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ORIGINAL CONTRIBUTION

Impact of Manufacturing Methods on the Mechanical Characteristics of Polymer Matrix Composites with Glass and Epoxy Fiber Reinforcement

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Abstract Mechanical evaluation revealed significant variations between polymer composite specimens made by hand lay-up and resin transfer molding (RTM). This study aimed to evaluate the impact of manufacturing processes on important mechanical characteristics using E-glass/epoxy fiber-reinforced polymer matrix composites. When comparing RTM specimens to hand-lay-up specimens, a comparative analysis showed that the mechanical properties of the former had significantly improved. More precisely, RTM specimens demonstrated an amazing 28.51% improvement in tensile strength when compared to hand lay-up specimens. Likewise, RTM manufacturing resulted in a noteworthy 12.54% increase in flexural strength and a noteworthy 49.25% improvement in compressive strength over hand lay-up competitors. Additionally, impact strength tests showed that RTM specimens performed significantly better than hand lay-up specimens by 25.75%.

Keywords Resin transfer molding (RTM) · Mechanical properties · E-glass/epoxy composites · Fabrication methods

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Introduction

Composite materials, because of their exceptional mechanical qualities, low weight, and design flexibility, composite materials especially fiber-reinforced polymer composites are becoming more and more important in a variety of engineering domains. With their exceptional strength-to-weight ratio, corrosion resistance, and ease of manufacture, E-glass/epoxy fiber-reinforced polymer composites stand out among them for structural applications [1, 2]. The fabrication techniques used have a significant impact on these composites' mechanical properties. A number of productions processes, such as vacuum infusion, filament winding, hand lay-up (HLU), and resin transfer moulding (RTM), have unique advantages that have a substantial impact on the final qualities of the composite material. Therefore, in order to maximize the performance of E-glass/epoxy composites in specific applications, it is important to understand how these fabrication techniques affect the mechanical behavior of the material. Alkali-free glass fibers are stronger and contain less alkali. It is harder and has excellent tensile and compressive strength [3]. Fiber-reinforced polymer matrix (FRP) composites offer many advantages over traditional metal components, including corrosion resistance, internal damping and reduced weight [4]. The link between fiber-reinforced polymer composites' mechanical characteristics and their production processes has been clarified by recent investigations. Alkali-free glass/epoxy composites' impact, bending, and tensile characteristics were examined in relation to several manufacturing processes, and the results demonstrated that the manufacturing process had a substantial impact on the material's mechanical properties [5]. To improve the mechanical properties and fabrication methods of alkali-free glass/epoxy composites, researchers

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have investigated other areas. Initially, they investigated how manufacturing factors affected fracture toughness and interlaminar shear strength, offering valuable insights for optimization [6, 7]. Temperature and humidity levels were also carefully examined, emphasizing the importance of these environmental parameters in ensuring the long-term durability of these composites during manufacturing [8]. Researchers have also studied post-curing treatments to improve dimensional stability and mechanical quality, demonstrating the likelihood of enhancing structural integrity through post-treatment methods [9]. Resin transfer molding (RTM) has proven to be superior compared to other production methods due to its advantages, which include the ability to adapt to complex geometries, dimensional stability, and excellent surface finishability [10]. Furthermore, studies have shown that RTM has better bending properties compared to the hand lay-up (HLU) method, with the latter's advantage being attributed to smaller void fraction [11]. In addition, RTM also improves the matrix quality and increases the interlaminar shear strength by reducing the void content in the sample [12]. This study is to examine the impacts of various production procedures, including hand lay-up, vacuum infusion, and RTM, to improve the dimensional stability and resilience of E-glass/epoxy fiber-reinforced polymer matrix composites for practical applications. Composites based on epoxy with e-glass fiber reinforcement are made via hand lay-up techniques or resin transfer molding. Followed ASTM requirements for tensile, compression, flexural, and impact testing when preparing test specimens. Composite samples fabricated by both manufacturing methods were rigorously analyzed and their respective mechanical properties such as flexural compressive, impact and tensile strength were evaluated through comparative analysis.

Materials and Methods

Matrix Material

The production of polymer matrix composites (PMCs) for various engineering applications makes heavy use of thermoset polymers such as polyester, vinyl ester, and epoxy resins. Among them, epoxy resin is highly valued by researchers for its excellent mechanical properties, moisture resistance, corrosion resistance, and long durability. The matrix system used in this study was created by combining LY556 epoxy resin with its amine-based hardener HY951 in a 9:1 ratio. Mix the mixture thoroughly using a mechanical mixer for 10 min. The datasheet provides densities for the epoxy resin and hardener, which range from 1.15 to 1.20 g/cm^3 and 0.97 to 0.99 g/cm^3 respectively.

Reinforcement

The reinforcement material, which was obtained from Suntech Fibre Private Limited, was bidirectional E-glass mat weighing 600 GSM. This completed the composite formulation for testing. The E-glass fiber utilized in this work has a density between 2.54 and 2.60 g/cc.

Fabrication Methods

Handlay up

A common process in the production of composites is the hand lay-up technique, which entails physically placing reinforcing fibers onto a mold surface and then saturating them with a resin matrix. In the layup procedure, every ply is meticulously molded into the required form by hand and then securely bonded to the mold surface or previous layer, preventing any air gaps between plies [13]. This method offers simplicity, versatility, and cost-effectiveness, making it suitable for small-scale productions and prototyping. It allows for flexibility in fiber orientation and facilitates the incorporation of complex geometries into composite structures. Additionally, hand lay-up offers the advantage of easy inspection and modification during the fabrication process, contributing to its popularity in various industries. Weighted manual steel rolls are employed in the hand layup technique to apply compressive load, which improves and incorporates bonding between fiber layers, leads to homogenous matrix spreading, and develops wettability among them. Gas entrapping was done in a wet composite, and the procedure worked well to get the required thickness. Maintain alignment in both the longitudinal and traversal directions of the fibers while positioning them [14]. Figure 1 shows the mould used during the composite laminate fabrication and after the completing the process, the composite laminate left for curing at room temperature for about 24 h. After the curing process was complete, the composite part was carefully removed from the mould. The laminates were employed for testing after being post-cured for an additional five hours at 100 °C in an oven [15].

Resin Transfer Molding (RTM)

Utilizing the RTM technology, the glass fiber reinforced epoxy composite material is fabricated. It is a closed mold, vacuum assisted process for fabrication of composite laminates [16, 17]. Initially, the cavity and mold surfaces undergo thorough cleaning to remove any dirt or dust particles, followed by surface preparation using a mold releasing agent. Next, a predetermined number of glass fiber mats are carefully positioned in the desired orientation within the cavity. Subsequently, the cavity is