, sports equipment, and construction, providing lightweight, strong materials for reinforcement and rigidity in composite structures.

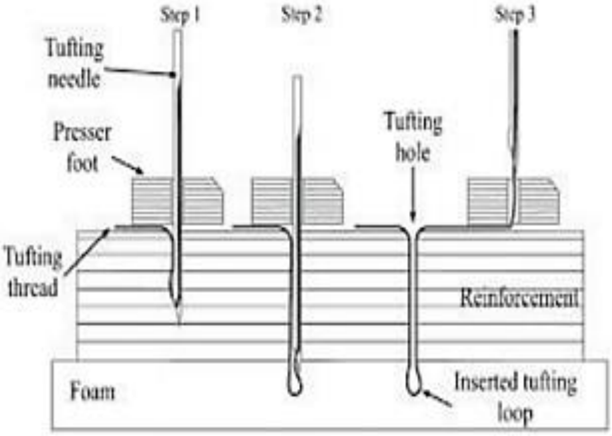


Figure 7 Tufting Process

3.4 Graphene oxide

Graphite oxide, a admixture of C, O2, and Ha, is generated by considering graphite with hard oxidizers and acids. Its maximum oxidized bulk product, graphene oxide, is used to prepare strong materials.

Figure 8 Graphene

Figure 9 Wax

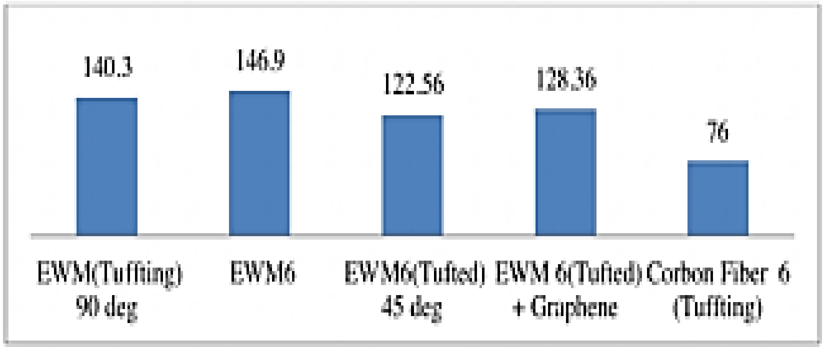
3.5 METHODS

Handlay-up technique is the oldest method of woven composite manufacturing. It involves treating the mould surface with antiadhesive agent, applying a plastic sheet, cutting woven reinforcement layers, and mixing resin with other ingredients to uniformly spread reinforcement. The process involves placing mats on a polymer layer, pressing them, closing the mould, and releasing pressure to create a single mat, then curing and removing the composite. Liquid injection molding involves mixing and dispensing plastic-based materials, with one plunger containing base-forming plastic and the catalyst in the second. Compounded material hardens, then removed from the moulding machine. Tufting is a single stitching technology employed in laminated composites, offering economic and flexibility compared to 3D weaving or braiding, and commonly used with Kevlar, glass, carbon, and PET threads.

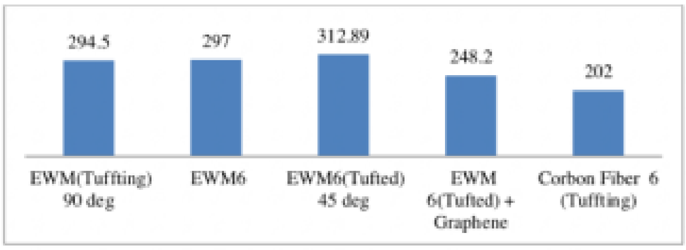
Figure 10 Hand lay-up method

3.6 SPECIFICATIONS

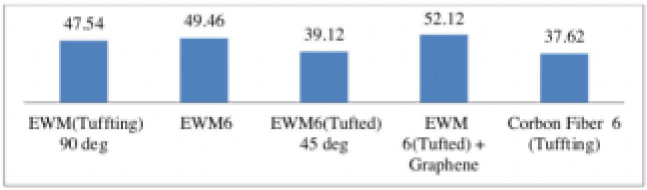
Laminate code	Laminates details
EWM6(TUFTED)	Glass fiber 6 layers tufted Epoxy resin
EWM6	Glass fiber 6 layers Epoxy resin
EWM6(TUFTED 450)	Glass fiber 6 layers tufted Epoxy resin
EWM6(TUFTED)+Graphene	Glass fiber 6 layers tufted graphene epoxy resin
Corbon Fiber 6(Tuffting)	Glass Carbon fiber 6 layers tufted_epoxy resin



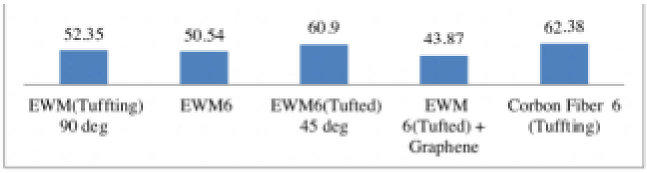
Gpraph 1 Comparison of Fibres on Weight Basis (grams)



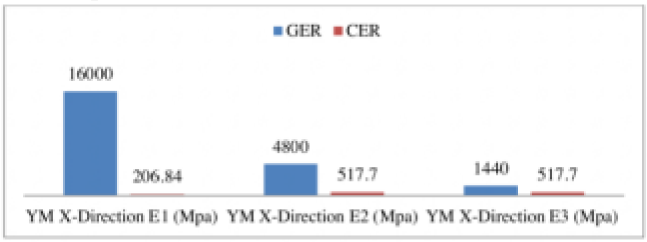
Gpraph 2 Comparison of Laminates on Weight Basis (grams)



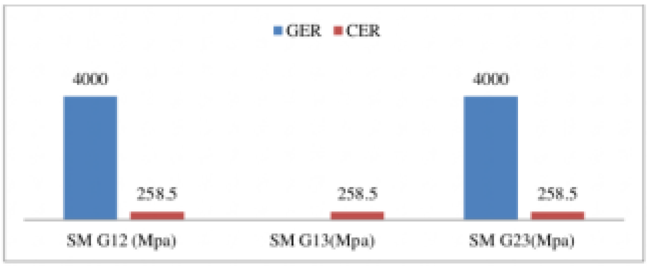
Gpraph 3 Comparison of Fibres on Volume Fraction (%)



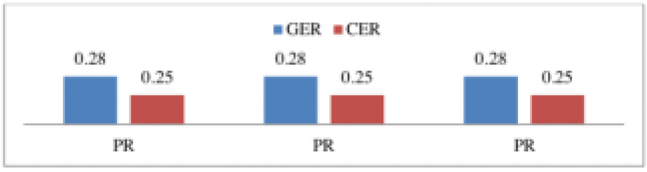
Comparison of Laminates on Volume Fraction (%)



Gpraph 4 Young’s Comaparision of Glass Epoxy Resin Vs Carbon Epoxy Resin



Gpraph 5 Shear Modulus Comaparision of Glass Epoxy Resin Vs Carbon Epoxy Resin



Gpraph 6 Poison’s Comaparision of Glass Epoxy Resin Vs Carbon Epoxy Resin

4. RESULTS AND DISCUSSIONS

When it comes to the compression test, load at peak is greater for glass fiber with tufted at 45 degrees, elongation at peak is greater for glass fiber tufted at 900 degrees, and compressive strength is greater for the combination of glass fiber tufted at 45 degrees, as demonstrated by the graphs showing load at peak, elongation at peak, and load at break, which are 10% to 15% more for the combination of glass fiber with tufted and graphene oxide than other laminates. When it comes to the Bending test, glass fiber at 45 degrees has a greater peak load, glass fiber tufted with graphene has a higher peak deflection, and glass fiber orientation has a greater bend strength. Tufted composites show improved damage tolerance compared to traditional composites, potentially overcoming limitations in aerospace. Research is needed to optimize tufting configurations, understand long-term durability, and investigate economic feasibility and scalability for large-scale manufacturing.

5. CONCUSIONS

Tutted material offers 10% to 15% more strength, high load peak, elongation, load at break, compression, and bending strength compared to traditional materials, demonstrating significant improvement in mechanical properties, durability, and damage tolerance for aerospace structures. Tufted composites have the potential to revolutionize aerospace structures by enhancing performance, safety, and service life. Their manufacturing feasibility is favorable, and their benefits are evident in their tensile strength and compression strength, with further research needed to fully exploit their potential. The EWM laminate demonstrated the highest bending strength, suggesting its use for high tensile strength areas in aircraft structures. Glass fiber tufted at a 45 degree angle is recommended for compression resistance. Further analysis and testing are needed.

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