Characterization of Composites Reinforced with Glass Fiber – A Review

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Abstract: One popular kind of glass fiber-reinforced plastic is glass fiber reinforced polymer (GFRP) composites. Now a days, GFRPs are used in a wide range of industries, including the automotive, aircraft, and electronics sectors. Glass fibers offer exceptional qualities such high strength, flexibility, stiffness, and resistance to chemical damage. They may be found as roving's, chopped strands, yarns, textiles, and mats. Because of their distinct qualities, several varieties of glass fiber are utilized to create polymer composites for a range of purposes. This paper provides an overview on the characterisation of glass fiber reinforced polymer composites.

Keywords: Characterization, Impact Test, Tensile Test, GFRP, Analysis.

INTRODUCTION

Polymer composites are used in hundreds of new items, ranging from sports goods to automotive components, airplanes, missiles, and spacecraft. Water storage tanks, rainy roofs, chemical equipment and machinery building, electrical and electronic equipment, and transportation are some of the other uses. A composite is a complex solid substance created by combining two or more distinct ingredients in a way that gives the finished product improved and better qualities. Polymer matrix hybrid composites are used in many everyday items because of their outstanding qualities. By virtue of their low weight, high strength to weight ratio, affordability, and rigidity, composite materials have significantly supplanted traditional materials like steel, aluminum, and wood. The combined material qualities of composite materials are unique and cannot be found in nature, which makes them appealing. These materials are designed specifically for a given product, are lightweight, strong, and stiff, which helps them save weight and use less energy. In fiber-reinforced hybrid composites, the fibers provide the structure with strength and stiffness, while the matrix resin acts as an adhesive to hold the fibers in place so that the necessary structural elements may be created. Because of their superior qualities—which include high specific stiffness and strength, good fatigue strength and damage tolerance, corrosion resistance, low density, low thermal expansion, nonmagnetic properties, low energy consumption during fabrication, and lower production costs—fiber reinforced polymer matrix composites are better suited for use in both structural and non-structural applications.

Natural and synthetic fibers are the two kinds of fibers that are utilized as reinforcements. Numerous studies on composite materials with these fibers have been conducted. Because of its excellent strength, excellent thermal and chemical qualities, low cost, and extremely high stiffness, fiber reinforced polymer, or FRP, is one of the most important materials needed for engineering applications. Glass fibres (GF) are randomly placed and then flattened into sheets (chopped strand mats) or woven into fabrics to create Glass Fiber Reinforced Polymers (GFRP). Based on the type of fiber glass used, the GFs are composed of several glass types. With varying concentrations of magnesium, calcium oxides, and generally chemical components, all of the glasses are composed of silica or silicate.

LITERATURE SURVEY

The laminate design of lightweight glass fiber reinforced epoxy composites for electrical transmission structures was researched by Haslan et al. in [1]. In this research, the mechanical strength and reserve factor of GFRP samples were calculated by the use of CompositeStar software to create a laminate design. The fiber orientation of the composite panels varied, and on samples with thickness ranges of 4 to 4.2 mm, it was intended to support a distributed load of 5kN service load in both longitudinal (x-axis) and transverse (y-axis) directions. The panels with fiber orientation in bi-direction and quasi-direction, the authors found through modeling, exhibit balanced strength and a respectable reserve factor in both the x and y directions. The parameters that required to be taken into account or controlled throughout the manufacturing process were the cause of a significant discrepancy in the E value between the simulation and the experimental results. The manufactured samples showed a lower modulus value than the simulated ones because of certain flaws. Because the Rt value simulated by the CompositeStar program followed the same pattern as the actual data, the authors concluded that the value was trustworthy.

Fraisse et al. conducted research on the thermal recycling and remanufacturing of glass fiber thermosetting composites in [2]. The effects of using thermally recycled glass fiber in remanufactured composites were examined and a unidirectional glass fiber thermosetting composite laminate was produced. To retrieve the glass fibers, the matrix in one area of the laminate was burned off. Using these recycled glass fibers, a new composite laminate with the exact same fiber architecture as the pristine one was created. After that, the recycled fibers were employed to create a brand-new composite laminate under the exact same processing parameters with as little handling of the fibers as possible to prevent damage. The two produced composite laminate kinds were determined to have low porosity contents and to be of excellent quality. There was a reduced fiber volume fraction in the remanufactured laminate because the recycled glass fibers could not be packed as well as the pristine fibers.

It was hypothesized that this resulted from the electrostatic attraction between the recycled fibers at the point of sizing removal. The recycling procedure had no appreciable effect on the composites' performance in terms of Young's modulus. In the event where the fiber volume fractions of the recycled and pristine glass fibers are similar, it is theoretically possible for the recycled glass fibers to have a bigger Young's modulus than the pure glass fibers. In comparison to the immaculate laminate, the maximum stress of the remanufactured laminate was 90% lower. It was impossible to totally prevent the effects of the manufacturing process on the re-manufactured laminate. It was discovered that throughout the vacuum infusion procedure, the fragile regenerated fibers were shattering.

Alexandre Landesmann et al. conducted research on the mechanical characteristics of GFRP for structural applications in [3]. The material samples utilized in this work were removed from the web and flange sections of a single, standard H-shaped GFRP single profile, using varied geometries, in compliance with the guidelines provided by ABNT-NBR15708:2011. The structural stiffness and strength properties of the GFRP element were covered by a very comprehensive testing program that included mechanical failure modes such direct tension and compression, two-point flexural bending, pin-bearing pushed-out, and interlaminar shear deformation. The findings revealed a distinct variation in the nonlinear behavior of the stress-strain curves before, at, and after the peak load with respect to the direct tension, both qualitatively and statistically. The scientists discovered that the ultimate strengths and mechanical behavior of the samples were directly and significantly impacted by the resultant fiber compositions.

Weiwen Li et al. reported the results of an experimental examination into the durability of glass fiber-reinforced polymer composites including nanocomposite in [4]. In this work, polymerization was used to create nanocomposites of 1.5wt% vinyl ester (VE) and 2wt% epoxy (EP)/organoclay. XRD analysis was used to examine the clay's dispersion states in the nanocomposites. The generated 1.5wt% VE/clay and 2.0wt% EP/clay nanocomposites were then used to build GFRP composites in order to examine the impact of a nanocomposite matrix on the long-term performance of GFRP composites. By adding montmorillonite, which is made of plain resin and organoclay nanocomposites and acts as a barrier to prevent chemicals and water from penetrating the matrix, the durability of GFRP was improved. The nanocomposites were prepared using vinyl ester resin and epoxy resin as the matrix components. XRD was used to measure the dispersion states of montmorillonite in the resin. To investigate the mechanical characteristics of GFRP, tensile tests were carried out. SEM was used to analyze the GFRP matrix, glass fibers, and fiber matrix interface deterioration. According to XRD measurements, the interlayer spacing of 3.23 nm signifies that some clay has been exfoliated or that polymer molecules have intercalated into the interlayer region. Tensile strength decreases of 22.48% and 21.38%, respectively, were observed in VE-GFRP and VE/clay nano-GFRP submerged in water at 60◦C. Both the VE-GFRP and the VE/clay nano-GFRP submerged in an alkaline solution had tensile strengths of 47.91% and 57.24%, respectively.

When submerged in water at 60°C, the tensile strengths of EP-GFRP and EP/clay nano-GFRP decreased by 10.24% and 18.74%, respectively. When submerged in an alkaline solution, the tensile strengths of EP-GFRP and EP/clay nano-GFRP decreased by 32.02% and 38.41%, respectively. Throughout the course of the accelerated degradation tests, the material characteristics of the VE/clay and EP/clay nano-GFRP composites declined less than those of VE-GFRP. The barrier created by the addition of montmorillonite may withstand the erosion caused by alkaline ions for up to 45 days, based on the measurement of the relative influences of water and alkaline ions on the durability of the samples. Thus, the inclusion of montmorillonite enhances the endurance of the nano-GFRP. Following 60 days of immersion in water (an alkaline solution), the tensile strength of VE/clay nano-GFRP reduced by 22.48% (47.91%), a loss that was more than that of EP/clay nano-GFRP as measured. The study's authors have concluded that among the materials evaluated, EP/clay nano-GFRP exhibits the best durability qualities. In addition, the authors suggested that the characteristics of EP/clay nano-GFRP might be enhanced even further by optimizing the production processes for EP/clay nanocomposites.

Maksimov et al. have outlined a few methods for updating machinery and technology to produce GFRP rebar in [5]. The usage of GFRP-rebar is common in the contemporary building sector. The imperfections of the epoxy adhesive impregnation unit were revealed by the production process analysis. Filaments are impregnated by either bending them around a rotating spindle or submerging them in a pastepot. The tools are then used to shape the rebar roving, remove extra glue, and guide rollers. The technique is inefficient and results in higher time and financial expenditures since the adhesive-contacting portions need to be cleaned on a frequent basis. The air in the working area is contaminated by an open pastepot containing the epoxy glue. The authors have suggested altering the impregnation unit in this case and combining it with the apparatus that twists filaments into a roving. Adhesive must be precisely dispensed from the nozzle to the filament attachment location. This will maintain precise adhesive dispensing, stop hazardous vapors from entering the work area, improve production purity, and lower the cost and processing line.

This construction doesn’t require large financial costs but can significantly improve the production efficiency. The proposed design of the equipment is realized with compact independent module that can be easily integrated into an existing manufacturing process.

Modernization of the line can be at the same time with the repair work or scheduled maintenance. The module has the ability to install tracking systems work line automatic. The authors opine that a new technology using the proposed scheme dimensional directly dispensing adhesive during the formation of the ribbed reinforcement roving surface will provide highly efficient and cost-effective materials.

The method is inefficient and requires more money and effort since the pieces that come into touch with the glue need to be cleaned on a frequent basis. The working area's air is contaminated by an exposed pastepot containing epoxy glue. Here, the authors suggest altering the impregnation unit and fusing it with the apparatus that twists filaments into a roving. It is important to precisely distribute glue from the nozzle to the filament connecting point. This will lower the processing line and its cost, preserve precise adhesive dispensing, enhance production purity, and stop hazardous vapors from entering the work environment.

Wazery et al.'s study on the mechanical characteristics of GFRP composites was conducted in [6]. In this study, an E-glass fiber with a random-oriented reinforced polymer composite was created using a hand lay-up process, with different weight percentages of fiber (15%, 30%, 45%, and 60%). It was looked at how much glass fiber there was in relation to mechanical attributes including impact, bending, and tensile strength. A Brinell hardness tester was used to assess the hardness of the composite materials. The mechanical characteristics of the manufactured composite exhibited a noteworthy enhancement as the percentage of glass fiber increased, according to the findings. The authors came to the conclusion during this experimental investigation that using a straightforward hand lay-up technique, it is possible to successfully fabricate glass fiber with random oriented reinforced polyester composites with varying fiber contents at a very low cost.

The results indicate that there are variations in tensile strength between 28.25 MPa and 78.83 MPa, flexural strength between 44.65 MPa and 119.23 MPa, and impact energy at room temperature between 3.5 Joules and 6.50 Joules when glass fiber content changes from 15% to 60%. The hardness value rose from 31.5 BHN to 47 BHN when the percentage of glass fiber-reinforced resin was raised from 15 wt% to 60 wt%. Because of the glass fiber reinforcement, polyester resin's mechanical qualities, including its tensile, flexural, and bending strengths, significantly enhanced. Mahmood et al. (2016) examined the characterization of GFRP composite made by hand layup technique [7]. Glass fiber reinforced epoxy composites were created in this project. Glass fiber served as the reinforcing material and epoxy resin served as the polymer matrix material. The primary goal of this endeavor was to find the most straightforward and affordable method of creating this composite material. Glass fiber reinforced epoxy resin composites were created for this using the hand layup technique, with

TiO2 material serving as the filler. Six different compositions were created, varying the epoxy resin in response to the addition of filler material while maintaining a consistent glass fiber content. Tensile, impact, hardness, compression, and flexural mechanical characteristics were all studied.

The results of the experimental studies demonstrate that the mechanical characteristics of the composites are generally poorer when filler material is not included. Hand layup was used to create glass fiber reinforced epoxy resin composites. The mechanical characteristics of GFRP composites with various compositions were examined. TiO_2 filled composites had greater values for tensile, impact, hardness, compression, and flexural strength than unfilled composites. For the GFRP composite, microscopic investigation was also performed. According to investigations, the composite with a composition of 15 weight percent TiO_2 and 20 weight percent TiO has a maximum tensile strength of 290 MPa, a maximum impact strength of 0.1972 J/mm^2, a maximum Rockwell hardness number of 71 HR, a maximum compression strength of 285 N/mm^2, and a maximum flexural strength of 2.70 kN/mm^2.

The mechanical qualities increased with the addition of filler material, according to the experimental results. Composites with a 20-weight percent filler material content showed superior mechanical capabilities compared to composites with different filler levels or no filler content. The findings showed that while mechanical strength rises with increasing filler material, composite strength peaks and subsequently declines at a given composition. Metallurgical microscope images were used to study the surface of the composites with and without filler material as well as the mixing circumstances. It happens as a result of uneven mixing, void content, or overuse of filler material, which produces a very viscous mixture and weakens the binding between the reinforcing material, resin, and filler.

The mechanical characteristics of epoxy hybrid polymer composites reinforced with carbon and glass fiber were covered by Jagannatha et al. in [8]. The mechanical characteristics of an epoxy hybrid composite reinforced with carbon and glass fibers were investigated in this work. For the creation of hybrid composite materials, the vacuum bagging process was used. The ASTM standards were followed in determining the mechanical characteristics of the hybrid composites, including ductility, peak load, tensile strength, hardness, and tensile modulus. As the amount of fiber reinforcement in the matrix material increased, improvements in mechanical qualities were noticed. In addition to measuring breaking load, tensile characteristics were examined. The ultimate tensile strength, yield strength, and peak load of the composite were all considerably increased by the addition of carbon fiber mat reinforced polymeric composite. It was discovered that carbon fiber reinforced composite has more ductility than other composites.

Bino et al. addressed the impact, flexural, and tensile characteristics of GFRP matrix composites in [9]. The authors performed an impact, flexural, and tensile test, among other tests. According to experimental findings, the proportion of silicon and hybrid composite loading progressively raised the tensile strength by 19.30%. As the amount of silicon composite hybrid composite grew, the flexural strength progressively climbed to 14.22%.

Carbon-Sisal-Glass Fiber Reinforced Composites with varying fiber compositions have been effectively manufactured by Arulkumar et al. in [10]. It was discovered that the fiber composition had a significant impact on the mechanical characteristics of the different composite laminates, including tensile strength, flexural strength, and impact strength. When compared to the other composition, the CSCSC composition produced the maximum tensile strength in the tensile test. The composition with the maximum flexural strength and flexural modulus in the flexural test was CSCSC. The SGSGS composition produced the maximum impact strength and impact energy in Joules during the Impact Test.

Patil Deogonda et al. investigated the mechanical characteristics of GFR epoxy composites in [11]. The authors of this work present the creation and mechanical characterisation of novel polymer composites using glass fiber reinforcement, epoxy resin, and fillers like ZnS and TiO2. The mechanical characteristics of these recently created composites are characterized. To determine the major impact of filler material on the mechanical properties of GFRP composites, experiments including the tensile test, three point bending, and impact test were carried out. According to the test findings, the strength of ZnS and TiO2 filled glass epoxy composites increased with the filler material volume percentage. Additionally, ZnS-filled composites had higher sustaining values than TiO2, and the inclusion of filler material increased the composites' tensile, bending, and impact strengths. When compared to empty and TiO2 filled composites, ZnS filled composites had noticeably better performance, such as greater tensile load. It was discovered that the impact toughness notch across the laminates was higher than that along the notch. The empty glass composite has a higher impact toughness rating than the filled composite. The material becomes more brittle and tougher when filled with ZnS and TiO2 filler materials, which lowers the impact toughness value. Compared to TiO2 filled composites, ZnS filled composites have noticeably higher values.

The mechanical characterisation of the GFRP composite's tensile characteristics under various strain rates and temperatures was investigated by Yunfu Ou et al. in [12]. In order to look into any potential implications on their mechanical characteristics and failure patterns, unidirectional GFRP was tested in this study at four initial strain rates (25, 50, 100, and 200 s-1) and six temperatures (25, 0, 25, 50, 75, and 1000C) using a servohydraulic high-rate testing system. Glass yarn samples were complementally evaluated using an Instron drop-weight impact system at four distinct strain rates (40, 80, 120, and 160 s-1) and temperatures (25, 50, 75, and 1000C) in order to provide light on the processes underlying the strain rate and temperature effects. Additionally, glass yarn and GFRP's quasi-static characteristics were added as references.

A discussion is held on the stress-strain responses at different strain rates and high temperatures. Weibull statistics are used to calculate the Weibull parameters for engineering applications and to assess the degree of variability in tensile strength. Glass yarn and GFRP sample failure patterns under various loading scenarios are the main experimental subjects of this investigation. Investigation and comparative discussion were conducted about the effects of temperature and strain rate on the mechanical characteristics and fracture morphologies. As per the authors' findings, there seems to be a correlation between the strain rate and the tensile characteristics of glass yarn and GFRP.

When glass yarn is subjected to a shift from quasi-static loading (1/600 s-1) to dynamic loading (40 s-1), its tensile strength and toughness rise to as much as 88.0% and 474.3%, respectively. However, when the strain rate drops from 120 to 160 s-1, toughness reduces by approximately 10.2% because of the reduction in strain. In GFRP, toughness improves dramatically (approximately 109.7%) after a shift from quasi-static loading (1/600 s-1) to dynamic loading (25 s-1), and tensile strength increases linearly (about 49.1%) across the strain rate range of 1/600–200 s-1. The temperature has an impact on the mechanical qualities of both GFRP and glass fiber. When the temperature rose from 25 to 75 °C, the tensile strength and hardness of glass yarn respectively dropped by roughly 25.3% and 31.1%. Nonetheless, glass yarn's tensile strength and toughness recover above 1000C because of an increase in the frictional force between the strands. When temperature rises from 25 to 500C, GFRP's tensile strength changes very little (by around 3%), but it drastically drops (by roughly 18.9%) between 50 and 1000C due to the resin matrix weakening when epoxy resins Tg is achieved.

The mechanical characteristics of woven glass-fiber reinforced polymer composites were investigated by Guangfa Gao et al. in [13]. Testing quasi-static compression and tension on a woven glass fiber-reinforced polymer composite was done to examine its mechanical characteristics. Compression experiments in the normal and tangent directions as well as tension testing in the tangent direction were performed on the composite, which is thought to be a transversely isotropic material. The analysis revealed that the composite is an elasto-brittle material with a much higher compressive failure strength than tensile strength. It was shown that the compressive behavior had a positive strain rate impact in the normal direction.

At various strain rates, the experimental findings demonstrate that the composite's failure stresses and strains in the normal direction are all noticeably higher than those in the tangent direction. In quasi-static uniaxial compressive force on the polymer, shear failure is the predominant failure mechanism. The interaction eventually got stronger as the load was compressed in a normal direction. Compressive strength was more heavily influenced by the fiber with the higher tensile strength in the normal direction than in the tangent direction. Nonetheless, the polymer was primarily responsible for this activity during the elastic stage since the deformation was so little. Consequently, there was similarity between the composites' Young's moduli in both directions.

Guanghui Li et al. investigated the glass GFRP bars' fatigue behavior following exposure to high temperatures in [14]. A total of 105 GFRP bars were tested in an experimental setting. For either one or two hours, the specimens were heated to temperatures of 100, 150, 200, 250, 300, and 3500C. The GFRP bars were exposed to extreme temperatures and tested under various cyclic load conditions. The findings demonstrated that when the temperature was raised and the holding duration increased, the tensile strength and elastic modulus of GFRP bars declined. When the temperature reached 250 °C, the tensile strength of GFRP bars clearly reduced by 19.5%. The maximum fall in GFRP bars' tensile strength within the test temperature range is 28.0%. It was shown that after exposed to extreme temperatures, GFRP bars degraded more quickly under cyclic stress. The deterioration impact of cyclic load on GFRP bars was amplified by the combination of increased temperature and holding duration. After being exposed to extreme temperatures (350 °C) under cyclic load, the tensile strength of GFRP bars decreased by 36.3% and by 50.5% as compared to room temperature. Furthermore, upon exposure to extreme temperatures at 3500C under cyclic stress, the elastic modulus of GFRP bars decreased by 17.6% as compared to room temperature and by 6.0% when compared to exposure at 3500C without cyclic load.

The impact of filament-wound GFRP reinforced composite pipes at low velocities was investigated by Khan et al. [15]. Glass fiber reinforced/epoxy and filament-wound glass fiber reinforced/vinylester composite pipes were subjected to low velocity single-bounce impact testing. For the impact testing, an instrumented drop weight testing equipment was employed. The tests were conducted on 300 mm length, 150 mm diameter pipe sections with a 6 mm wall thickness. It was discovered that the impact energy needed to just start the damage in glass fiber reinforced epoxy pipes was more than the energy necessary in glass fiber reinforced vinylester pipes. The load-time curves also demonstrated that the failure of the vinyl ester-based pipes under impact was ductile, whereas the failure of the epoxy-based pipes was more brittle.

A device for measuring instrumented drop weight was used to assess the low velocity impact response of filament-wound glass fiber reinforced/vinylester (GFRV) and glass fiber reinforced/epoxy (GFRE) pipes. The authors noticed that the load-time, energy-time, and load-deflection histories were predictive of the start and spread of the damage based on the impact reaction data and damage evaluation. We found two different reactions to impact. There was no significant damage during the initial response, which was elastic deformation. Under elastic and plastic deformation, the second response was the start and spread of significant damage. Major damage starts and propagation involved the waste of energy, followed by elastic deformation up to the peak load. The peak load of GFRE pipes stayed rather constant and could be regarded as independent of the incident impact energy's size, in contrast to the GFRV pipes, whose peak load rose as the incident impact energy grew. GFRE pipes were shown to have much lower energy to peak load and deflection at peak load values than GFRV pipes. Since the vinyl ester matrix is less brittle than the epoxy matrix, the latter is more likely to be fractured. This is indicated by the lower energy to peak load and deflection at peak load values.

Rabindra Kumar et al.'s experimental study of the mechanical characterisation and drilling of manufactured GFRP composites enhanced with Al2O3 microparticles was done in [16]. The authors of this paper investigated the creation of glass fiber composites with microparticles to improve mechanical properties like hardness, flexural strength, impact strength, and tensile strength by performing tests like the micro-Vickers hardness test, impact strength test, flexural strength test, and tensile strength test, respectively. Drilling a hole in the composite is a must if you want to combine the structural pieces made of composites using joints, rivets, or nut-bolts.

Composites suffer substantial damage to their topmost and bottommost layers during the entrance and exit of the drill bit into the hole, which causes the layers to delaminate. Therefore, in this study, the thrust force and delamination factor of the composites were adjusted by optimization of the drilling process parameters, including cognate speed, feed, and the weight percentage of alumina microparticles. The retaliatory surface paradigm notion guided the tuning of the settings. 1213 rpm speed, 0.16 mm/rev feed, and 5.2% weight % of alumina microparticles were the ideal input parameter values. For these parameters, the corresponding ideal values were 179.4 N thrust force, 1.12 for the entry delamination factor, 1.17 for the exit delamination factor, and 0.838 for the desirability. The development of fatigue delamination cracks in GFRP composite laminates was examined by Ijazet al. in [17]. The formation of delamination cracks between the various plies that make up a laminate can be initiated and propagated easily by GFRP composite materials. The failure of GFRP laminates as structural components may eventually be caused by the crack propagation. A thorough mathematical model is provided in this work to investigate the development of delamination cracks in GFRP composite laminates under fatigue stress. A fatigue damage model is derived from a modified version of the Allix and Ladevèze static damage model. The model is then implemented using the UMAT subroutine in commercial finite element software.

The experimental findings of Kenane and Benzeggagh on the fatigue fracture development in GFRP composite laminates are confirmed by the finite element modeling results. Delamination crack development models under fatigue stress for GFRP composite laminates are reported in this paper. There is also an explanation of the suggested mathematical model's specifics. The UMAT function in the CAST3M program is used to implement the model. For mode I and mode II load scenarios, the linear Paris plot behavior is generated by plotting the crack development rates, which are derived from FE analysis, against the energy release rates. The available experimental data on GFRP composite laminate is compared with the modeling findings, and it is discovered that they approximate the data rather well. The applied loading levels were expected by the findings of the FE study to result in substantial fracture development rates at high amplitude.

CONCLUSION

The characteristics and production processes of GFRP composite laminates are highlighted in the literature review that was supplied in the preceding section. The authors' recommended techniques provide an understanding of the developments in the field of composites. It is evident that GFRP composite laminates may be effectively constructed using a variety of methods, such as the hand layup process with varying reinforcement and matrix compositions. Additionally, the twin rolling approach may be used to create GFRP composite laminates, which may result in better mechanical qualities.

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