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Preliminary Investigation of Unsaturated Polyester/Jute Fibre (UPE/JT) Composites: Effects of Fabrication Methods and Fibre Orientations

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ABSTRACT

This study focuses on the development of unsaturated polyester (UPE)/ jute fibre (JT) composites using two fabrication methods such as vacuum resin infusion and compression moulding. The effects of different JT fibre orientations (randomly oriented, 0°, and 90°) on UPE composite properties were investigated. The results indicate that UPE/JT composites fabricated via vacuum resin infusion exhibit higher tensile strength, elongation, and Young's modulus compared to those produced by compression moulding. In terms of fibre orientation, 0° oriented UPE/JT composites produced via vacuum resin infusion showed the highest tensile strength (92.4 MPa), elongation at break (12.3%), and Young's modulus (3654 MPa) when compared to both randomly oriented and 90° oriented composites, as well as all specimens fabricated through compression moulding. This improvement is attributed to better fibre impregnation achieved through vacuum resin infusion and the load bearing capacity of 0° oriented JT fibres, which effectively transfer stress between the fibre and matrix, enabling joint load-bearing by JT fibre and UPE matrix during the tensile test.

1. INTRODUCTION

A polymer composite is a material made by mixing of a polymer matrix with reinforcing agents [1]. These reinforcements improve the mechanical strength, durability, and other properties of the polymer composite. The polymer matrix holds the reinforcement fibres together and enhance its overall mechanical properties [2]. The primary objective of making polymer composites is to combine the properties of both the polymer matrix and the reinforcement material, resulting light weight, good mechanical properties and more wear resistant materials compared to the neat polymer matrix [3]. Common examples of polymer composites include glass fibre reinforced polymer (used in boats and car bodies) and carbon fibre reinforced polymer (used in aircraft and sports equipment).

Polymer composites offer several advantages. They are lightweight, which makes them ideal for applications like automotive and aerospace [4]. Polymer composites also exhibit corrosion and chemical resistance, making them useful in environments where other materials might rust or degrade [5]. However, polymer composites also have disadvantages. They can be more expensive to produce, especially advanced composites like carbon fibre composites, due to complex manufacturing processes. Moreover, composites can be more challenging to repair if they are damaged, often requiring replacement instead of simple fixes [4].

Unsaturated polyester (UPE) is one of the most widely used thermoset polymer matrices, commonly bind the fibre reinforcement together to improve the mechanical properties of the UPE composite [6]. Despite this, UPE is still used in different applications due to its low cost, high strength, and flexibility. Not only can synthetic fibres be used to reinforce UPE, but natural fibres can also use as reinforcements in a wide range of applications [7]. Furthermore, the natural fibres have emerged as sustainable alternatives to synthetic reinforcements in thermoset polymer composites [8].

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The addition of natural fibres into UPE composites has gained a lot of attention from researchers due to increasing environmental concerns. These composites are widely used in various industries. In the automotive industry, it's used to make interior panels, dashboards, and door trims, to reduce the weight and fuel consumption of the vehicles [9]. In construction, it's used to make wall panels, partitions, and even furniture, providing a sustainable alternative to neat polymer or wood products. The UPE composite is often chosen for applications that because of cost-effectiveness, reduced environmental impact, and good strength.

Among natural fibres, jute fibre is one of the most common used as reinforcement fibre. The jute fibre is extracted from the stems of jute plants grown in tropical regions like China, India and Bangladesh [10]. Jute fibre is good mechanical properties, durable, and biodegradable, which means it breakdown naturally without harming the environment. The addition of the jute fibre into petroleum-based polymers enhances mechanical properties of composite while also reducing its environmental impact. This is due to the reducing the amount of petroleum-based polymer required, making the material more sustainable and eco-friendlier [11]. It is commonly used to make items like burlap sacks, ropes, carpets, and even eco-friendly shopping bags [10-11]. Due to its rough texture, jute is not typically used in clothing, but it is great for industrial and household products. Jute also has the advantage of being easy to grow with little need for pesticides or fertilizers, making it a sustainable crop. Furthermore, due to jute's low cost, eco-friendliness, and good strength make it a valuable fibre, hence, more researchers seek alternatives of jute fibre to replace the synthetic fibres like glass fibre, carbon fibre and Kevlar [12].

Polymer composite materials can be produced using various processing methods, such as injection moulding, extrusion, thermoforming, compression moulding, vacuum infusion, resin transfer moulding, hand lay-up, and spray lay-up. The selection of a fabrication method depends on the intended application. For example, compression moulding, hand lay-up, and spray lay-up are commonly used for large-scale applications, however, injection moulding is suitable for complex shapes and high-volume production. Extrusion is ideal for manufacturing products with simple shapes [13-14]. Furthermore, different types of polymeric materials use different fabrication methods. For example, thermosetting polymers are processed using hand lay-up, spray lay-up, vacuum resin infusion, compression moulding, and resin transfer moulding. On the other hand, thermoplastic polymers are commonly fabricated using injection moulding, extrusion, compression moulding, thermoforming, and blow moulding [15].

This study focuses on the tensile properties of unsaturated polyester/jute fibre (UPE/JT) composites produced using different fabrication methods such as compression moulding and vacuum resin infusion. Additionally, the study evaluates the influence of fibre orientation on the tensile performance of the composites.

2. METHODOLOGY

2.1 Materials

The matrix material used in this study was unsaturated polyester (UPE) resin, which was purchased from Berjaya Bintang Timur Sdn. Bhd. (Malaysia). The resin was cured using methyl ethyl ketone peroxide (MEKP) hardener in a safe and controlled manner. Jute fibre (JT) was used as the reinforcement, sourced from local market in Dhaka, Bangladesh.

2.2 Preparation of Jute Fibre

The jute fibre was cleaned and rinsed with distilled water to remove impurities. After cleaning, the jute fibres were oven dried at 60ºC for 24 hours to reduce the moisture content. The fibres were then prepared in three different orientations: randomly oriented fibres, unidirectional fibres (0^o orientation), and 90^o orientated fibres. For each orientation, 40 g of jute fibre was used.

2.3 Preparation of Unsaturated Polyester/Jute Fibre Composites

The unsaturated polyester/jute fibre (UPE/JT) composite was prepared by mixing the 200g UPE with 1.5% MEKP hardener, followed by stirring for 1 minute to prevent the gelation occurred. Before pouring the resin mixture, a layer of release wax was applied to the mould surface to facilitate easy demoulding. The gel time of the UPE resin is 5 minutes. Therefore, the preparation of all UPE composites mixtures must be completed within this timeframe to prevent premature gelation.

For the compression moulding process, the prepared jute fibre (randomly oriented 0° and 90° orientations) was placed in the mould along with the resin mixture. The mould was subjected to controlled pressure of 2.1 MPa using a hydraulic press for 2 minutes. After compression, the mould was removed from the compression machine and left to cure to room temperature for 24 hours before demoulding the composite.

For the vacuum resin infusion technique (Fig. 1), an acrylic board was used as the mould base, and mould release wax was applied to aid in demoulding. Layers of randomly oriented jute fibres were placed on the board, followed by a layer of peel ply trimmed to size. An infusion mesh was then placed on top to help the resin flow evenly across the fibres. The peel ply and infusion mesh were properly positioned, and a vacuum bag was sealed around the setup using tacky sealant tape. Resin infusion was performed at a vacuum pressure of 0.71 bar to fully impregnate the jute fibre. The composite was left at room temperature for 24 hours to cure. The vacuum resin infusion process was performed in the fume hood to minimize exposure to gas emissions.

All composite samples underwent post-curing process in an oven at 60ºC for 2 hours to ensure complete curing. After post-curing, the composites were trimmed and cut according to the required dimensions for tensile testing. All the composites with different JT fibre oriented were using the same compression moulding and vacuum resin infusion methods to produce UPE/JT composites.

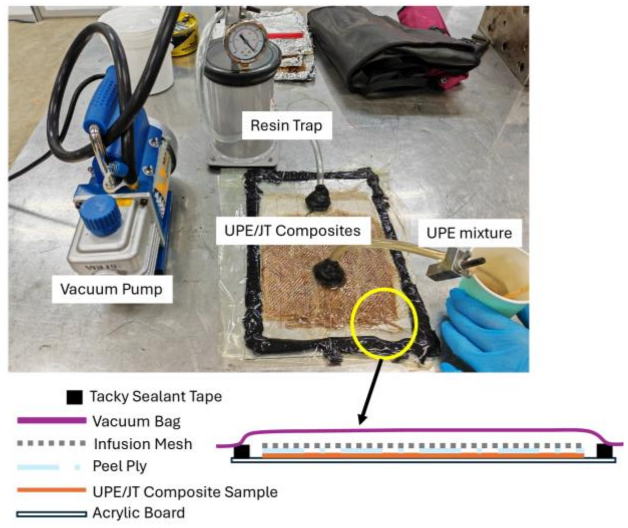

Fig. 1. Vacuum resin infusion setup.

2.4 *Tensile Test*

A tensile test was conducted using the Shimadzu Universal Tensile Machine AGS-X 100kN 400V to evaluate the tensile properties (such as tensile strength, elongation at break and Young's modulus) of the tensile specimens. Five specimens from each sample were evaluated. The test was carried out following the ASTM D638 standard for plastics, using Type I dumbbell-shaped samples. All tests were performed in a controlled laboratory environment at 23±2°C. The overall process flow of this research study was shown in Fig. 2.

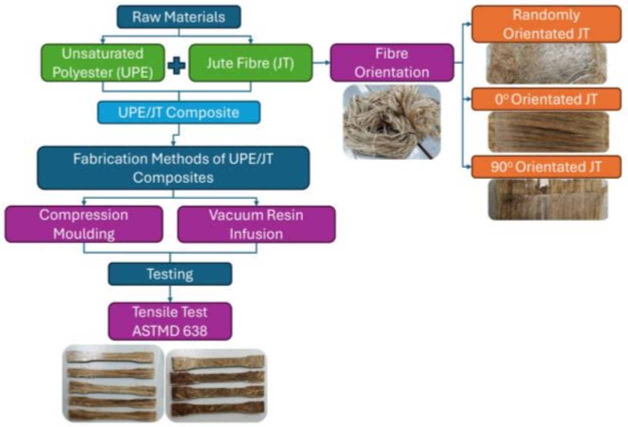

Fig. 2. Overall process flow of UPE/JT composites

2.5 *ANOVA Statistical Analysis*

A single-factor Analysis of Variance (ANOVA) was carried out to evaluate the effect of JT fibre orientation (0°, 90°, and randomly orientated) on the tensile properties such as tensile strength, elongation at break and Young's modulus of UPE/JT composites. The analysis was performed using Microsoft Excel with the significance level set at $\alpha = 0.05$. P values less than 0.05 were considered statistically significant, indicating the JT fibre orientation impact on the measured tensile properties.

3. RESULTS AND DISCUSSION

Fig. 3(a) shows the tensile strength of UPE/JT composite fabricated using different techniques and fibre orientation. The results indicate that vacuum resin infusion UPE/JT composites exhibit higher tensile strength than the UPE/JT composites produced by compression moulding. This difference can be attributed to the complete impregnation of JT fibres by UPE resin during the vacuum resin infusion process. However, compression moulding may lead to incomplete fibre wetting, leaving some JT fibres uncovered by the UPE resin and resulting in air bubbles trapped within the composite structure. These air bubbles acted as stress concentrations points, which can initiate cracking under applied tensile loads.

In term of JT fibre orientation, the 0° orientated JT fibres show the highest tensile strength. This is because the JT fibres are aligned parallel to applied tensile load, allowing them to efficiently bear the forces. A similar finding was reported by Tan, Chan & Koay (2021). They studied corn husk fibre reinforced unsaturated polyester composites. Their research results showed that the highest tensile strength was achieved at the fibre orientation of 0° because the corn husk fibre was parallel to the loading direction, resulting in more effective stress transfer from unsaturated polyester matrix to corn husk fibre [16]. The Fig. 4(a) shows that the failure mode of 0° orientated JT composite, the failure occurred in both the JT fibres and the UPE matrix. In this case, the fibres and the matrix work together to withstand the tensile load, with the aligned fibres providing maximum reinforcement along the load direction. On the other hand, the 90° orientated JT composites show the lowest tensile strength among the three orientations. This occurs because failure initiates at the weak points in the matrix, and the stress is not effectively transferred from the matrix to the fibres, as shown in Fig. 4(b). As a result, the JT fibres do not bear the applied tensile load, leading to failure. The Fig. 4(b) exhibits the failure occurs primarily in the weaker UPE matrix. The fibres do not effectively withstand the applied tensile load, as the stress is not efficiently transferred from the matrix to the fibres. As a result, the composite fails due to matrix cracking rather than fibre reinforcement. For randomly oriented JT fibres, the tensile strength is higher than that of the 90° oriented composite but lower than that of the 0° oriented composite. The failure mode is shown in Fig. 4(c), failure occurs in both the JT fibres and the UPE matrix. The random fibre distribution limits the composite's maximum strength and stiffness because the fibres are not fully aligned with the direction of applied tensile load.

Fig. 3(b) presents the elongation at break of the UPE/JT composite fabricated using different methods and fibre orientations. The results indicate that the samples fabricated via vacuum resin infusion exhibit a higher elongation at break compared to those produced through compression moulded samples. This could be due to the more uniform resin distribution and better fibre impregnation achieved through vacuum resin infusion, which enhances fibre-matrix bonding and allows the composite to deform more before failure. In contrast, the compression moulded specimens, with uneven resin distribution and incomplete fibre impregnation, show weaker fibre-matrix bonding, resulting in lower elongation at break when subjected to tensile loads. Besides, composites with 0° oriented JT fibres display the highest elongation at break. This is because the fibres aligned with the tensile load not only bear more load but also contribute to the overall ductility of the composite before fracture.

The Young's modulus of UPE/JT composites was illustrated in Fig. 3(c). The Young's modulus of all vacuum resin infusion composites higher than all the compression moulded composites. Moreover, the 0° oriented fibre composites exhibit the highest modulus of elasticity. This is because fibres aligned along the direction of the applied load (0°) enhance the stiffness of the composite by efficiently transferring the load along the fibre direction. The incorporation of stiffer fibres significantly increases the ability of UPE/JT composite to resist deformation.

Overall, in this research study shows that the UPE/JT composites fabricated with vacuum resin infusion show better tensile properties compared to those made using compression moulding. Furthermore, the composites with fibres oriented at 0° consistently demonstrate the best tensile strength, elongation at break, and modulus of elasticity, followed by randomly oriented fibres, with 90° oriented fibres showing the lowest performance. Statistical analysis using ANOVA indicated a significant effect of JT fibre orientation on tensile strength, Young's modulus, and elongation at break ($P<0.05$), confirming that fibre alignment plays a critical role in determining the tensile properties of the UPE/JT composites.

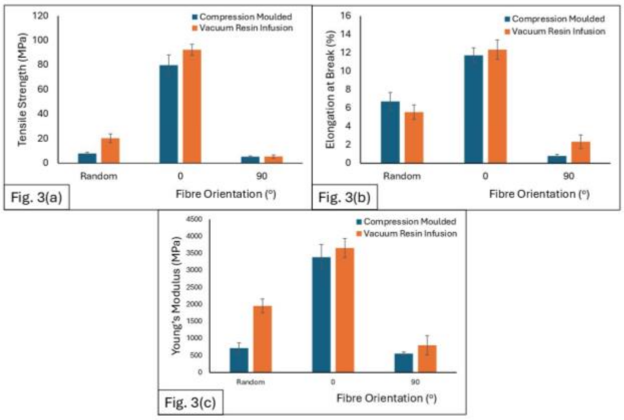

Fig. 3. Tensile properties of UPE/JT composites (a) Tensile strength, (b) Elongation at break and (c) Young's modulus with different fabrication methods and JT orientation.

4. CONCLUSION

The UPE/JT composites fabricated using vacuum infusion show better tensile properties compared to those produced by compression moulding. This is due to the incomplete impregnation of JT fibres by the UPE resin in compression moulded composites, leading to trapped air bubbles that weaken the material. Furthermore, 0° oriented JT fibres in UPE/JT composites demonstrate the best tensile performance compared to 90° oriented and randomly oriented fibres. This is because the 0° fibre alignment is parallel to the applied load, allowing efficient stress transfer from the matrix to the fibres. As a result, both the fibres and the matrix share the load and work together to resist failure during tensile testing. The failure pattern observed in 0° oriented composites shows that both the UPE matrix and JT fibres break together, indicating that both components contribute effectively to load bearing before failure. Additionally, further investigations into the fatigue resistance or impact strength of the composites are recommended to provide a more comprehensive understanding of their mechanical properties.

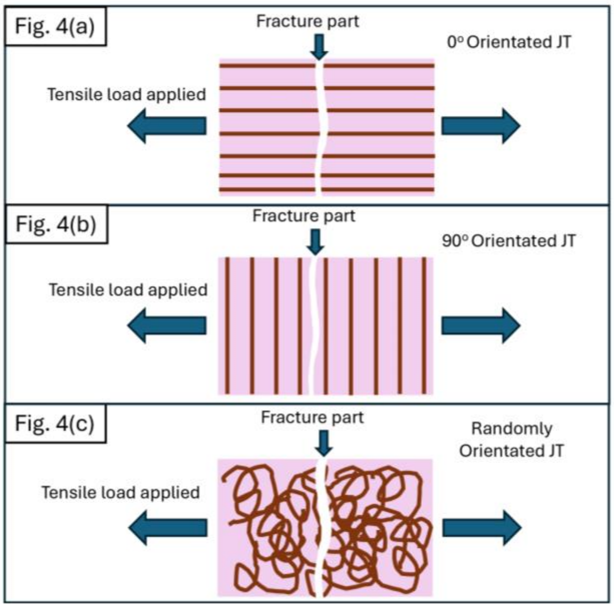

Fig. 4. The proposed failure mode of UPE/JT composites at different JT orientation (a) 0° orientated JT, (b) 90° orientated JT and (c) Randomly orientated JT

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