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# Effect of variation of granite powder filler content on the mechanical and thermal behaviour of jute-flax reinforced epoxy hybrid composites

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The current research focuses on the development of hybrid composites utilising natural fibre reinforcement and fillers with polymer resin for engineering applications. Natural fibres and filler materials have received substantial interest because of their environmentally beneficial and sustainable properties. Using the hand lay-up method, five hybrid composite samples were fabricated by keeping the jute fibre and flax fibre weight % ratio at 5(wt.%): 15(wt.%) and altering the granite powder filler weight percentage (0, 5, 10, 15, and 20 wt.%) in epoxy resin. A universal testing machine was used to assess the hybrid composites' tensile and flexural strengths, and an Izod impact tester was used to determine their impact strength. Mechanical tests demonstrated that the inclusion of granite powder filler improved the mechanical properties in the fibres up to 15 wt.%, but then decreased owing to filler agglomeration. The thermo-gravimetric analysis was used for evaluating the thermal response of the samples, or thermal stability of the hybrid composites and are thermally stable up to 420°C. Furthermore, Fourier Transform Infra-Red spectroscopy was used to trace the existence of chemical functional groups in the hybrid composite. Scanning Electron Microscopic examination was used to confirm the interfacial bonding and failure modes of tested hybrid composites. The results indicate that these hybrid composites can be used in various applications, such as structural panels for vehicles, automobiles, aerospace, and construction. Thus, combining otherwise-unused granite powder with jute and flax fibres yields methods for recycling waste and making eco-friendly composites.

**Keywords:** Characterisation, Epoxy, Granite powder proportion, Hybrid composite, Jute/ Flax fibres

## 1 Introduction

Novel materials were developed by modifying the constituent components to match customer requirements and market expectations, particularly in the composite industry, which requires light weight with improved strength for structural applications[1]. It is challenging to continue using traditional materials like steel and iron because they are heavy and more prone to corrosion, while synthetic reinforcements like carbon, Kevlar, glass, and nylon are susceptible to environmental contamination[2]. Selecting the right kind of constituent reinforcements for innovative materials is crucial. Natural fibre in for cements are a feasible alternative to synthetic fibres due to their positive attributes such as lightweight, low cost, abundance, and biodegradability. Natural fibres originate from a variety of sources on Earth, including plants, animals, and minerals. Fibres like bamboo, banana, Cissus Quadrangular is, jute, coir and flax are used in polymer composites[3]. These composites offer high strength, low specific weight, and high stiffness, making them suitable for a variety of applications including automobiles, infrastructure, and packaging[4,5]. One of the main drawbacks of natural fibre may be its hydrophilic nature, which could result in poor bonding, less dimensional stability, and decreased resistance to water absorption. Those drawbacks can be minimized by treating the fibre surface with various chemical substances such as sodium hydroxide, sodium silicate, potassium hydroxide, and saline[6,7]. Vinu Kumar *et al.*[8] applied alkali treatment to Alstonia macrophylla fibres taken from seed pods and investigated the effect of treatment on thermal stability, surface roughness, and crystallinity in comparison to the untreated fibre. Analyses using atomic force microscopy and field emission scanning electron microscopy showed that treated fibres have significantly more surface roughness than untreated ones

Jute is one of the strongest bast fibres available at a low cost and is also biodegradable; hence it has effectively substituted with synthetic fibres. This feature renders jute a very desirable reinforced fibre for composites, resulting in rising interest in construction, aerospace, infrastructure, automotive,

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and many other fields of engineering[9]. Cellulose, hemicellulose, and lignin—the three primary components of jute fibre—range from 61 to 73%, 13.6 to 23%, and 12 to 16%, respectively, for the different jute grades. There are also small quantities of fats, waxes, and pectin[10]. Delfi *et al.*[11] treated jute fibre with alkali, silane, or a combination of the two, and investigated the effects on flexural, interfacial shear strength, dynamic mechanical analysis (DMA), and water absorption characteristics. Results showed that the combination of two treatments enhanced mechanical and DMA properties of composites when compared to the untreated fibre composite owing to significant fibre–matrix surface bonding. Flax fibres were chosen by Bozaci*et al.*[12] as reinforcing elements for polymer composites, and surface treatment with atmospheric plasma enhanced the fibre-matrix bonding and mechanical performance. Perremans *et al.*[13] investigated the bonding between unidirectional flax fibre and epoxy resin using a range of chemical treatments, including silane and NaOH. According to tensile testing, the stress-strain curve has a tri-linear structure that includes amorphous, crystalline, and visco-elastic behavior. Kumar and Singh[14] investigated the effect of NaOH and/or silanetreatment on micro-hardness, thermal, wear and morphological behavior of the flax fibre. After that, these fibres are reinforced into epoxy resin to form the composite. SEM images showed that chemical treatment removes waxy and other substances from the fibre surface. Chemical treated flax fibres exhibit improved thermal stability than untreated flax fibres. The alkali-treated flax composite has the highest micro-hardness value compared to the other composite.

According to the available literature, jute and flax fibres are promising materials for single reinforcement in polymer composites. In many engineering applications, a single reinforcement may not offer the required composite properties. A hybrid composite, which combines two fibres and/or filler provides an ideal solution to the limitations of a single reinforced composite[15]. Agrawal *et al.*[16] created the hybrid composite by reinforcing jute and sisal fibres in an epoxy matrix and investigated its tensile and flexural properties as well as moisture uptake behavior. Tensile stress is highest with 100% sisal fibre and minimum with 100% jute fibre. Based on the findings, the author suggested using a hybrid composite made of 75% jute and 25% sisal, if tensile strength and moisture resistance are equally important. Using a hand lay-up technique, Reddy *et al.*[17] created a hybrid composite consisting of flax and jute into polyester resin, and they examined its mechanical and water-absorbing properties. The results showed that the 15F/5J composite had the superior mechanical properties because of the high cellulose content of flax fibre. Based on the findings, the produced composites are used in both indoor and outdoor applications.

Nowadays, hybrid composites are made with natural fibres and fillers to improve their mechanical strength and reduce cost. The characteristics of hybrid composites are influenced by the fibre's weight content and quality, as well as the filler shape, weight content of filler and uniform mixing of filler and resin[18]. Kadam *et al.*[19] investigated the impact of adding boron carbide filler to jute and palm fibre on the mechanical and dynamic properties of the resulting hybrid composite. The findings indicate that these hybrid composites perform well in engineering applications such as automobiles, sports equipment, marine environments, and construction. In order to create the hybrid composite, Reddy *et al.*[20] combined tannin fibres modified by NaOH with a mixture of polyester resin and granite powder. The results showed that the mechanical properties of the hybrid composite is determined by its weight content, alkali treatment, uniform distribution, and bonding of taps fibre, granite powder and polyester resin. Suriya Prakash *et al.*[21] treated Luffa cylindrica and sisal fibres with 5% NaOH and inserted boron carbide particles into the epoxy resin. Composite laminates were produced using the compression moulding method with a range of compositions; enhanced mechanical properties were seen with 11.25 wt. % Luffa cylindrica, 11.25 wt. % sisal fibre, and 7.5 wt. % $B_4C$ particles in 70 wt. % epoxy resin. As a result, the mechanical properties of the produced composites were significantly improved with the addition of $B_4C$ particles. Seal *et al.*[22] investigated the effect of bio fibres such as sisal, kenaf, and pineapple reinforced into epoxy resin, together with bio fillers like seashell, eggshell, and coconut, on the mechanical and water-absorbing properties of the resulting composite. SEM analysis demonstrated the adhesion between fibres and fillers, as well as matrix and fibre fracture after mechanical testing.

Now the objectives of present study, based on the reviewed literature are set to be: To fabricate a hybrid composite with the natural fibres reinforced into epoxy matrix; to investigate the effect of addition of granite powder filler in the composite and evaluate various properties of the fabricated hybrid composite; and to investigate the suitability of this composite for various applications. To achieve these objectives, fabrication of the hybrid composite with jute and flax natural fibres is undertaken using the hand lay-up method, five distinct composites were created by fixing the jute and flax fibre reinforcement to a total weight of 20%, changing the weight percentage of granite powder from 0% to 20% by multiples of 5%, and adjusting the epoxy weight percentage in every composite from 80% to 60% accordingly. Mechanical tests were performed on the specimens to determine which weight percentage of granite powder content (including 0 wt.%) provides the optimum tensile, flexural, and impact strengths. The thermo-gravimetric analysis was employed for evaluating the thermal response, or thermal stability, of the hybrid composites. Scanning Electron Microscope (SEM) was used to examine the bonding of jute, flax, granite powder, and epoxy resin.

Based on the results obtained these composites are suitable for infrastructure, construction, thermal, sports, ship hull and automobile applications. The primary goal of this study is to use unused granite powder to reduce landfills and protect the environment by preventing air pollution.

## 2 Materials and Methods

This section covers the selection of appropriate materials for composite fabrication, as well as the methods and processes required to carry out the experiments. Jute and flax with a combination of granite powder filler and epoxy has not been noticed in the literature hence, motivated to select these materials for the fabrication of the hybrid composites.

### 2.1 Materials

Go Green Products in Guntur, Andhra Pradesh, India, is the supplier of the jute and flax fibres that were utilised as reinforcing materials. Unused granite powder, with a particle size of 75 μm, was collected from Bethamcherla town, which is close to Kurnool in Andhra Pradesh, India. Ram Composites, located in Vishakhapatnam, Andhra Pradesh, India, supplied the hardener (HY 951) and epoxy (LY 556 grade) as a matrix material[23].

#### *2.1.1 Modification of Jute and flax fibre surface with NaOH*

Jute and flax fibres, cut to 250 mm lengths, were subjected to an alkali treatment for two hours at room temperature using a 5% sodium hydroxide (NaOH) solution. The objective of this treatment is to modify the fibre surface from hydrophilic to hydrophobic; during this process, the fibre surface becomes clean and rough, affecting interfacial adhesion between the fibres and the matrix. After that, the jute and flax fibres were repeatedly washed with clean water to completely rinse the leftover alkali solution until the pH of the cleaning solution was neutral[24]. Thus, the hydrophilicity of the natural fibres used was removed to make the composite suitable for more applications.

#### *2.1.2 Fabrication of Hybrid Composite*

Table 1 shows the various proportions of the jute, flax fibre, granite powder and epoxy resin used in hybrid composite.

The hand lay-up method is a widely used low-cost composite fabrication technique where clean and pre-cut fibre materials are manually applied to an open mold. This method is carried out at a controlled room temperature of 26°C by maintaining the relative humidity around 55% to prevent moisture absorption by the fibres, ensuring proper wetting and curing. To create the hybrid composite, the hand lay-up approach was used[24]. Using a computerized analytical balance, 5wt. % of jute and 15wt. % of flax were measured, for a fixed total of 20wt.% of fibres. To obtain unidirectional jute and flax fibres, the measured fibres were then equally spread out across a glass mold and weighed. In a separate glass container, epoxy and hardener mixture was maintained with a weight ratio of 100:10. Different weight percentages of granite powder (5%, 10%, 15%, and 20%) were mixed with the previously prepared resin mixture, and mechanical stirring was employed to ensure that the granite powder was evenly dispersed throughout the resin. Total weight percentage of resin plus hardener plus granite powder filler is fixed at 80. To make it easier to remove the composite from the glass mould, a thin layer of release gel has been applied first, followed by a granite epoxy mixture poured over the glass mold and spread to all corners, and then jute and

Table 1— The weight proportions of Jute-Flax fibre-granite powder and epoxy hybrid composite samples

| Designation | Jute-Flax fibre (Fixed 20wt. % ) | Granite powder (wt. %) | Epoxy and Hardener Resin (100:10) (wt. %) |
|---|---|---|---|
| G0 | 5wt.% of Jute+15wt.% of Flax | 0 | 80 |
| G5 | 5wt.% of Jute+15wt.% of Flax | 5 | 75 |
| G10 | 5wt.% of Jute+15wt.% of Flax | 10 | 70 |
| G15 | 5wt.% of Jute+15wt.% of Flax | 15 | 65 |
| G20 | 5wt.% of Jute+15wt.% of Flax | 20 | 60 |

flax fibres were added on top. The remaining mixture was poured on top of it, the OHP sheet was laid over it and a roller was used to form a flat surface and avoid air bubbles. After covering the mold with a glass plate and adding sufficient weight, it was left to cure for a day at room temperature. The samples were made according to ASTM standards for several sorts of characterizations. The hybrid composite fabrication process is drawn schematically in Fig. 1.

Figure 2 shows the Pictures of manufactured hybrid composite samples. Thus, the hybrid composite samples with jute and flax fibres, granite powder and epoxy resin are fabricated using hand layup method, fulfilling the first objective.

To check whether the thickness of a sample has increased with the addition of granite powder, thicknesses of each sample designation along with volume fraction of the fibres have been evaluated and presented in Table 2. It is observed that no significant increase in thickness has been noticed.

### 2.2 Methods

#### *2.2.1 Tensile Test*

Tensile test was used to evaluate the tensile properties of hybrid composites fabricated with jute-flax, granite powder and epoxy resin. Test samples were prepared using ASTM D-3039 standards and tested using a Universal Testing Machine (INSTRON-Model-3369) with a cross-head speed of 2 mm/min. The dimensions of the tensile test specimen were 3.2 mm in thickness, 25 mm in width, and 250 mm in length. Figure 3(a) shows the setting of tensile test specimen in Instron UTM Machine.

#### *2.2.2 Flexural Test*

The three-point bend test was used to determine the flexural strength of the prepared hybrid composites, and samples were generated in compliance with ASTM D790-03 standard. The samples prepared for flexural tests were analyzed using the INSTRON-Model-3369 Universal Testing Machine equipment with a cross-head speed of 2 mm/min. For each outcome, five test specimens with dimensions of 127 x 12.7 x 3.2 mm were made. Figure 3(b) shows the setting of flexural test specimen in Instron UTM Machine.

#### *2.2.3 Impact Test*

The hybrid composite, which consisted of jute, flax, granite powder, and epoxy samples, was subjected to an impact test to determine its capacity to absorb energy under impact loads. The ASTM D256 standard is followed when performing impact testing

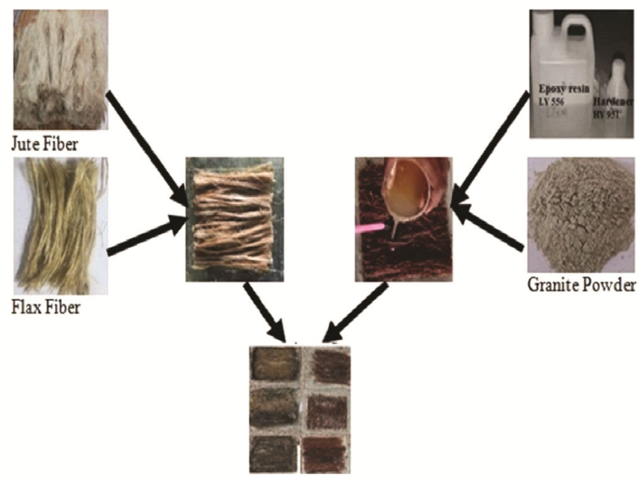


Fig. 1 — Shows the outline of fabrication process for hybrid composite

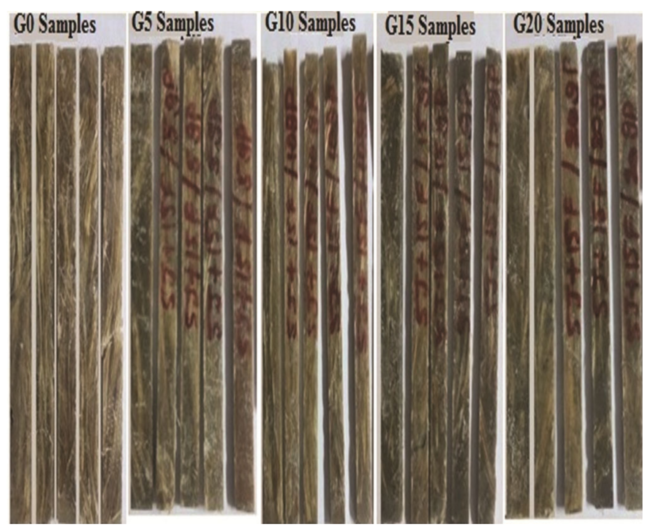


Fig. 2 — Fabricated hybrid composite samples

Table 2 —Void content, thicknesses, Volume fraction of fibres of all the sample designations

| Sample designation | Void content, % | Thickness sample, mm | Volume fraction of Jute | Volume fraction of Flax |
|---|---|---|---|---|
| G0 | 5.68273 | 3.21±0.02 | 4.340 | 12.57083 |
| G5 | 8.41454 | 3.22±0.01 | 4.470 | 12.94631 |
| G10 | 8.42208 | 3.22±0.01 | 4.607 | 13.34491 |
| G15 | 8.42088 | 3.22±0.01 | 4.754 | 13.76884 |
| G20 | 8.47891 | 3.23±0.01 | 4.909 | 14.22058 |

with a PSI Izod Impact tester. A notched specimen with a $45^0$ angle and a 2.5-mm depth was made. This test used sample sizes of 63.5 (length) x 12.7 (width) x 3.2 (thickness) $mm^3$. Figure 4 shows the setting of impact test specimen in Izod Impact tester.

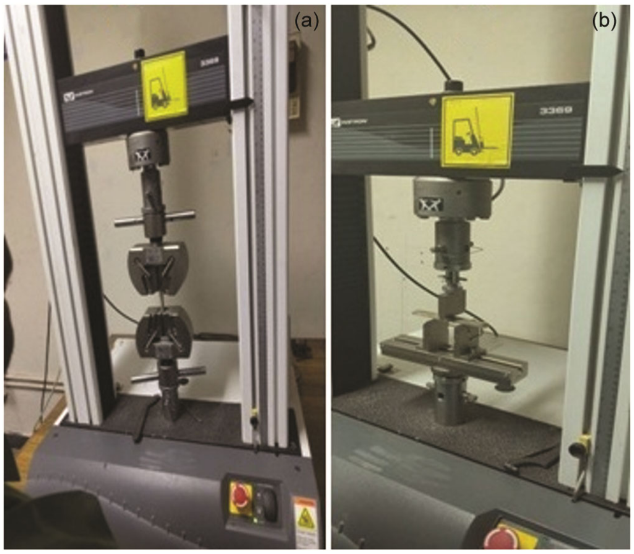


Fig. 3 — Instron 3369 UTM machine and samples set for testing (a) Tensile Test, and (b) Flexural test

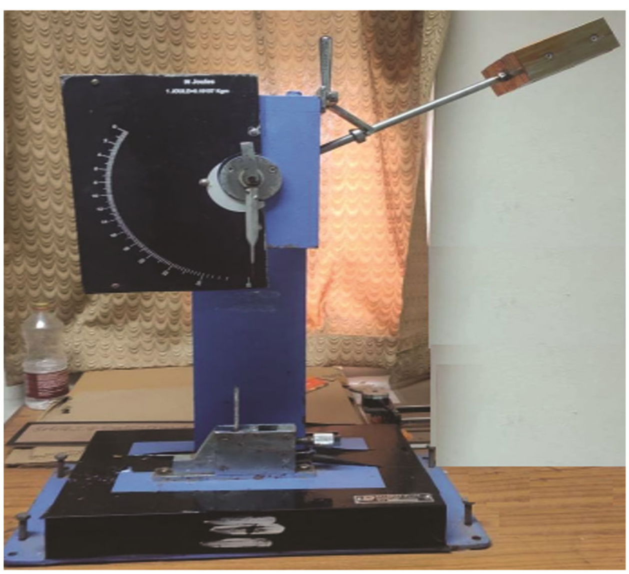

Fig. 4 — Izod impact tester with the sample set for

#### *2.2.4 TGA Analysis*

The Hitachi STA7300 thermo-gravimetric analyzer was used to examine the hybrid composite's thermal stability and degradation process. In order to record mass loss, this specimen was heated up in a maintained nitrogen gas atmosphere ($N_2$) between 40°C and 750°C.

#### *2.2.5 Scanning Electron Microscopy (SEM)*

A JEOL/EO Scanning Electron Microscope (Model-JSM-6390) was used to investigate the morphology, bonding, and types of failure of reinforcement and resin in mechanically tested hybrid composite samples. The investigated specimens contain natural fibres as well as inorganic components, both of which are non-conductive for SEM imaging. Therefore, they were clad with a thin slice (3µ) of conductive materials such as gold or platinum.

#### *2.2.6 FTIR Spectroscopy*

FTIR spectra were collected using FTIR spectroscopy (Model-Thermo Nicolet, Avatar 370) to determine which chemical functional groups were present in the produced hybrid composites. In order to investigate the spectra, the position and intensity of the absorption peaks identified. To identify functional groups and validate the material composition, the peaks were compared to reference spectra or values found in the literature. The absorption bands of composite samples were scanned from 4000 $cm^{-1}$ to 400 $cm^{-1}$, with a resolution of 4 $cm^{-1}$ and a total of 32 scans.

## 3 Results and Discussion

To fulfill the second objective of evaluating various properties of the composite, various tests like mechanical, TGA, FTIR and SEM morphology have been carried out. After the hybrid samples were examined and characterized, their results were presented in the form of tables and figures, and a discussion ensued about the findings.

### 3.1 Tensile Properties

Table 3 presents the tensile strength and modulus values of the hybrid composite specimens (G0, G5,

Table 3 — Tensile, flexural properties and impact energy of hybrid composites

| Composite Designation (Wt.%) | Tensile Strength (MPa) | Tensile Modulus (MPa) | Flexural Strength (MPa) | Flexural Modulus (MPa) | Impact Energy (J) | COV,% of Impact Energy |
|---|---|---|---|---|---|---|
| G0 | 75.42 | 3047.86 | 131.62 | 10484.98 | 16.4 | 2.06 |
| G5 | 99.05 | 3711.10 | 158.35 | 17495.81 | 19.8 | 3.58 |
| G10 | 107.01 | 4181.04 | 181.13 | 18400.06 | 20.7 | 2.99 |
| G15 | 147.54 | 5030.70 | 257.49 | 22632.83 | 22.2 | 3.47 |
| G20 | 94.76 | 3981.90 | 211.81 | 15699.19 | 21.5 | 2.25 |

G10, G15 and G20). Among these, specimen G15 has the highest tensile strength (147.54 MPa) and modulus (5030.70 MPa), indicating superior load-bearing capacity and stiffness of G15. Increased strength and modulus could be ascribed to the inclusion of well-dispersed granite powder fillers, which facilitate load transfer between the matrix, reinforcements, and filler particles[18]. Granite powder filler enhances the modulus more than the strength because, it stiffens the matrix and reduces its flexibility. The highest strength and modulus can be attributed to material composition, internal microstructure, and the presence of inorganic fillers[25]. In contrast, specimen G0 has the lowest strength (75.42 MPa) and modulus (3047.86 MPa), indicating poor mechanical performance. Its poor performance is caused by the presence of solely fibre reinforcements such as jute and flax fibres within the matrix, with no fillers supplemented. Figure 5 depicts the increasing trend of strength and modulus as granite powder filler concentration increases from 0 to 15 wt.%. In comparison to the G0 composite, the G5 and G10 samples had tensile strength (99.05 MPa) and modulus (3711.10 MPa), tensile strength (107.01MPa), and modulus (4181.04 MPa), respectively. However, the G20 sample deviates from this trend, with significantly lower values of tensile strength (94.76 MPa) and modulus (3981.90 MPa) when compared to the G15 sample. Poor filler dispersion (agglomeration and aggregation), poor matrix distribution, or excessive filler content (20wt.%) could have causeed stress concentration and brittleness, which may explain the irregularity exhibited in specimen G20[26]. Velmurugan *et al.*[27] studied the influence of silicon dioxide ($SiO_2$) and aluminiumtrihydrate ($Al\ (OH)_3$) fillers at different weight percentages (3, 6, and 9 wt.%) in hemp and epoxy hybrid composites. The results revealed that 6 wt.% of nanofillers significantly increased the tensile strength of $Al\ (OH)_3$ (59.84 MPa) and $SiO_2$ (66.14 MPa). Hybrid composites are well-suited for construction and automotive applications due to their enhanced mechanical properties.

### 3.2 Flexural Properties

Table 3 summarises the flexural strength and modulus values of the hybrid composite specimens (G0, G5, G10, G15 and G20). Among these, specimen G0 exhibits the lowest flexural strength (131.62 MPa) and modulus (10484.98 MPa) in comparison to other prepared composites, suggesting that the absence of fillers and the presence of only fibre reinforcements, such as flax and jute fibres, within the matrix are the primary causes of poor mechanical performance. On the other hand, specimen G15 exhibits the highest flexural strength (257.49 MPa) and modulus (22632.83 MPa), revealing greater stiffness and load-bearing capacity. This could be related to the use of well-dispersed granite powder fillers, which aid in load transfer between the matrix, reinforcements, and filler particles[18]. The highest flexural strength and modulus can be attributed to material composition, internal microstructure, and the presence of inorganic fillers[25]. Figure 6 illustrates that strength and modulus improve as the concentration of granite powder filler raises from 0% to 15wt. %. In contrast to the G0

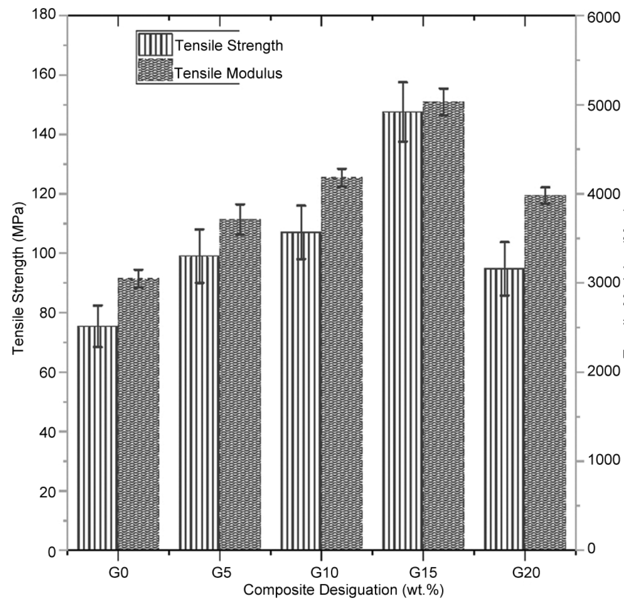


Fig. 5 — Shows tensile properties of hybrid composite

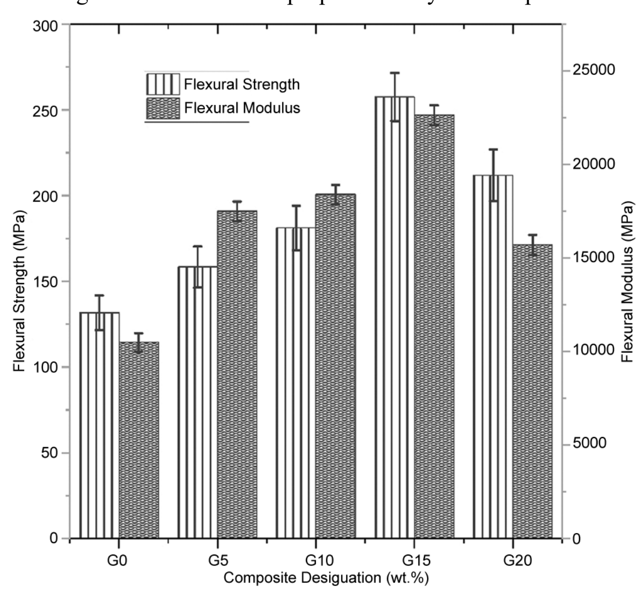


Fig. 6 — Shows flexural properties of hybrid composite

composite, the G5 and G10 samples exhibited flexural strength (158.35 MPa) and modulus (17495.81MPa), flexural strength (181.13 MPa), and modulus (18400.06 MPa), respectively. However, the G20 sample deviates from this pattern, having lower values of flexural strength (211.81 MPa) and modulus (15699.19 MPa) than G15 sample. Poor filler dispersion (agglomeration and aggregation), poor matrix distribution, or high filler content (20wt.%) can all result in stress concentration and brittleness, which could explain the variation shown in specimen G20[26]. Velmurugan *et al.*[27] studied the influence of silicon dioxide ($SiO_2$) and aluminium trihydrate (Al $(OH)_3$) fillers at different weight percentages (3, 6, and 9 wt.%) in hemp and epoxy hybrid composites. The findings of the evaluation of nanofiller concentrations indicated that 6 wt.% of nanofillers significantly increased the flexural strength of $SiO_2$ to 18.74 MPa and Al $(OH)_3$ to 21.74 MPa. According to Suriya Prakash *et al.*[28], combining coco shell powder to reinforcements made of snake grass and luffa cylinderica fibres improved their flexural properties. 7.5 wt.% of coco shell powder yields the greatest results for this hybrid composite, with a 28.31% increase in flexural strength.

### 3.3 Impact Energy

The impact energy of the hybrid composite specimens (G0, G5, G10, G15 and G20) was compiled in Table 3 and Fig. 7. The jute-flax reinforced (G0) composite's impact energy was measured to be 16.4J, and it increased steadily after adding the granite powder filler from 0wt.% to 15wt.%. When compared to 0wt.% granite filler, the impact energy rose by 20.73% at 5 wt% and 26.22% at 10 wt%. At 15wt%, the impact energy was maximum at 22.2 J because the impact load was first transferred to fibres and subsequently uniformly disseminated granite powder fillers due to strong bonding between the reinforcement's jute-flax-granite powder and epoxy matrix (Fig. 8). Granite powder fillers can also act as barriers for micro cracks, limiting their spread. The impact energy decreases when the granite powder filler content is increased to 20wt.% due to filler agglomeration and poor dispersion over the jute-flax fibre reinforced epoxy composites, as illustrated in Fig. 9. Impact strength raises up to 2 wt% flyash, but then decreases due to lower matrix deformability. Surface morphology analysis reveals that greater loadings lead to agglomeration, while lower filler concentrations lead to efficient dispersion[26, 29].

### 3.4 Thermo Gravimetric Analysis (TGA)

Thermal behavior of the Jute-flax-epoxy (G0) and jute-flax-granite powder-epoxy (G15) hybrid composites was examined using thermo-gravimetric analysis. Figure 8 shows how the weight of the created hybrid samples changed over time as the temperature increased. The starting temperature for both TGA graph samples is approximately 190 °C. At this temperature, a 5% weight loss was noticed, which is explained by the removal of volatile compounds

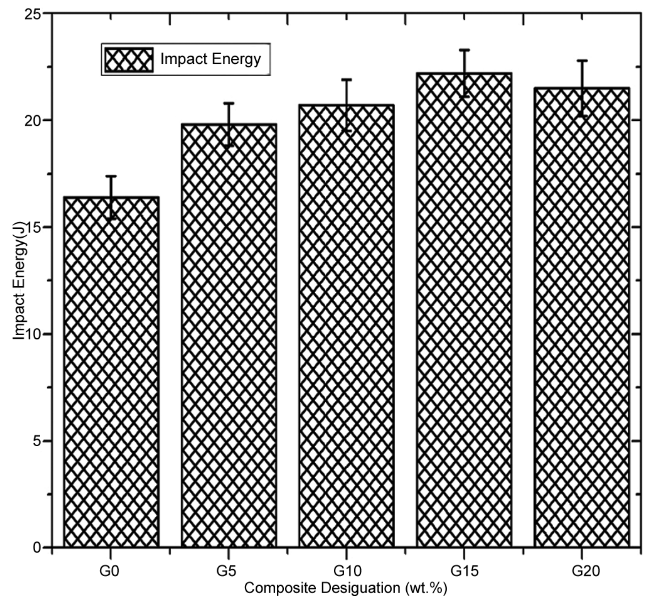


Fig. 7 — Impact energy of hybrid composite

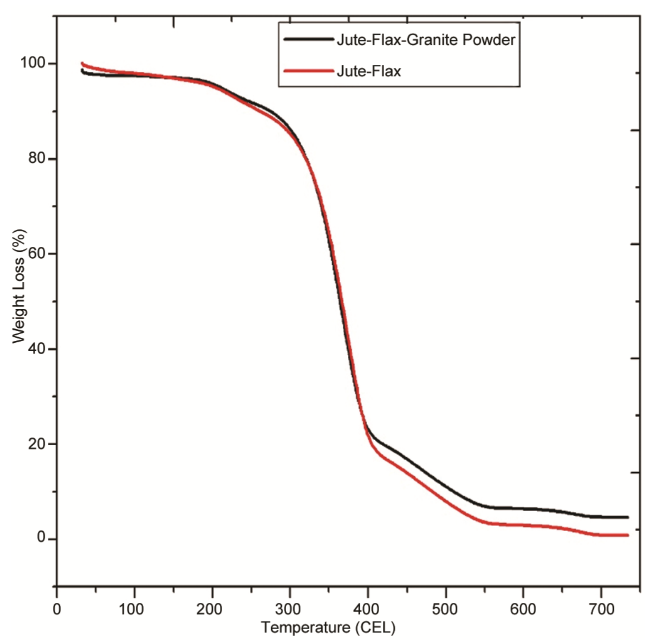


Fig. 8 — TGA graph of jute-flax-epoxy and jute-flax-granite powder-epoxy hybrid composites

and captured moisture content from the composite reinforcement. As temperature rises, G0 begins to decompose at ~ 190-305°C, followed by G15 at ~ 200-310°C. The temperature of maximal deterioration rate shifted by around 10-15°C in the presence of granite powder, showing a little improvement in thermal stability. At this stage, both samples lost 15% of their weight due to matrix disintegration, chemical components such as hemicelluloses, and cellulose in the hybrid composite. In the subsequent phase, the G0 and G15 samples begin to decompose at ~ 305–400°C and ~310–405°C, respectively. They also lose 80% and 77% of their weight, respectively, and the temperature is slightly delayed by 5%. At these temperatures, cellulose and lignin may degrade. The next stage of disintegration takes place at temperatures ~400-535°C and ~405-545°C for G0 and G15 composites. The weight reduction was 95% for the G0 sample and 93% for the G15 sample. This disintegration was induced by the degradation of chemical components in the composite reinforcement, particularly the cellulose and lignin content, as well as the granite powder filler.

According to the results above, the G15 composite has better thermal stability than the G0 composite. This could be because the composite contains inorganic materials like granite powder. This enhancement is indicated by a greater disintegration temperature and improved resistance to heat degradation.

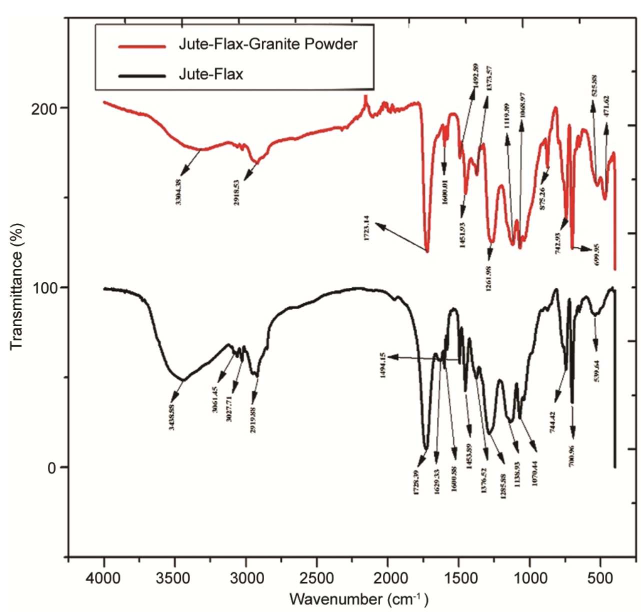


Fig. 9 — FTIR spectra of jute-flax-epoxy and jute-flax-granite powder-epoxy hybrid composites

### 3.5 Fourier Transform Infra Red Spectroscopy (FTIR)

Figure 9 displays the FTIR spectra of the hybrid composites of jute-flax-epoxy (G0) and jute-flax-granite powder-epoxy (G15). The spectra of the jute-flax fibre-granite powder (G15) composite exhibit an absorption peak at 3304.38 $cm^{-1}$, which is attributable to the H-bonded O-H stretching of cellulose with hydroxyl functional groups[30].The C-H asymmetric stretching vibration detected in cellulose, hemicelluloses, and lignin in natural fibres relates to the peak 2918.53 $cm^{-1}$and verifies the existence of Methylene group[31]. A peak at 1723.14 $cm^{-1}$, representing the stretching of C=O (carbonyl group), verifies the existence of aldehyde groups in hemicelluloses[32]. The absorption peak at 1600.01 $cm^{-1}$ are due to aromatic C=C stretching of aromatic rings or alkenes in lignin[30]. Identical peaks at 1492.89 $cm^{-1}$ and 1451.93 $cm^{-1}$ correspond to Aromatic skeletal vibration (C=C in benzene ring) and C-H inplane bending of methylene and methyl groups in lignin[30].The peak at 1373.57 $cm^{-1}$ indicates the symmetric bending vibration of methyl groups ($-CH_3$). This peak is often linked to C-H deformation modes in aliphatic hydrocarbons and is frequently found in materials comprising cellulose and natural fibres[30, 31]. The FTIR peak at 1261.98 $cm^{-1}$ is attributed to C-O stretching vibrations, which often arise from ether bonds or ester functionalities. This peak indicates the presence of hemicellulose, lignin, or other oxygen-containing groups in the natural fibre or polymer matrix[30,33,34,35]. A peak at 1119.89 $cm^{-1}$ corresponds to the aromatic C-H in-plane guaiacyl and syringyl units of lignin[30]. The FTIR peak at 1068.97 $cm^{-1}$ represents the C-O stretching vibration found in alcohols, ethers, and cellulose-based compounds[30].The 742.93 $cm^{-1}$ and 699.95 $cm^{-1}$ peaks correspond to aromatic C-H bending of benzene in cellulose[30].The existence of inorganic components inside the composite is suggested by the FTIR peaks at 525.88 $cm^{-1}$ and 471.65 $cm^{-1}$, which are attributable to metal–oxygen (M–O) stretching vibrations. This indicates that inorganic additives were successfully incorporated into the polymer or fibre matrix[30, 31]. These groups—which include H-bonded, O-H, C-H, C-O, and M-O contribute to the mechanical strength, stiffness, and thermal stability of the composite. Table 4 shows FTIR results of the prepared hybrid composites.

### 3.6 Scanning Electron Microscope

Mechanically tested samples of G0, G15 and G20 composites were scanned with a scanning electron

Table 4 — Comparison of FTIR results with the prepared composites

| Wave numbers ($cm^{-1}$) | | Assignment | Functional Group | Reference |
|---|---|---|---|---|
| G0 | G15 | | | |
| 3438.88 | 3304.38 | H-bonded O-H stretching | Hydroxyl | [30] |
| 3061.45 & 3027.71 | - | Aromatic C - H stretching | Alkane | [34] |
| 2919.88 | 2918.53 | C-H asymmetric stretching | Methylene | [31] |
| 1728.39 | 1723.14 | stretching of C=O | Aldehyde | [32] |
| 1629.33 | - | C=O stretch | Aromatic ring | [35] |
| 1600.88 | 1600.01 | C=C stretching | Alkenes | [30] |
| 1494.15 | 1492.89 | C=C in benzene ring | Aromatic ring | [30] |
| 1453.89 | 1451.93 | C-H inplane bending | $–CH_2–$ (methylene) and $–CH_3$ (methyl) | [30] |
| 1376.52 | 1373.57 | C-H deformation | Methyl | [30,31] |
| 1285.88 | 1261.98 | C-O stretching | Ether | [30,33] |
| 1138.93 | 1119.89 | C-H in-plane guaiacyl and syringyl | Aromatic ring | [30] |
| 1070.44 | 1068.97 | C-O stretching | alcohols | [30] |
| 744.42 | 742.93 | Aromatic C-H bending | Benzene | [30] |
| 700.96 | 699.95 | Aromatic C-H bending | Benzene | [30] |
| 539.64 | 525.88 | (M–O) stretching | Metal–Oxygen | [30,31] |

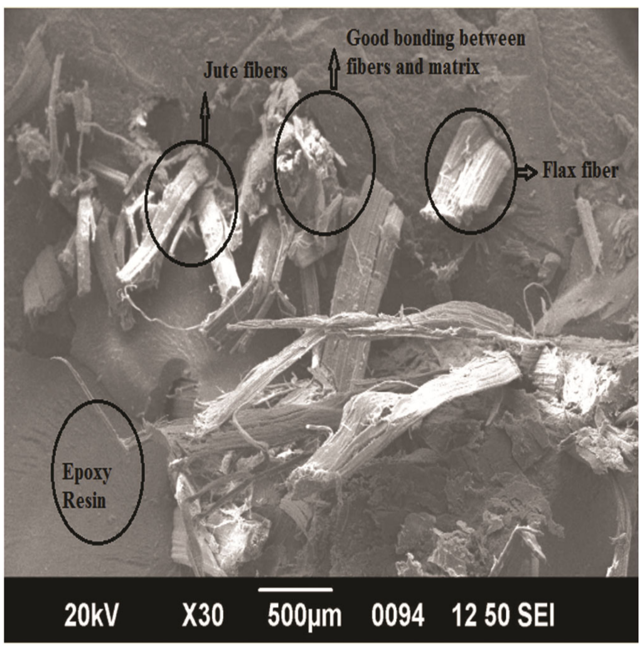


Fig. 10 — SEM scan of Jute-Flax-Epoxy composite

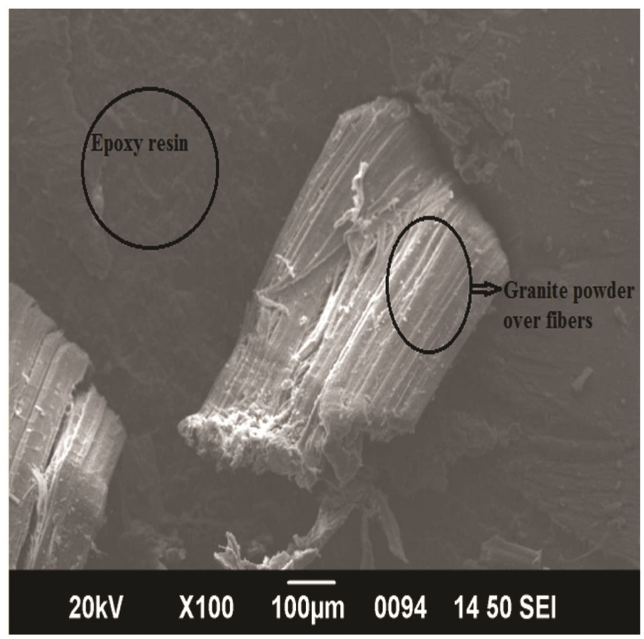


Fig. 11 — SEM image of Jute-Flax-Granite powder-epoxy composite

microscope; the resulting pictures are shown in Fig. 10, 11, and 12. A SEM scan of the fracture surface of the Jute-flax fibre and epoxy resin composite sample (G0) is shown in Fig.10. This illustrates that jute-flax fibres are clearly seen in the SEM image and that the both fibres and epoxy resin have a sufficient connection, which leads to effective load transmission between the two elements. An additional factor that impacts fibre-matrix bonding is the NaOH treatment of fibres. Jute-Flax fibre, granite powder fillers, and epoxy resin (G15) are visible in the SEM image in Fig. 11. These have been obtained by consistently mixing epoxy resin and granite powder using a mechanical stirrer. Granite powder fills in the minuscule gaps between the fibres and within the resin matrix. The presence of lumps of granite powder that are not evenly distributed throughout the Jute-Flax fibre and epoxy resin is shown in Figure 12. Agglomeration of these particles produces weak areas that hasten the development and spread of cracks. This process decreases mechanical properties because aggregated particles do not effectively support the matrix[28, 29,36].

Thus, various properties of the composite specimens were evaluated to determine the suitability of these composites for specific applications.

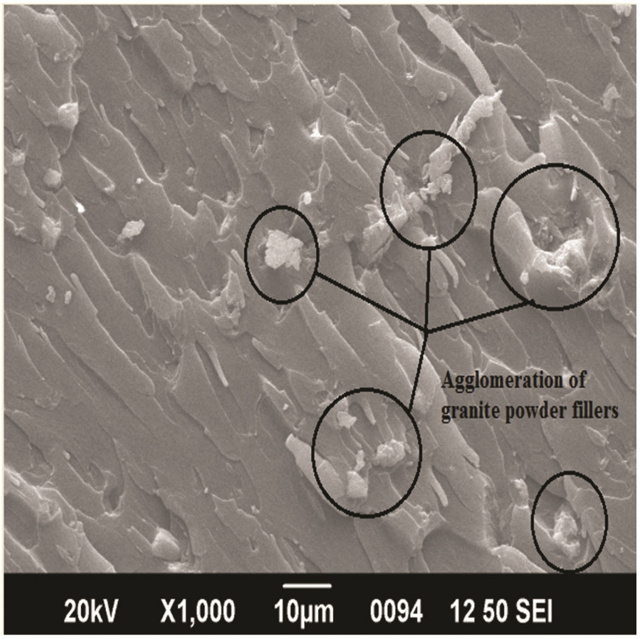


Fig. 12 — SEM image of Jute-Flax-Granite powder-epoxy composite

***3.6.1 Tensile Applications***

The prepared composite with Tensile strength 147 MPa and Tensile Modulus 5030 MPa is well-suited for 1. Door panels, dashboard frames, and seat backs in Automotive Interior and Semi-Structural Components. 2. Partition panels and interior components in Building and Construction panels. 3. Chair backs, table tops and cabinet panels in Furniture and Home Components. 4. Bicycle mudguards and skating boards in Sporting Goods. 5. Cabin interior panels and boat interior panels in Aerospace and Marine Components.

***3.6.2 Flexural Applications***

1. Seat frames and supports and door side impact beams in Automotive Structural and semi structural parts. 2. Load bearing wall panels, structural partition boards, and door and window frames in structural building and construction components. 3. Bicycle frames and wheel spokes composite hockey sticks, bats, and racquets in Sporting Goods. 4. Boat deck reinforcements, cabinet interior panels and structural ribs in Aerospace interior components and Marine applications.

***3.6.3 Impact Applications***

Helmet shells for recreational applications and Paddle blades and protective fairings in sport goods.

***3.6.4 TGA***

1. Heat shields, engine bay covers, and fire wall insulation for automotive components. 2. Cabin insulation panels and ducting covers in aerospace and aircraft interior panels.

To sum up, the hybrid composite with better properties namely G15 is recommended to be employed for the production of seat frames, semi structural components and other relevant members in automobile industry.

## 4 Conclusion

Using the hand layup process, the hybrid composite was created by adding flax - jute fibre and granite powder filler reinforcement to epoxy resin. This study examined how different weight percentages of granite powder—0, 5, 10, 15, and 20 wt. %—affect mechanical properties when employed as a filler in flax and jute fibre composites. Flax and jute fibres were modified by a NaOH treatment. The granite powder reinforced composites (G15) and their mechanical, structural, thermal, and morphological characteristics were examined and contrasted with those of the granite powder-free composites (G0). The flax and jute fibre-epoxy matrix composite's tensile, flexural, and impact strengths were enhanced by the addition of granite fillers up to 15% by weight. The SEM morphology of the samples under examination showed that the flax-jute fibre and granite filler were uniformly distributed and interfacially interacting within the matrix. However, as demonstrated by SEM morphology, adding more than 15 wt.% caused aggregation and agglomeration, reducing mechanical characteristics. When the G0 and G15 composites are compared, the former shows better thermal stability. Thermal stability was shown for the G0 and G15 composites up to 400$^{o}$C and 545 $^{o}$C, respectively. The introduction of inorganic components in the epoxy resin, such as granite filler, increased the thermal stability of the hybrid composite by boosting the disintegration temperature. FTIR is used to verify the stretching of the H-bonded O-H, C-H, C=O, and C=C components that support the mechanical strength, stiffness, and thermal stability of the composite. Based on the results of the tests results, the composites are suitable for a wide range of applications, including packaging, decking, sports, automotive, and infrastructure. The use of natural fibres and leftover granite powder for industrial applications reduces the cost of composites, mitigates the negative effects of synthetic fibres, and encourages environmentally beneficial production processes.

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