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Mechanical Characterization of Elettaria Cardamomum Leaf Midrib Reinforced Polyester Composites: Flexural and Impact Performance

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Abstract

This study investigates the mechanical properties of natural fiber-reinforced polymer composites fabricated using leaf midribs of Elettaria cardamomum (cardamom) as reinforcement in a polyester resin matrix. The midribs were collected from cardamom cultivations in Kerala, India, cleaned, sun-dried, and processed for composite fabrication using a manual hand lay-up technique with unidirectional fiber orientation. Composite specimens with fiber weight fractions of 30% were fabricated and subjected to three-point bending (flexural) tests in compliance with ASTM D790 and Charpy impact tests in compliance with ASTM D256. Results indicate that flexural strength and impact strength both peak at a 30 wt.% fiber loading, achieving values of 32 MPa and 1.3 J, respectively. The findings demonstrate that cardamom leaf midrib fibers constitute a viable, sustainable reinforcement alternative for lightweight structural composite applications.

Keywords: Natural fiber composites; Elettaria cardamomum; polyester resin; flexural strength; impact strength; hand lay-up.

1. Introduction

Natural fiber-reinforced polymer composites' mechanical behavior has been thoroughly studied using a variety of fiber sources and matrix configurations. Key studies in this field are surveyed in the following review, which is arranged according to how relevant they are to the current work. The flexural and impact properties of coconut palm leaf midrib (MCL) reinforced polyester composites made using the hand lay-up method at different fiber weight fractions were examined [1]. According to the study, MCL/polyester composites outperformed a number of other natural fiber/polyester systems described in the literature in terms of flexural and impact performance, demonstrating the structural appropriateness of MCL fibers as a reinforcing agent. [2] evaluated the material and mechanical characteristics of Cocos nucifera leaf midrib, including density, moisture content, tensile, flexural, and impact strengths in fiber form, extending the characterization of MCL fibers. A single fiber pull-out test was used to assess the heat distortion temperature, tensile characteristics, and interfacial shear strength of composites made with different fiber weight fractions. MCL's potential as a workable reinforcement for polymer matrix composites was demonstrated by the study. Melamine Urea Formaldehyde (MUF) and polyester resins bonded with khadi, coconut leaf midrib (CLM), and glass fibers by hand lay-up were used to create five hybrid composite systems [3]. MUF-based composites regularly outperformed polyester-based composites in terms of Young's modulus and specific modulus, according to mechanical assessment. The maximum specific modulus was shown by the khadi-CLM hybrid in MUF resin, suggesting that MUF resin is more compatible with natural fiber reinforcements than polyester resin. The mechanical and structural characteristics of coir fiber/polyester composites made from leftover coconut shells were assessed [4]. Under two molding pressures, composites with fiber contents as high as 80% were created. Up to 50 weight percent fiber loading, rigid composites were produced; beyond that, the material changed to a more flexible, agglomerate-like behavior. These composites were compared to traditional engineering materials using flexural strength tests. The mechanical performance of hybrid composites reinforced with glass, pineapple leaf, and jute fibers in a 1:1:1 ratio inside polyester and epoxy matrices with fiber volume fractions ranging from 0.18 to 0.42 was studied [5]. All compositions' tensile, flexural, and impact qualities were evaluated. In every mechanical parameter tested, epoxy-based hybrid composites reinforced with the three-fiber combination performed better than their polyester equivalents. Dynamic Mechanical Analysis (DMA) was performed on polyester composites reinforced with glass, banana, and pineapple leaf fibers at natural fiber loadings of 10%, 20%, and 30% at frequencies of 1 to 10 Hz and temperatures ranging from room temperature to 130°C [6]. Storage modulus, loss modulus, damping factor (Tan delta), and glass transition temperature as functions of fiber content and frequency were all well quantified in the study. The thermal characteristics of polyester composites reinforced with banana and pineapple leaf fibers at volume fractions ranging from 0.112 to 0.346 were examined, particularly thermal conductivity and specific heat capacity [7]. It was discovered that while thermal conductivity increased with temperature, it decreased with increasing fiber concentration. Differential scanning calorimetry confirmed that specific heat capacity had a similar pattern to thermal conductivity. In compliance with ASTM guidelines, randomly inserted reinforced coconut leaf sheath fibers into a polyester matrix and assessed their tensile, flexural, and Charpy impact characteristics [8]. Tensile strength and modulus values of 17.73 MPa and 254.21 MPa were found for fiber weight fractions of 12.83% and 11.06%, respectively. As the amount of fiber grew, the Charpy impact strength rose from 1.93 to 5.36 kJ/m², and morphological examination verified that the fiber and resin had a strong interfacial connection. The impact of alkali treatment and H2O2 bleaching on the tensile characteristics of short pineapple leaf fiber (PALF) reinforced polyester composites at fiber weight fractions up to 30% was investigated [9]. With a maximum tensile strength of 88.7 MPa, treated PALF composites at 30 weight percent loading outperformed plain polyester by 68.95% and untreated fiber composites by 22.68%. Tensile modulus increased gradually with increasing fiber loading in both treated and untreated fiber composites. In order to assess mechanical, morphological, free vibrational, and damping properties, created randomly orientated PALF/polyester composites by hand lay-up and compression molding at 17 MPa [10]. According to the law of mixtures, tensile, compressive, and flexural characteristics increased with PALF loading. Improved fiber/matrix adherence at higher fiber percentages and the 45 weight was confirmed by SEM analysis. PALF composite was shown to be a good option for applications involving structural building. The effects of temperature and fiber composition on the thermal conductivity, specific heat capacity, and thermal diffusivity of natural fiber composites with fiber volume fractions ranging from 0.18 to 0.42 were investigated [11]. It was discovered that whereas thermal diffusivity was influenced by fiber content with little sensitivity to temperature change, thermal conductivity decreased with increasing fiber concentration but increased with temperature. Alkali-treated Palmyra palm leaf stalk fiber (PPLSF) and jute fiber hybrid composites made by compression molding in a bi-layer unidirectional configuration in an unsaturated polyester matrix were studied [12]. Tensile, flexural, storage modulus, and loss modulus all improved as the amount of jute fiber increased, indicating a positive hybrid effect from hybridization. The hybrid composites showed potential for lightweight automotive applications with performance levels equivalent to those of natural/glass fiber hybrid systems. Examined tensile and flexural behavior as factors of fiber length and volume percentage in sisal fiber/polyester composites made by compression molding and Resin Transfer Molding (RTM). In both procedures, mechanical characteristics improved as fiber loading increased. Compared to compression-molded specimens, RTM composites showed reduced void content and water absorption, and SEM examination verified a significant relationship between mechanical performance and morphological quality. Additionally, RTM composites demonstrated strong agreement with theoretical predictions for Young's modulus [13].

The use of lignocellulosic natural fiber reinforcements in polyester matrices has a solid foundation thanks to the amount of research discussed above. The primary factors influencing composite mechanical performance are generally found to be fiber type, loading percentage, surface treatment, and processing technique. The current study assesses the potential of Elettaria cardamomum leaf midrib fibers, an understudied agricultural byproduct, as reinforcing agents in polyester composites.

2. Experimental Work

2.1 Materials

The midrib of Elettaria cardamomum (cardamom) leaves served as the main reinforcing material in this investigation. The midribs were gathered from well-established cardamom plantations in Kerala, India. After being collected, the midribs were thoroughly cleaned with clean running water to get rid of any remaining organic impurities that had accumulated during harvesting and transportation, as well as surface dust, soil particles, and insect detritus. The midribs were cleaned and then left to sun-dry for seven days in ambient air. Using a metal ruler and a sharp knife, the sun-dried midribs were then cut into uniform sizes appropriate for composite processing and specimen creation. Polyester resin, which was purchased from a nearby industrial source in Karur, Tamil Nadu, India, was used as the matrix material. Cobalt naphthenate was provided as an accelerator and methyl ethyl ketone peroxide as a hardener with the resin.

2.2 Preparation of Composites

A manual hand lay-up method was used to create the composite. In this work, all midrib fibers were orientated in the same longitudinal orientation using the unidirectional fiber alignment approach. To stop the cured composite from sticking, a flat wooden mold covered with a thin release agent (polyvinyl alcohol) served as the manufacturing surface. According to the supplier's instructions, the polyester resin was combined with MEKP hardener at a ratio of two parts per 100 parts of resin, and cobalt naphthenate accelerator was added at a ratio of 0.5 parts per 100 parts of resin. To guarantee uniform dispersion, the liquid was vigorously agitated for around three minutes. For a full day, the composite was left to cure at room temperature. A switch board cutting machine was then used to properly demold and trim the cured composite to the necessary specimen dimensions.

2.3 Mechanical Testing

2.3.1 Flexural Testing

In complete accordance with the ASTM D790 standard for flexural characteristics, the composites' flexural qualities were assessed utilizing a three-point bending configuration on a Universal Testing Machine (UTM). From the manufactured composites, test specimens were cut to a nominal dimension of 127 mm × 12.7 mm × 3.2 mm (length × width × thickness). Each specimen was placed symmetrically across two support pins during testing, and the support span length was kept constant at 80 mm. In accordance with ASTM D790 specifications for the tested specimen geometry, the crosshead speed was set at 2 mm/min. Each composite formulation was evaluated on a minimum of three specimens, and the mean and standard deviation data are shown.

2.3.2 Impact Testing

Using a pendulum-type Izod Impact Testing Machine, the composite specimens underwent Izod impact testing in compliance with the ASTM D256 standard. The cured composite was used to create rectangular specimen blanks with measurements of 63.5 mm × 12.7 mm × 3.2 mm. Unnotched specimens were used for testing in this investigation. The impact strength was determined by dividing the recorded impact energy by the cross-sectional area of the specimen at the time of failure. The impact energy expended during fracture was immediately recorded from the testing machine's calibrated dial gauge. Every impact test was conducted at room temperature. A minimum of three specimens underwent testing, and average results together with standard deviations are presented.

3. Results and Discussion

3.1 Flexural Strength

Figure 1 illustrates how the flexural strength of each composite was ascertained using three-point bending tests. The findings unequivocally show that the fiber reinforcing content has a systematic and significant impact on the polyester matrix's flexural performance. A notable increase in flexural strength was noted at 30 weight percent with the addition of cardamom leaf midrib fibers. In order to maximize the fibers' contribution to flexural resistance, the unidirectional fiber alignment further guarantees that the fibers are orientated parallel to the major bending stress axis. Increased composite stiffness is caused by the midrib fibers' intrinsic greater cellulosic stiffness in comparison to the polyester matrix. All of these findings suggest that the ideal fiber loading for flexural performance in Elettaria cardamomum leaf midrib/polyester composites is 30 weight percent.

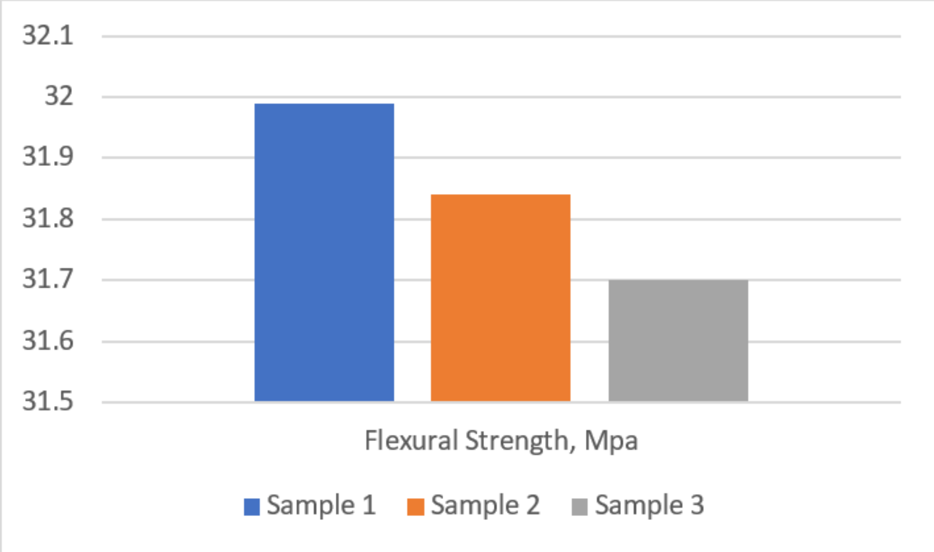

Figure 1. Flexural Strength

3.2 Impact Strength

Figure 2 illustrates how the unnotched Izod impact tests were used to calculate the impact strength for each composite. The fibers serve as physical barriers to the propagation of fractures under impact loading, causing them to deflect around the fibers, bridge over the faces of the cracks, and release energy through mechanisms such as fiber debonding, fiber pull-out, and fiber fracture. A well-developed fiber network that offers several concurrent processes of energy dissipation during dynamic fracture is consistent with the noticeable improvement at 30 weight percent loading. There are more fiber matrix interfaces per unit volume due to the higher fiber density at this loading level, and each one gradually increases energy absorption through debonding. Furthermore, the unidirectional fiber arrangement delays catastrophic fracture by ensuring that fibers parallel to the specimen length offer maximal resistance to the bending moment exerted upon Izod impact.

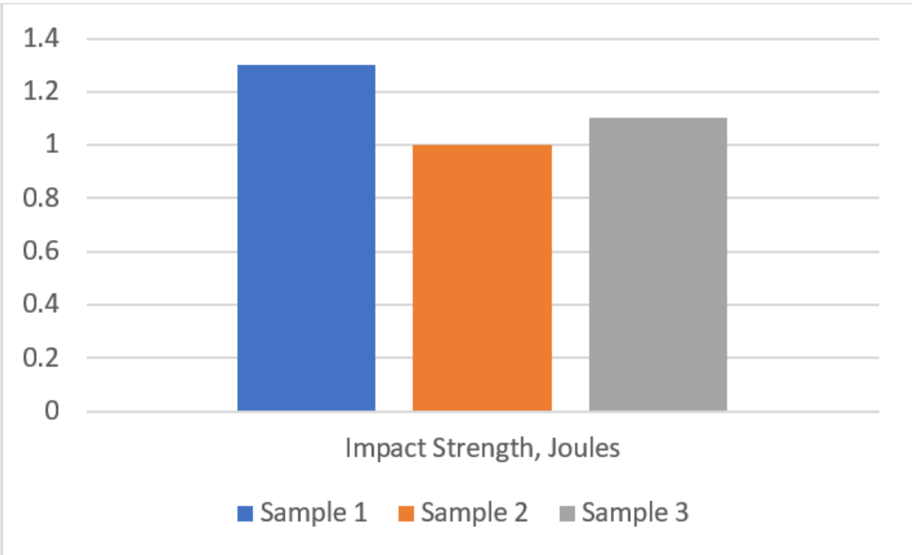

Figure 2. Impact Strength

4. Conclusions

The flexural and impact mechanical properties of Elettaria cardamomum (cardamom) leaf midrib reinforced polyester composites, which were made using the hand lay-up technique with unidirectional fiber alignment at fiber weight fractions of 30%, have been systematically investigated in this study. The reinforcing effectiveness of this agricultural by-product fibre was confirmed when cardamom leaf midrib fibers were incorporated into the polyester resin matrix, leading to notable increases in both flexural and impact mechanical characteristics. For both flexural and impact performance, a fiber weight fraction of 30% was found to be ideal. Flexural strength reached 32 MPa and impact strength reached 1.3 J at this loading, indicating that 30 weight percent is the critical reinforcing threshold for this composite system under the processing circumstances used.

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