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Dynamic Mechanical Analysis of Natural fiber Reinforced Epoxy Hybrid Composites

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Abstract: The dynamic mechanical characteristics of the ramie fibre and jute fibre composite were examined in this study, and the impact of the loading pattern was evaluated. Four different laminate designations, namely Ramie, RJJR, JRRJ, and Jute, were developed using the hand layup approach. According to the testing outcomes, the ramie fibre composite outperformed all other composites in terms of storage and loss modulus values due to the fiber's high stiffness and superior bonding with the matrix. Due to the presence of two outer layers of very rigid ramie fibre, RJJR composite among hybrid composites showed a greater storage modulus and loss modulus than JRRJ hybrid composites composite. Additionally, the composites' thermal stability was found to be in the following order: Ramie > RJJR > JRRJ > Jute. The more mobile polymer chain also contributed to the superior damping characteristics of the jute fibre composite and JRRJ composite over other composites.

Keywords: *Ramie fiber; Silk fiber; Biocomposites; Dynamic mechanical Analysis; Hand layup*

1. Introduction

The investigators, material scientists, and entrepreneurs are drawn to natural fibre composites because of its environmentally beneficial and biodegradable qualities. The physical properties of the matrix are improved by the fibre reinforcement, according to a number of recent studies on natural fibre composites (Sadashiva *et al*. 2023; Maran *et al*. 2020; Tabaght *et al*. 2023). Comparing composite materials to conventional reinforced materials offers various benefits, including lower cost, acceptable specific strength, low density, and high thermal and acoustic insulating characteristics (Sadashiva *et al*, 2022). Natural fibres are more cost-effective, environmentally benign, renewable, biodegradable, and have a higher specific strength when compared to conventional reinforced materials (Balaji *et al*, 2023). According to reports, the manufactured biocomposites successfully minimized losses caused by packaging (Yaghoobi and Fereidoon 2019). Due to their low weight, high specific strength, and increased fuel efficiency, natural fiber-reinforced hybrid composites are being used more and more in the structural fields of cars and aero planes (Jamir, Majid, and Khasri 2018). Due to their capacity to enhance the qualities of the composite material, ramie fibres have been used by many investigators in the past as a reinforcing agent in hybrid composites (Sadashiva *et al*. 2022; Margem *et al*. 2010). The ramie stem can be used to obtain natural cellulosic fibres that are both strong and appealing in terms of cellulose content, elongation, and strength. Compression-molded composite fabrics made of polyester/hybrid ramie and cotton were explored. They came to the conclusion that ramie fibres have a lot of promise as fibre reinforcement in resin matrix composite materials, which demonstrated an improvement in tensile strength of up to 220% over neat resin (Paiva Junior *et al*. 2004). Since jute is a plant that is widely produced throughout India, it can be used as a cheap supply of cellulose fibres to replace or augment other fibrous raw materials currently employed as reinforcing agents. A strong fibre from the ramie plant is used to make carpets, fishing nets, ropes, and sewing thread. The same plant's bast fibres have a variety of uses in the textile and manufacturing industries. Viscoelastic properties of polymer materials are studied and characterized using dynamic mechanical analysis, where the complex modulus is calculated by measuring the material's strain during the application of a sinusoidal stress. In order to locate the composite material's glass transition temperature and to pinpoint changes in molecular motion, the stress frequency or the sample temperature must be changed. This changes the complex modulus, which results in variances. The analysis may assess the glass transition temperature (Tg), storage modulus (E''), loss modulus (E'), tan δ, and glass transition temperature as a function of temperature of polymer composites reinforced with natural fibres (Essabir *et al*. 2013; Etaati *et al*. 2014). According to the literature review, the hybridization of the material affects its dynamic mechanical properties. Therefore, this study analyses the dynamic mechanical behaviour of ramie and jute fibre hybrid composites, and it investigates the impact of stacking order.

2. Materials and Methodology

2.1 Materials

Jute and ramie fibre, as well as epoxy resin, were used to develop a hybrid composite. Vruksha Composites in Guntur, Andhra Pradesh, India, provided the jute and ramie fibres. Ultra Nanotech, Bengaluru, Karnataka, India, provided the epoxy resin grade (LY556), hardener grade (HY951), and silica release gel. Table 1 illustrates the ramie and jute fibres' physical characteristics.

Table 1. Physical Properties of ramie and jute fibers

Properties	Ramie Fiber	Jute fiber
Density (g/cc)	1.55	1.42
Tensile strength (MPa)	665	450
Young's modulus (GPa)	85-130	60-95
Elongation (%)	3.5	2.9

2.2 Composite Preparation

The raw components used to make the composites were ramie fibre, jute fibre, epoxy resin (LY556), and hardener (HY 951). In this study, the composite material was manufactured employing a plain weave mat made of 0.4mm-thick ramie and jute fabrics as a natural reinforcement. Epoxy resin was the matrix substance. Composites were made using the hand layup method since it is generally cheaper than other manufacturing techniques. In the hand lay-up method, a layer of resin is initially applied, followed by the application of the needed number of fibre layers, kept in the required orientation, and another layer of resin. Figure 1 depicts the schematic diagram of the ramie fibre, jute fibre, and hand lay-up processes.

Ramie Fiber

Jute fiber

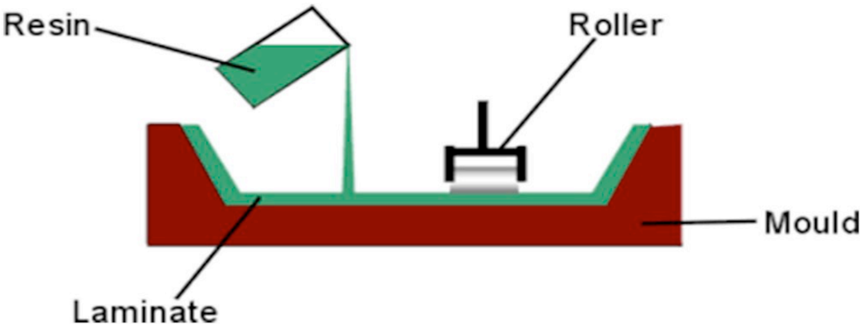

Figure 1. Reinforcements and hand layup method

2.3 Characterization

The DMA 8000 dynamic mechanical analyzer was used to conduct a dynamic mechanical analysis of the composite materials that were created. The experiment was conducted in bending mode at temperatures ranging from 30 to 120 degrees Celsius. To carry out this study, a heating rate of 3°C/min and a frequency of 1 Hz were kept constant. The schematic diagram of DMA and specimens were shown in figure 2.

3. Results and Discussion

3.1 Storage modulus (E')

An understanding of a material's elastic properties is aided by its storage modulus, which quantifies the energy the material has stored. Higher storage modulus indicates stiffer or more elastic material. **Figure 3** illustrates the storage modulus fluctuation for the fundamental ramie and jute fibre composites at temperatures ranging from 50 to 200 C. A range of 500 and 1200 C is shown by the E' curves. It is possible that the ramie fibres' behaviour inside the matrix explains why the E' value for the ramie in is larger. The storage modulus is reduced in composite materials because of the relatively weak JJJJ contact interaction. Additionally, the larger loss in E' value in the case of the JRRJ nano composite can be connected to the GO influence on the viscoelastic behaviour, which could lower the storage modulus. The end of polymers' glassy state is similarly related to the sharp decline in E' in **Figure 3**. One of the primary uses of DMA analysis is the glass transition (Tg) area, and the beginning of this zone can be determined by the appearance of a dip in E' curves. Three steps can be distinguished between the E' curves. The first stage, which is below the glass transition region and may be referred to as a glassy region, is where polymeric chain movement is constrained because of the poor mobility of the packed and frozen molecular arrangement. As a result, the storage modulus is greater. The glass transition area appears in the second stage when the arrangement of the tightly packed molecules starts to collapse, giving the polymer chains a high molecular mobility. The storage modulus consequently undergoes a significant reduction. Finally, in the third stage, the storage modulus is revealed when a rubbery zone hits a plateau.

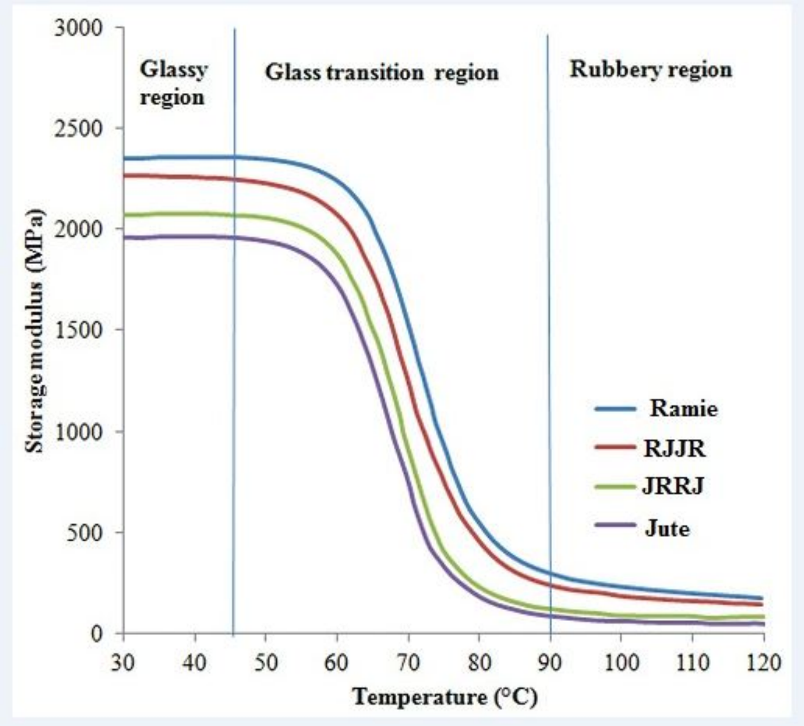

Figure 3: Storage modulus Vs Temperature of hybrid composites

3.2 Loss modulus (E”)

The When a material is subjected to a single cycle load of sinusoidal deformation, the loss modulus a measure of its viscous response indicates the amount of energy either lost as heat or dissipated. Internal friction in a material is typically correlated with the value of E". Additionally, it is referred to as the viscoelastic response of a polymer-based material and is predominantly influenced by molecular configurations, heterogeneities, and phase transition processes (Mathapati *et al*. 2022; Muralidhar N *et al*. 2019). Furthermore, a high loss modulus provides enhanced ability to dissipate energy, so suggests superior damping abilities to lessen forces caused by mechanical energy. **Figure 4** displays the E" curves as a function of temperature for the basic epoxy resin and the hybrid composites made of ramie fibre and jute fibre. The E" curves show that the maximum peak height was obtained by all test groups between 700 and 1000 C, which is the glass transition region. It is also well known that the material is stiff and rigid in the glassy zone, where the temperature is below 700 C, and that the loss modulus is small and constant. The viscous behaviour of the substance, however, dramatically increases when it passes through the glass transition region and transitions from a glassy to a rubbery state. This might be accounted for by the molecular mobility in the polymer chain combined with mechanical deformation, leading to a high internal friction and non-elastic deformation (Chee S.S *et al* 2019; Jesuarockiam N, *et al.*2019).

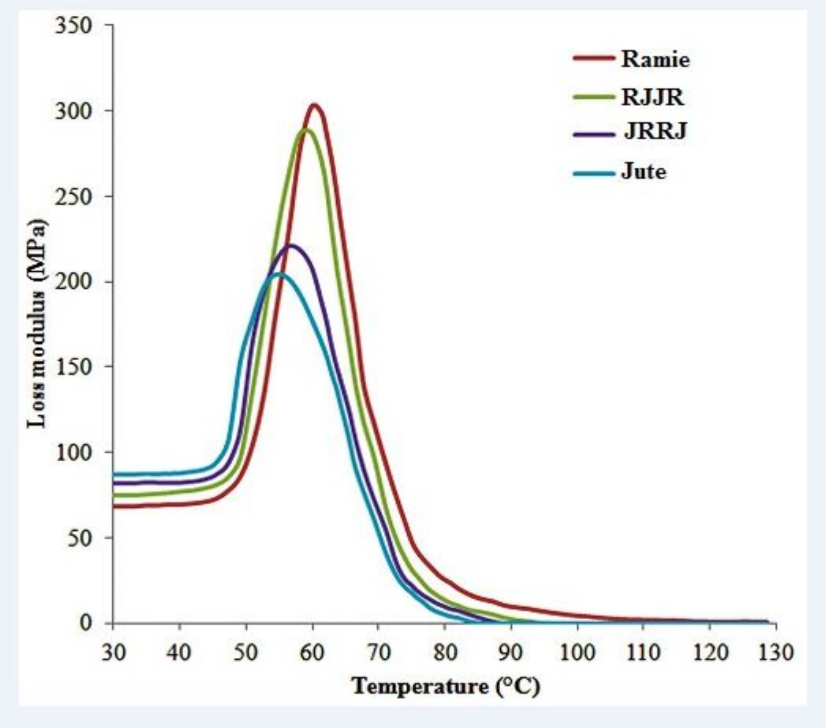

Figure 4: Loss modulus Vs temperature of hybrid composites

As a consequence, the system has a high Tg temperature and a loss modulus that reaches its maximum peak height. The molecules are more relaxed once they get there, which reduces internal friction and causes the loss modulus to decrease. Comparing the E" values of the JRRJ and RJJR composites, the jute nano composite has the lowest value. It is hypothesized that, similarly to the storage modulus, the GO functioning as a matrix to fibres inhibits molecular mobility, lowering the matrix's capacity for viscoelastic friction

3.3 Damping factor (tan δ)

The damping factor (Tan δ), calculated as the difference between the loss modulus and the storage modulus, and describes a material's resistance to deformation in a polymeric structure. The damping qualities of the material are what keep the viscous and non-viscous phases in balance. (Ebnesajjad S *et al*.2018). A higher interfacial fiber/matrix bonding leads to a higher Tan d value for polymer composites reinforced with fibres. Because interlocked molecule structures cannot move freely, there is a decreased energy loss from internal molecular motion. **Figure 6** shows the temperature and damping factor of several hybrid composites as well as temperature variation. The modification of damping characteristics as a function of temperature can be observed. The JRRJP composite has a Tan δ of 0.55 and the jute composite shows a Tan δ of 0.75, both of which are greater than the ramie composites. This indicates that the composites have a higher damping factor, which is connected to a higher non-elastic deformation and energy dissipation. The ramie fibres' decreased peak height, however, might be explained by a restricted polymer chain motion. Additionally, it suggests that the composites did not have a robust interfacial interaction, which led to a larger energy loss at the interface.

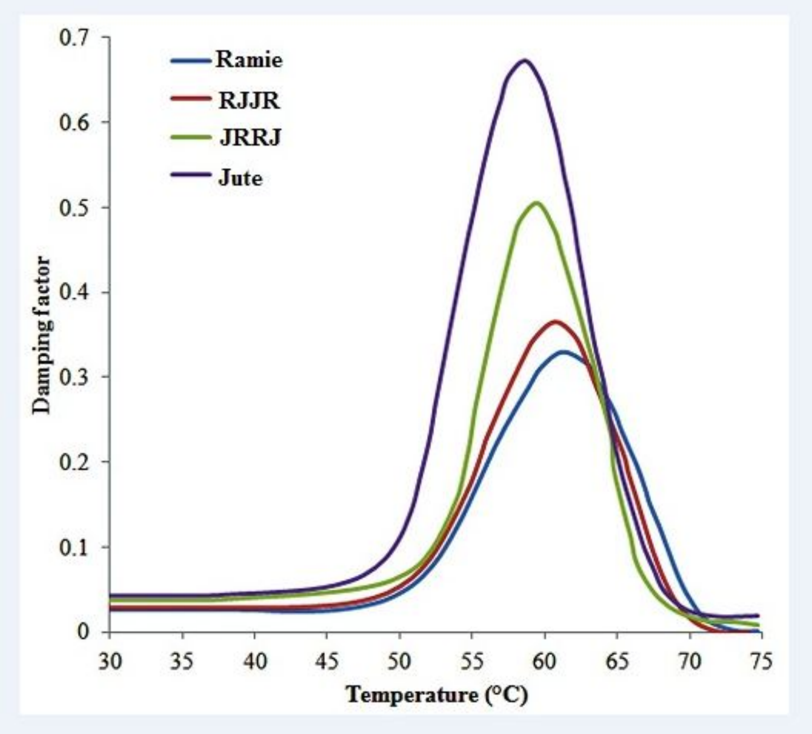

Figure 5: Damping factor Vs Temperature of various composites

Conclusion

In this work, the ramie fibre and jute fibre composite's dynamic mechanical properties were investigated, and the effect of the loading pattern was assessed. Using the hand layup method, four distinct laminate designations Ramie, RJJR, JRRJ, and Jute were create. Due to the high stiffness of the fibre and its superior bonding with the matrix, the ramie fibre composite beat all other composites in the tests in terms of storage and loss modulus values. The RJJR composite among hybrid composites demonstrated a greater storage modulus and loss modulus than JRRJ hybrid composites composite due to the presence of two outer layers of very stiff ramie fibre. Ramie > RJJR > JRRJ > Jute was discovered to have the highest thermal stability among the composite materials. The better damping properties of the jute fibre composite and JRRJ composite over other composites were also a result of the more mobile polymer chain.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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