



Jute Reinforced Epoxy Switch Panels Fabrication and Preliminary Characterization

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ABSTRACT

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Natural fibre reinforced polymer composites are increasingly being explored as lightweight and sustainable alternatives for engineering applications. In the present study, a jute fibre reinforced epoxy composite was developed and fabricated into a six-opening electrical switch-panel prototype using the hand lay-up technique. The jute reinforcement was subjected to alkali treatment prior to fabrication, while epoxy resin and hardener were mixed in a 10:1 ratio. The fabricated composite was evaluated through water absorption, impact, and thermogravimetric tests to obtain a preliminary understanding of its physical, mechanical, and thermal behaviour. Three specimens were subjected to water immersion for 24 h, resulting in water absorption values ranging from 2.03% to 2.51%, with an average value of $2.23 \pm 0.25\%$. Impact testing of three specimens produced energy values of 70, 68, and 70 J, corresponding to an average of 69.33 ± 1.15 J. Thermogravimetric analysis indicated a gradual initial mass reduction followed by a more pronounced degradation region at elevated temperatures. The study demonstrates the feasibility of fabricating a jute–epoxy composite into the required switch-panel geometry and provides preliminary information regarding its moisture absorption, impact response, and thermal behaviour. Further investigations involving electrical insulation properties, flammability, long-term moisture exposure, and comparison with conventional switch-panel materials are recommended before considering the composite for practical electrical applications.

Keywords — Jute fibre, epoxy composite, natural fibre composite, switch panel, hand lay-up, water absorption, impact behaviour, thermogravimetric analysis.

1 INTRODUCTION

Natural fibre reinforced polymer composites combine a polymer matrix with plant-derived reinforcement and are investigated for components where material availability, mass, and manufacturing simplicity matter. Bledzki and Gassan [1] established the importance of fibre structure, moisture sensitivity, and interfacial compatibility in cellulose-based composites. Faruk et al. [2] surveyed natural fibre biocomposites, while Pickering et al. [3] identified fibre characteristics, architecture, processing, and interfacial bonding as determinants of mechanical performance. These studies provide a basis for exploring jute reinforcement in a shaped panel, but do not imply that any natural fibre laminate meets electrical-component requirements.

The interface between hydrophilic plant fibres and a polymer matrix is a recurrent limitation. Li et al. [4] and Kabir et al. [5] reviewed chemical treatments intended to alter fibre surfaces and improve compatibility. Gassan and Bledzki [6] directly investigated alkali-treated jute/epoxy composites, showing that treatment conditions influence mechanical response. Therefore, sodium hydroxide treatment is a defensible processing variable, but its benefit must be demonstrated using an untreated control and a defined treatment history. A nominal treatment concentration alone cannot establish improved adhesion in a new laminate.

Moisture exposure is particularly relevant to panels containing lignocellulosic reinforcement. Dhakal et al. [7] studied the relationship between water uptake and mechanical properties in hemp/polyester composites, providing adjacent-



system evidence that moisture screening should be coupled to residual-property measurements. Gassan and Bledzki [8] examined absorption–desorption cycling in jute/epoxy composites. Tezara et al. [9] investigated woven jute/ramie epoxy laminates and demonstrated the relevance of stacking sequence and aqueous exposure. Their results motivate longer immersion and conditioning studies, although different matrices, reinforcements, and exposure durations preclude direct numerical comparison with a single 24 h measurement.

Surface modification and thermal characterization also require distinct evidence. Wang et al. [10] combined chemical and microscopic analyses with mechanical and thermal testing of silane-modified jute/epoxy laminates. Ashraf et al. [11] reviewed jute composites and their application-dependent limitations, and Alsuwait et al. [12] emphasized the interaction between processing and properties in epoxy-based natural fibre composites. Nurazzi et al. [13] reviewed thermogravimetric behaviour and treatment effects. Collectively, this literature supports systematic material characterization; it does not justify inferring flame resistance or electrical insulation performance from a thermogravimetric curve alone.

The present study investigates the feasibility of fabricating a jute fibre reinforced epoxy composite into a six-opening switch-panel faceplate and evaluates its preliminary moisture absorption and impact behaviour. The work focuses on the design, fabrication and basic characterization of the composite panel using the available experimental data. The results are intended to provide an initial understanding of the material performance and to identify areas that require further detailed investigation before considering practical electrical applications. Since no neat epoxy or commercial switch-panel material was included for comparison, the study is limited to preliminary performance assessment rather than direct comparative evaluation.

II MATERIALS AND METHODS

2.1 Materials and Study Scope

The switch panel was fabricated using jute fibre as reinforcement and epoxy resin as the matrix material. A suitable hardener was mixed with the epoxy resin during composite preparation. The experimental work involved fabrication of the jute–epoxy laminate, development of the switch panel, water absorption testing, impact testing, and thermal characterization.

Jute reinforcement was arranged in the form used during the fabrication process and impregnated with the epoxy–hardener mixture by hand lay-up. The fabricated laminate was subsequently cured and processed to obtain the required switch-panel geometry. Specimens prepared from the composite laminate were used for evaluating water absorption and impact behaviour. Three specimens were considered for each of these tests, while the thermal behaviour of the composite was examined using thermogravimetric analysis.

The present study primarily focuses on assessing the feasibility of producing a jute fibre reinforced epoxy composite switch panel and obtaining preliminary information regarding its moisture absorption, impact response, and thermal behaviour.

2.2 Panel Geometry and Design

The switch panel was designed with an overall dimension of 220×145 mm. Six square openings, each having a nominal dimension of 45×45 mm, were arranged in two rows with three openings in each row, as shown in Fig. 1. The panel was developed to provide the required openings for accommodating electrical switches and accessories.

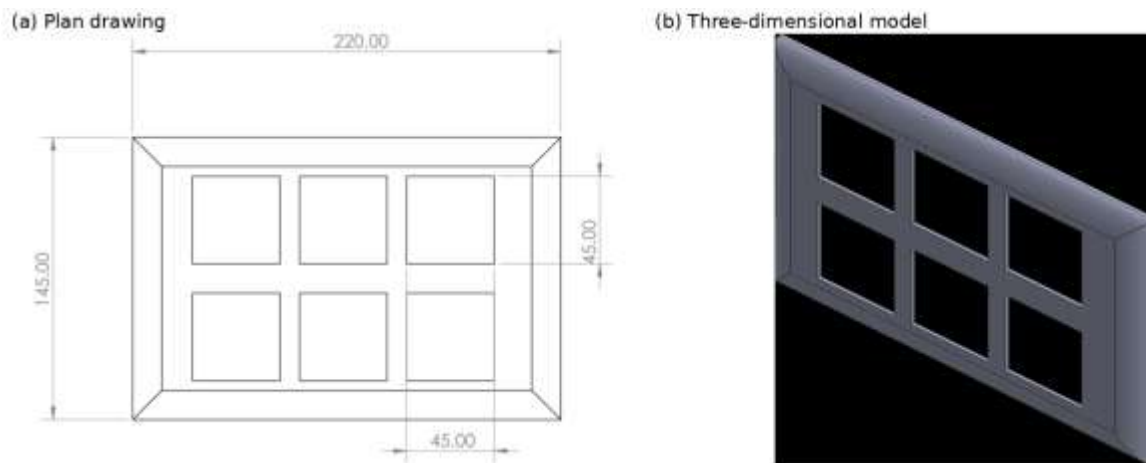


Fig. 1. Switch-panel design views

A three-dimensional model of the proposed panel was prepared before fabrication to visualize the overall configuration and peripheral profile. Based on this design, the composite laminate was fabricated and subsequently trimmed and machined to obtain the required panel shape and opening arrangement. The final fabricated panel was visually compared with the proposed design to confirm the overall configuration.

2.3 Preparation and Fabrication of the Composite

Prior to fabrication, the jute fibres were cleaned and subjected to alkali treatment using a 5% sodium hydroxide solution for approximately 2–3 h. The treated fibres were then washed thoroughly with distilled water until a neutral pH was attained and subsequently dried. The drying process was carried out within a temperature range of approximately 60–80 °C for several hours before composite fabrication.



Fig. 2. Major stages involved in the fabrication of the jute–epoxy composite laminate.

Epoxy resin and hardener were mixed in a mass ratio of 10:1. A flat mould of approximately 300 × 300 × 6 mm was used for laminate preparation, and a release coating was applied to facilitate demoulding. The jute reinforcement was placed in the mould and impregnated with the epoxy–hardener mixture using the hand lay-up technique. A roller was used during lay-up to improve resin distribution and minimize entrapped air within the laminate.

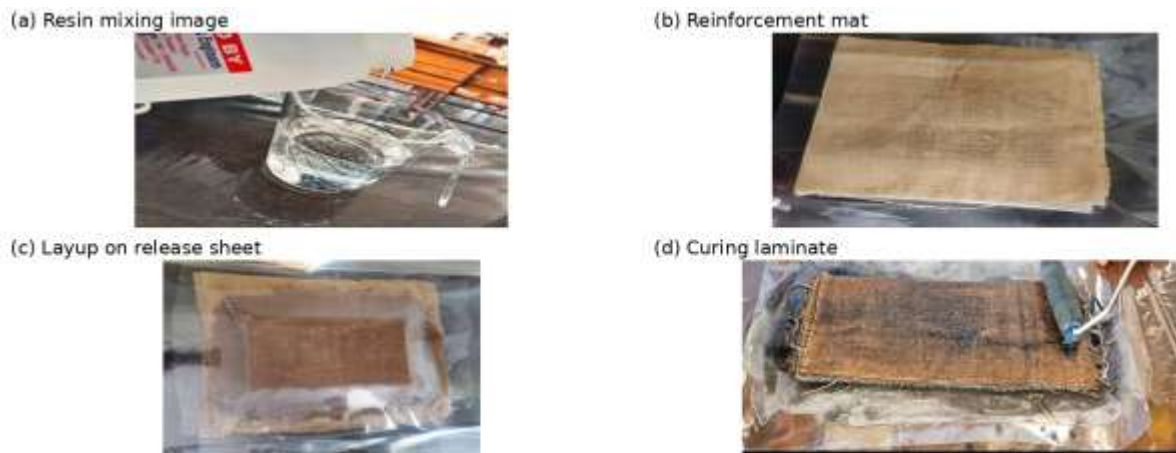


Fig. 3. Additional stages of composite preparation, lay-up and curing.

After lay-up, the laminate was consolidated under a pressure of approximately 0.4 MPa and allowed to cure at room temperature for about 24 h. This was followed by post-curing at an elevated temperature in the range of 80–100 °C for approximately 2–3 h. After curing, the laminate was removed from the mould, trimmed and sanded to obtain the required surface finish and dimensions. The major stages involved in the fabrication process are illustrated in Figs. 2 and 3. Following fabrication, the laminate was conditioned at room temperature before preparation of the specimens required for subsequent testing. Test specimens were stored under laboratory conditions of approximately 23 ± 2 °C and $50 \pm 5\%$ relative humidity prior to characterization.

2.4 Water Absorption Test

Water absorption behaviour of the fabricated composite was evaluated using three specimens with nominal dimensions of $76.2 \times 25.4 \times 3.2$ mm, following the general procedure of ASTM D570 [14]. Each specimen was initially weighed to obtain its dry mass, W_1 . The specimens were then immersed in water at room temperature for 24 h. After immersion, the specimens were removed, the surface moisture was wiped off, and the wet mass, W_2 , was recorded.

The percentage water absorption after 24 h was calculated using Eq. (1):

$$A_{24}(\%) = \frac{W_2 - W_1}{W_1} \times 100 \quad (1)$$

where W_1 is the initial dry mass and W_2 is the mass after 24 h of water immersion. The test provides an indication of the short-term moisture uptake behaviour of the fabricated jute–epoxy composite.

2.5 Impact Test

The impact behaviour of the composite was evaluated using three specimens having nominal dimensions of $63.5 \times 12.7 \times 3$ mm. Testing was carried out using an RI 300 impact testing machine with reference to the Izod impact test procedure described in ASTM D256 [15]. Each specimen was positioned in the impact testing apparatus and subjected to pendulum loading. The energy absorbed during impact was recorded directly from the testing equipment. Three readings were obtained and subsequently used to determine the average impact energy and the variation among the specimens. Since only the recorded impact-energy values were available for analysis, the present study uses these values primarily for preliminary assessment of the impact response of the fabricated composite.

2.6 Thermogravimetric Analysis

Thermal behaviour of the composite was examined using thermogravimetric analysis with reference to ASTM E1131 [16]. A small composite sample of approximately 10 mg was considered for the test, and heating was carried out at a nominal rate of 10 °C min^{-1} . The sample was heated progressively to an elevated temperature while the variation in its mass was monitored. The resulting thermogravimetric curve was used to examine the general pattern of mass loss with increasing temperature and to identify the principal region of thermal degradation.



Fig. 4. Specimens prepared for water absorption, impact and thermal characterization.

The available thermogravimetric curve indicates a gradual initial change followed by a more pronounced reduction in mass at higher temperatures. Since complete instrument-generated numerical data were not available, the thermal result is interpreted qualitatively in the present investigation.

III RESULTS

3.1 Fabricated component

The fabricated jute–epoxy composite panel is shown in Fig. 5. The final component consisted of six openings arranged in two rows of three, corresponding to the proposed switch-panel design. A woven fibre texture was visible on the panel surface, confirming the presence of the jute reinforcement within the laminate. Minor variations in surface finish and edge quality were observed after trimming and machining. The successful preparation of the panel demonstrates the practical feasibility of producing the required switch-panel geometry using the hand lay-up method.

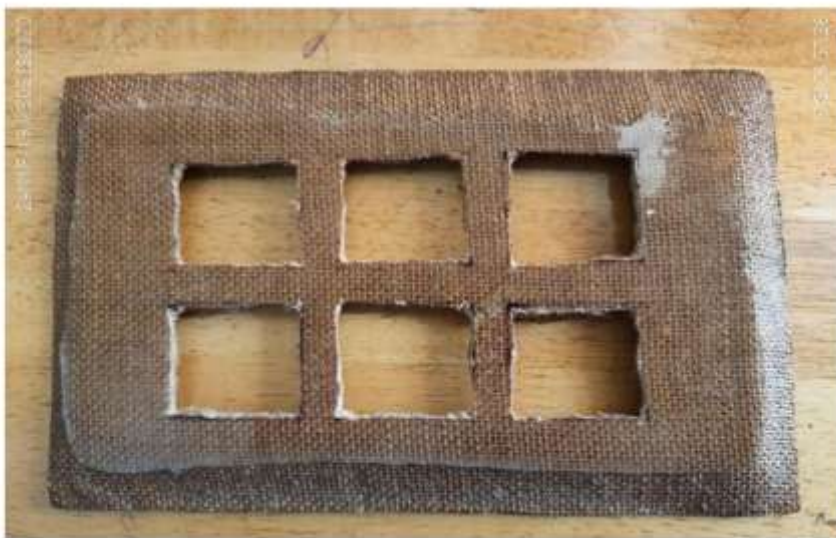


Fig. 5. Fabricated switch-panel

3.2 Water absorption

The water absorption results obtained after 24 h of immersion are presented in Table 1. In all three specimens, the mass increased after immersion, indicating moisture uptake by the composite. The calculated water absorption values were 2.157%, 2.509%, and 2.030% for specimens 1, 2, and 3, respectively. The average water absorption was therefore $2.23 \pm 0.25\%$

Table 1. Recorded mass pairs and recalculated 24 h water absorption

Specimen	Dry mass W_1	Wet mass W_2	Mass gain	Absorption (%)
1	25.038	25.578	0.540	2.157
2	24.156	24.762	0.606	2.509
3	25.126	25.636	0.510	2.030
Mean $\pm$ SD	—	—	—	2.232 ± 0.248

The relatively small variation among the three specimens indicates reasonably consistent moisture absorption behaviour within the tested samples. Moisture uptake in natural-fibre composites is generally associated with the hydrophilic nature of lignocellulosic fibres as well as the presence of microscopic voids and fibre–matrix interfaces



through which water can penetrate. The present result represents short-term water absorption after 24 h of immersion. Longer exposure durations and repeated measurements would be required to determine equilibrium moisture uptake and to assess the influence of absorbed water on the mechanical and dimensional stability of the composite.

3.3 Impact Behaviour

The impact-energy values obtained from the three specimens are presented in Table 2. The measured values were 70 J, 68 J, and 70 J, resulting in an average impact energy of 69.33 ± 1.15 J.

The relatively narrow range of measured values indicates limited variation among the tested specimens. The ability of the composite to absorb impact energy can be attributed to the combined contribution of the epoxy matrix and jute reinforcement, where the fibre network may assist in resisting crack propagation and redistributing the applied impact load. Since the present investigation involved only three specimens, the results should be considered as an initial assessment of the impact response of the fabricated laminate. Additional testing with a larger number of specimens and clearly defined notch geometry would improve the reliability of the impact characterization.

Table 2. Impact-energy readings

Specimen	Energy (J)
1	70
2	68
3	70
Mean $\pm$ sample SD	69.33 ± 1.15

3.4 Thermal Behaviour

The thermogravimetric curve obtained for the composite is shown in Fig. 6. The curve indicates a relatively small reduction in mass during the initial stage of heating, followed by a more pronounced decrease at higher temperatures. The major mass-loss region appears approximately within the 300–450 °C temperature range, after which the rate of mass reduction gradually decreases. The initial mass reduction may be associated with the removal of absorbed moisture and low-molecular-weight constituents. The major degradation stage is generally associated with thermal decomposition of the lignocellulosic reinforcement and degradation of the epoxy matrix. At still higher temperatures, the remaining material gradually decomposes, leaving a smaller residual mass.

The available TGA curve provides a useful preliminary indication of the thermal degradation pattern of the fabricated composite. More detailed thermal characterization using complete instrument-generated data would allow determination of parameters such as onset degradation temperature, maximum degradation rate, and residual mass fraction.

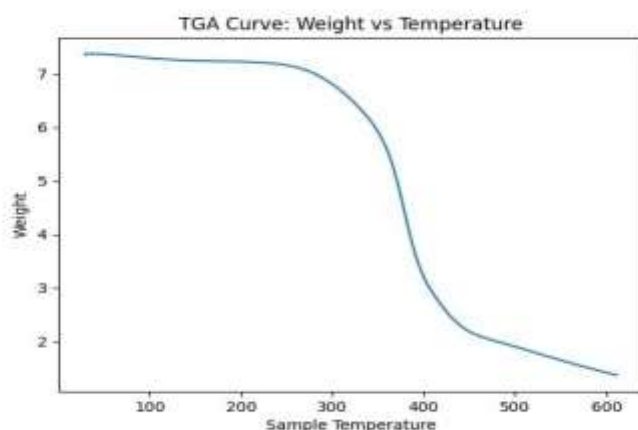


Fig. 6. Thermogravimetric behaviour of the fabricated jute–epoxy composite.



IV. DISCUSSION

4.1 Fabrication and Material Behaviour

The present study demonstrates that a jute fibre reinforced epoxy composite can be successfully fabricated into a switch-panel configuration using a relatively simple hand lay-up process. The final component retained the intended arrangement of six openings and showed adequate structural integrity during trimming and handling. Hand lay-up is widely used for natural-fibre polymer composites because of its simplicity, low equipment requirement, and suitability for producing flat or moderately complex components.

The alkali treatment applied to the jute reinforcement was intended to improve fibre–matrix interaction by removing surface impurities and modifying the fibre surface. Previous studies have shown that alkali treatment can improve bonding between natural fibres and polymer matrices by increasing surface roughness and improving interfacial contact [4–6]. However, a direct comparison between treated and untreated fibres was not included in the present work. Therefore, the effect of the treatment should be investigated separately in future studies.

4.2 Moisture Absorption Characteristics

The average water absorption after 24 h was **2.23%**, indicating that the composite absorbed a measurable quantity of water during immersion. This behaviour is expected in jute-based polymer composites because jute contains cellulose and hemicellulose, both of which contain hydroxyl groups that attract moisture.

Moisture can enter the composite through the fibres, exposed edges, microscopic voids, and fibre–matrix interfaces. Previous investigations have shown that prolonged moisture exposure can affect the strength, stiffness, and dimensional stability of natural-fibre composites [7–9].

The present water absorption value should therefore be considered as a short-term indicator rather than a complete measure of long-term moisture resistance. Future investigations should include longer immersion periods, repeated measurements, and evaluation of the mechanical properties before and after moisture exposure.

4.3 Impact and Thermal Performance

The average recorded impact energy of **69.33 J** indicates that the fabricated specimens were capable of absorbing a considerable amount of energy during impact loading. The jute reinforcement may contribute to impact resistance by bridging cracks and delaying crack propagation through the epoxy matrix.

However, impact behaviour in fibre-reinforced composites depends strongly on fibre orientation, fibre content, interfacial bonding, specimen geometry, and testing conditions. Additional tests using standardized specimen preparation and a larger number of samples would therefore be useful for establishing reliable impact-performance values.

The thermogravimetric curve showed a major mass-loss stage at elevated temperature, which is characteristic of natural fibre reinforced polymer composites. Thermal degradation in such systems usually involves evaporation of moisture at lower temperatures, decomposition of lignocellulosic constituents at intermediate temperatures, and degradation of the polymer matrix at higher temperatures.

The present thermal analysis gives a preliminary understanding of the degradation behaviour of the composite. Additional thermal characterization, including derivative thermogravimetry and differential scanning calorimetry, would provide more detailed information regarding the thermal stability and transition behaviour of the material.

4.4 Potential Application and Scope for Further Work

The fabricated panel demonstrates the potential of jute fibre reinforced epoxy composites for lightweight non-structural panel applications. The use of natural fibre reinforcement provides an opportunity to reduce dependence on fully synthetic reinforcement materials while utilizing a renewable fibre resource.

However, before such a composite can be considered for practical electrical switch-panel applications, several additional properties must be evaluated. These include dielectric strength, insulation resistance, flammability, thermal



resistance, dimensional stability, long-term moisture resistance, and the ability of the panel to securely retain switches and mounting components.

Further investigations should also compare the proposed composite with conventional switch-panel materials and neat epoxy specimens. Such comparisons would help determine the actual advantages and limitations of incorporating jute reinforcement in this application.

V. CONCLUSION

A jute fibre reinforced epoxy composite switch panel was successfully fabricated using the hand lay-up technique. The developed panel incorporated six switch openings and demonstrated the feasibility of producing the required component geometry using natural fibre reinforced polymer composites.

The 24 h water absorption of the composite was found to be $2.23 \pm 0.25\%$, indicating moderate moisture uptake during short-term immersion. The three impact tests produced an average recorded impact energy of $69.33 \pm 1.15 \text{ J}$, with comparatively small variation among the specimens. Thermogravimetric analysis showed a major mass-loss region at elevated temperature, indicating the progressive thermal degradation of the jute–epoxy composite.

Overall, the study demonstrates the feasibility of fabricating a jute–epoxy composite switch-panel prototype and provides preliminary information on its moisture, impact, and thermal behaviour. Further experimental work involving larger sample sizes, comparative materials, electrical insulation testing, flammability assessment, and long-term environmental exposure is required before the material can be considered for practical electrical applications.

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Material and fabrication records

Confirm whether the laminate contains only jute or includes bamboo. Supply resin and hardener grades, suppliers, actual fibre fraction, fabric areal mass or chopped-fibre dimensions, ply count, layup sequence, final thickness, and batch IDs. Resolve drying, pressure, and postcuring ranges against laboratory records; specify the basis of 5% NaOH, treatment temperature, and solution-to-fibre ratio.

Water absorption data

Confirm whether the mass readings are grams, individual-coupon masses, or another quantity. The stated geometry gives 6.194 cm³, which is inconsistent with roughly 25 g for the listed system. Verify coupon identity and actual dimensions, balance precision, dry conditioning, immersion temperature, and weighing procedure. The corrected 2.23% mean should be used only if the input pairs are confirmed.

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Obtain the impact laboratory certificate: machine configuration, suitable Izod fixture, pendulum range, units, notch geometry, calibration, corrections, and specimen failure type. Verify whether 68–70 represents joules or another scale. Obtain the original TGA export and replace the supplied graph with labelled axes and a traceable specimen ID. Resolve 500 versus 600 °C and nominal 10 mg versus the plotted initial ordinate; add atmosphere, gas flow, and instrument details. Do not reconstruct an experimental curve from assumed data.

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