Experimental Studies of Mechanical Behaviour of Luffa Cylindrica Fiber Epoxy Composites

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Abstract- *The green composites with reinforced agricultural materials that are natural fibers are considered as the better replacement of synthetic fiber based composite. Natural fibers are getting higher demand in recent times due to high availability, less cost, no environmental threats, comparable mechanical properties and low density. Natural fibers extracted from various parts of plants possess an excellent alternative. The natural fiber-reinforced composite materials gain the benefits of a lightweight, low cost, and eco-friendly nature. This research work aims to explore the crown rot fiber as reinforcement the epoxy matrix to develop lightweight natural fiber composites for potential engineering applications. To enhance the compatibility of luffa fiber with epoxy the crown rot fiber was treated with 5wt% alkali, further to enhance the mechanical performance of crown rot fiber epoxy composites. The present work is focused on to analyses the influence of fiber loading on the mechanical behavior of luffa fiber reinforced epoxy matrix. Different types of composites are fabricated using 45 to 70 wt% rest matrix material. The composites are manufactured by compression moulding process. Specimens cut and tested according to ASTM standards. The mechanical and physical properties are studied.*

I. INTRODUCTION

The environmental issues associated with the recycling of synthetic fiber products created an interest to develop alternatives from renewable resources. Natural fibers extracted from various parts of plants possess an excellent alternative. The natural fiber-reinforced composite materials gain the benefits of a lightweight, low cost, and eco-friendly nature. Despite the advantages, natural fiber composites have some limitations such as poor compatibility with polymers and high moisture absorption as compared to synthetic fibers. Hence to make the natural fiber as potential reinforcement in polymer composites, modifications using filler, chemical treatment of fibers needs to be further investigated.

Composite materials were used during the Stone Age; materials like straw and mud were reinforced to make composite materials, and those materials were used for constructing houses, making bows and paper by the Egyptians, Mesopotamians, and Mongols. During the Second World War, the demand for lightweight materials increased, and to satisfy this need the fibers such as Glass, Carbon, Kevlar, and Aramid were used in composites for making lightweight materials. In 1935 glass fiber was first introduced by Owens Corning as reinforcement with polymer to create incredible materials with lightweight and strong structures.

The British royal air force was the first to use glass fiber laminates for making lightweight fighter jet planes in military applications. The development of technologies has made it possible for composite materials to be used in various applications such as automobiles, aerospace, marine, packing, etc. For the past few years, researchers have been focusing on developing eco-friendly materials and for making those materials they have used natural fibers as a reinforcement and polymers as a matrix.

II. COMPOSITE MATERIALS

In the present technological era, on account of the increasing environmental awareness and demand for low-cost sustainable materials, researchers are constantly trying to produce cheap, biodegradable, and environmental friendly products from bio-mass or industrial by-products. Traditionally, the fiber based materials are being used by the small scale enterprises for fabricating low cost products such as carpets, mats, ropes, bags etc., Nowadays most of the researchers are focusing their research on pollution free environment, bio-degradable nature and balanced ecological aspect while fabricating the composite materials rather than mechanical strengths, costs, processing methodologies.

The composite materials consist of more than one physically different material whose mixture results in aggregated characteristics that vary from those of their basic composition's characteristics. Composite materials could be incredibly helpful with higher strength-to-mass fraction and stiffness despite their low weight. Their strength-to-weight and structural rigidity are many old stronger than metals, and it is feasible to attain combinational characteristics, which are not easily achievable with metallic and/or ceramic substances.

CLASSIFICATION OF COMPOSITE MATERIALS

A Composite is made up of two or more materials with different physical and chemical properties. It is classified based on different parameters out of which one is based on the matrix used.

POLYMER MATRIX COMPOSITES (PMC)

Polymer Matrix composites consist of different short or long fibers bound by organic/ inorganic polymers. The function of a matrix in the composite material is to Transfer the stress between fibers Keep the fibers in desired orientation and locations Protect the fibers from chemicals and moisture Protect the fibers from mechanical abrasion. The commonly used matrix materials are Epoxy, Polyester, Vinyl Ester, Polyamide, and Polypropylene.

METAL MATRIX COMPOSITES (MMC)

Matrices like Aluminum, Magnesium, and Titanium were used with fibers like carbon and silicon carbide to form metal matrix composites. To enhance the elastic stiffness, strength, and properties of metals metal matrix composites are introduced. The metal matrix composites can be used at high temperatures, are moisture resistant, and have good thermal and electrical conductivity. The applications of MMCs include Tank armors Bicycle frames Sports equipment High-performance tungsten carbide cutting tools

CERAMIC MATRIX COMPOSITES (CMC)

In ceramic matrix composites, ceramic fibers were embedded in a ceramic matrix to overcome the problems associated with conventional ceramics. Generally, conventional ceramics like Zirconium, Alumina, and Silicon Carbide get fractured easily under mechanical loads. To overcome problems like low fracture toughness, low thermal shock resistance, and elongation, materials like whiskers, and long strand fibers were embedded in the ceramic matrix. The role of fibers in ceramic matrix composites is to avoid abrupt brittle failure and initial resistance to crack propagation. Generally, ceramic fibers are Carbon, Alumina, Mullite, and Silicon Carbide.

APPLICATIONS OF CMCs INCLUDE

- Heatshield parts in space vehicles
- Parts of high-temperature gas turbines
- Automobile brake discs
- Cladding and structural materials in nuclear reactors

REINFORCEMENTS

Reinforcement is also known as the irregular phase, that embed with the matrix and it is typically stronger than the matrix. Generally, the reinforcements used in composite materials are in different forms such as fibers and particulates or whiskers. Fiber reinforcements are of two types one is long fiber and another one is short fiber reinforcement. The long fiber reinforcements have preferred orientation, whereas the short fiber reinforcements have no preferred orientation. The whiskers have desirable shapes, but it is small in diameter and length as compared with fiber reinforcements. The main function of reinforcement is to increase the mechanical properties of pure resin materials. Generally, it is strong, stiff and is used as a load-carrying medium in polymer matrix composites. The physical properties and geometry of reinforcements are most important for making lightweight composites. The orientation and distribution of the reinforcement influence the properties of the composite material. The shape and size of reinforcement influence the interaction between the fiber and the matrix.

FIBER REINFORCED COMPOSITES

Generally, fiber-reinforced composites are made up of a mixture of reinforcing fibers (natural or synthetic) and polymer as a matrix. The development and usage of fiber-reinforced composites increased recently since their properties were better than the properties of the individual constituent materials. Generally, the properties of fiber-reinforced composites depend on the different types of fiber orientations such as mat, random, unidirectional, and bidirectional used in fiber-reinforced composites.

ADVANTAGES, DISADVANTAGES AND APPLICATIONS OF NATURAL FIBERS

ADVANTAGES

- It is biodegradable and eco-friendly
- Easily available
- Low cost and low weight Low density compared with man-made fibers
- It has excellent acoustic and insulation properties

DISADVANTAGES

- Less strength compared to synthetic fibers
- Water absorption is high for natural fiber composites
- It has a low impact strength compared to synthetic fibers
- Poor interfacial bonding with the matrix

APPLICATIONS

- They are used in making
- Doormats, seat covers
- Soundproofing materials
- Door panels
- Packing trays
- Interior parts in automobiles
- Interior parts in buildings

LUFFA FIBER AS REINFORCEMENTS

Luffa fiber also known as sponge gourd is from the family Cucurbitaceae and it is available in Africa, South America, and Asian countries. The fiber is extracted from luffa fruit, and the fruit before maturing is used as a vegetable in Asian and African countries. The ripened luffa fruit has a fibrous mat-like structure and it is often named luffa fiber. The luffa fiber is used as a scrubbing sponge in kitchens and bathrooms. The length of a luffa sponge is around 15 to 25 cm. The transformation of luffa fiber from the luffa fruit is shown in Fig.1.2 and Fig.1.3. The content of cellulose in the luffa fiber varies from 55 - 66 wt. %, the content of lignin varies from 10 - 17 wt. % and the content of hemicelluloses vary from 8 - 20 wt. %. The luffa fiber has both extractive content and an ash content of 3.2 and 0.4 wt. %. The luffa fibers are of the 3D mat-like structure after drying and it is not found in other natural fibers like jute and sisal. In this work, luffa fiber is used as reinforcement for making polymer composites. The natural mat-like appearance of the luffa fiber makes it easy to use as a potential reinforcing material for making polymer composites. Some important facts regarding luffa fiber are,

- It is biodegradable and non-toxic
- It has a high degree of porosity
- It has a high degree of water absorption capability
- It has a high degree of sound absorption and shock absorption properties
- It is also used for medical purposes to treat immune-stimulatory and anti-inflammatory problems
- It is a potential fiber for polymer composites.

POLYMER MATRIX

The matrix is an important constituent material for making polymer composite materials. The main purpose of using matrix materials is to keep the fibers in desirable positions, to hold the fibers, to transfer stress between reinforcements, and to protect the reinforcements from chemicals, moisture absorption, and mechanical abrasion. The selection of the proper matrix provides good mechanical properties to the polymer composites. Generally, two types of polymers are employed for making polymer composites: one is thermoset polymers and another one is thermoplastic polymers. Thermoset polymers are stronger than thermoplastic polymers due to their 3D network structure and they are called cross linked polymers. The thermoset polymer has strong covalent bonds between polymer chains so that it has a high resistance to chemical attacks and heat degradation**.**

The crosslinking behavior of thermoset polymers shows better mechanical properties and hardness than thermoplastic polymers. Some commonly used thermoset polymers in industrial applications are Epoxy Resin, Polyester Resin, Bakelite, and Vinyl ester. As thermoplastic polymers have weak bonds, during heating, the polymer softens, and that made it easy to be remolded into different shapes and sizes, based on the requirements of the user. It can be used again and again by heating and it is called a recyclable polymer. Some commonly used thermoplastic polymers are polypropylene, Acrylonitrile Butadiene Styrene (ABS), polystyrene, polycarbonate, etc.

POLYMER MATRIX (EPOXY RESIN-THERMOSTAT POLYMER)

The good interfacial bonding of epoxy with synthetic fibers like glass and carbon fibers made it useful as a matrix for making natural fiber polymer composites. The polymers added with natural fibers may minimize the water absorption behavior of fibers. Epoxy is a thermoset polymer with good mechanical, high thermal, and chemical resistance. It is a copolymer that is formed by chemicals, namely, a hardener and resin. The uncured epoxy has low mechanical and heat resistant properties: however, better properties can be achieved by treating liner epoxy with a proper curing agent hardener to get 3D cross-linked polymer structures.

PROPERTIES OF EPOXY RESINS ARE

- It has good resistance to chemicals and moisture
- It is non-toxic and odorless
- It has good mechanical and electrical properties
- It has good adhesion behavior with other materials.

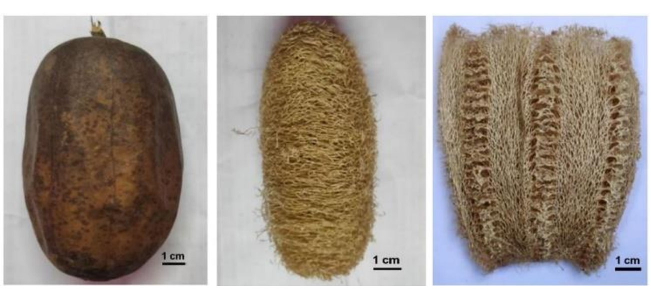
MATERIALS

The materials used to fabricate the natural fiber composite in the present study are,

- Luffa cylindrica fiber
- Epoxy Resin and Hardener

LUFFA CYLINDRICA FIBER

Luffa cylindrica fiber is also known as luffa sponge guard, which is obtained from the family Cucurbitaceae. The undeveloped luffa fiber is known as luffa fruit and it is green in color, whereas the ripped luffa fruit has a thick peel outside covering the fibers and it is brown in color, having a hollow cylindrical shape. The chemical compositions of luffa fiber such as cellulose 66%, lignin 15%, hemicellulose 17%, ash 0.4%, and extractives 1.6%, which is related to some frequently used natural fibers. The young luffa fruit contains the compounds like phenolics, flavonoids, ribosome-inactivating protein, and triterpenoids, made to use as medicine for immune-stimulatory and anti-inflammatory agents. The fibers contain various compounds, such as lavonoids, phenolics, and triterpenoids, and the presence of those compounds serves to use them for medical purposes and as vegetables in Asian countries. The developed luffa fruit has a thick peel outside and the inner core contains a multidirectional array of fibers and it resembles the form of a regular mat-like structure. The matured luffa fruit has a unique knitting arrangement and it appears as a 3D mat-like structure after drying, which does not exist in other natural fibers. The striking features of luffa fiber over other natural fibers are lightweight, remarkable stiffness, strength, sound absorption properties, and low extraction cost trigger to use as reinforcement in polymer composites.

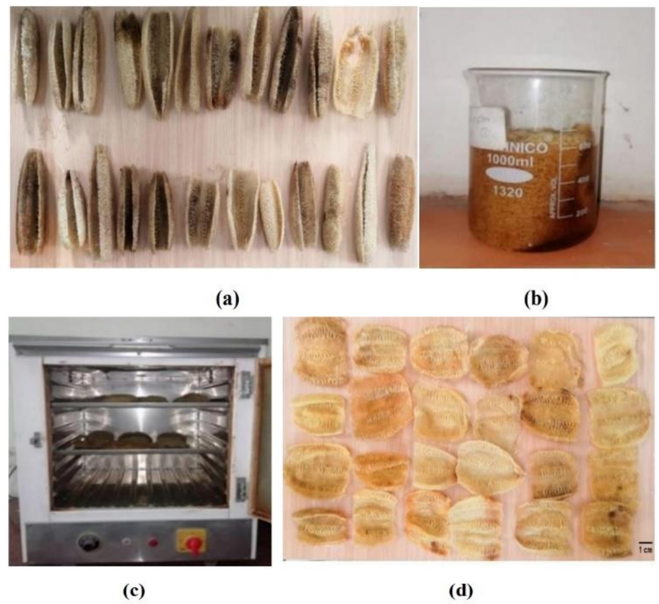


III.METHODS

SURFACE TREATMENT OF LUFFA CYLINDRICA FIBER

Based on the observations from the literature survey many researchers used alkali treatments for treating the fiber surfaces. It is a simple technique by which the lignin, hemicellulose, and waxy substances were eliminated from the natural fibers. The main objective of the alkali treatment is to eliminate the hydrophilic nature of the fibers, enhance the surface roughness, and increase the adhesion between the fiber and the matrix.

Luffa Fiber–OH+NaOH→Fiber–O–Na^+ + H_2O



(a) Luffa fibers before surface treatment
(b) Fibers immersed in alkali solution
(c) Oven
(d) Luffa fibers after surface treatment

EPOXY

(a) Epoxy (Araldite LY 556) **(b)** Hardener (HY 951)

Epoxy is the most commonly used thermoset polymer for various applications such as fiber-reinforced polymer materials, electronic components, electrical insulators, etc., In this study, the resin with base Bisphenol – A Epoxy (Araldite LY 556) and hardener (Aradur HY 951), were procured from Javanthee enterprises, Chennai, India. The Epoxy and hardener are mixed homogeneously in the proportion of 10: 1

as recommended by various researchers. The epoxy (Araldite LY 556) and hardener (Aradur HY 951) used are shown in Figures 3.3 (a) and (b).

S.No.	Properties	Values
1	Tensile strength(MPa)	6.9
2	Tensile Modulus (MPa)	166
3	Appearance	Milky white
4	Impact strength (kJ/mm^2)	1.1
5	Solid content (%)	80
6	Viscosity (Centipoises)	550
7	Specific gravity (g/cc)	1.12
8	Density (g/cm^3)	1.1-1.4

FABRICATION OF COMPOSITE MATERIAL

(a) (b)

(a) Compression molding setup **(b)** Fiber arrangement in mold

Composite samples were prepared using a hand layup method followed by the compression molding technique as shown in Figure 3.4 (a-c). The required quantities of fiber, epoxy, and filler materials were weighed. Epoxy and the filler were mixed to get a homogeneous mixture using a stirrer. At first, the luffa fibers were placed inside the mold cavity of size 300 mm x 300 mm x 3 mm; then the epoxy matrix modified with the filler was poured into the mold cavity. Then the upper plunger is forced on top of the mold with a pressure of 10 bar and temperature in the range of $45^{\hat{U}}$C - $50^{\hat{U}}$C. After curing the prepared composite samples were taken from the mold and cut to the dimensions of 250 mm x 25 mm x 3mm for the tensile test, dimensions of 127 mm × 12.7 mm × 3 mm for the flexural test, and dimensions of 63.5mm x 12.5mm x 2.5mm, for the impact test.

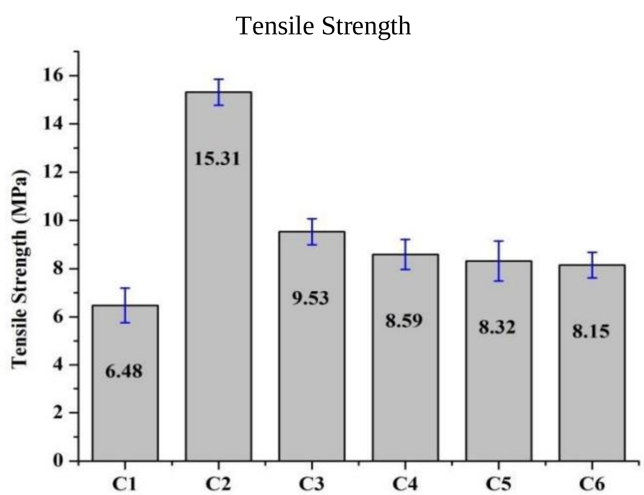
S.No	Samples	Fibers	Matrix
1	C1	45	55
2	C2	50	50
3	C3	55	45
4	C4	60	40
5	C5	65	35
6	C6	70	30

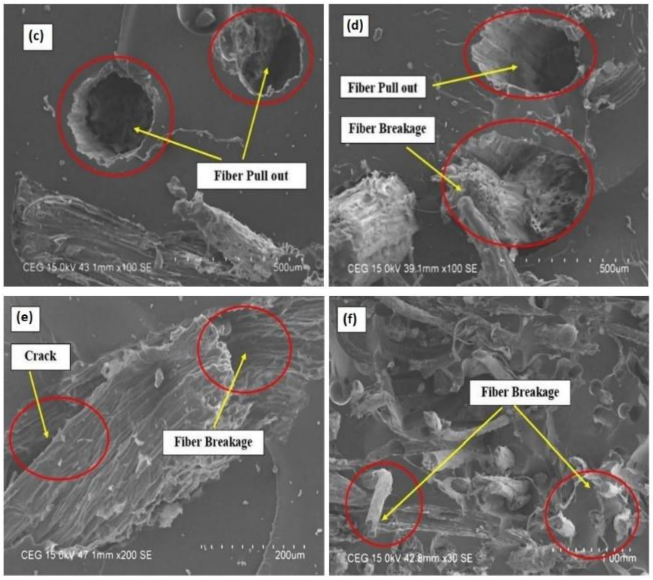
IV.RESULT

TEST RESULTS OF MECHANICAL PROPERTIES

TENSILE STRENGTH

The tensile test was conducted on the luffa fiber composite samples to understand the tensile strength and to know the contribution made by the matrix phase. The results show that 50 wt. % fiber added epoxy composite yielded the maximum tensile strength values of 15.31MPa. It was observed that when the fiber load was increased, the tensile strength decreased and it is mainly due to the poor adhesion between the matrix and the fiber. This results in good bonding between the fiber and the matrix, and due to this effective stress transfer takes place between the fiber and the matrix. The addition of the filler may minimize the free spaces and thereby increase the stiffness of the fabricated laminates. The addition of fiber beyond 50 wt. % decreases the tensile strength. Figure 4.2 illustrated the SEM images of after test samples composites.

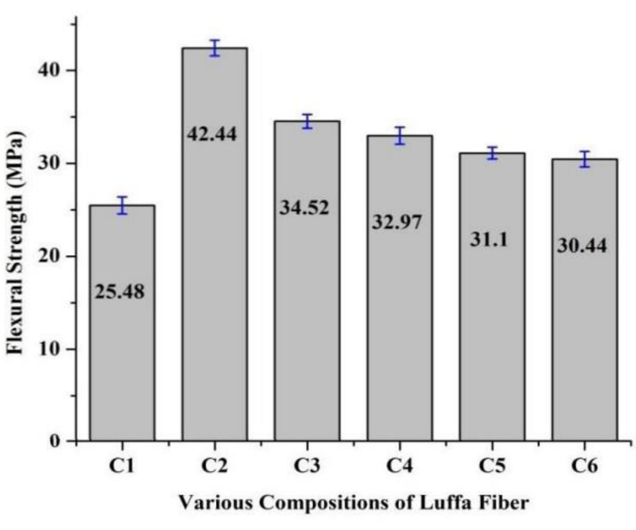


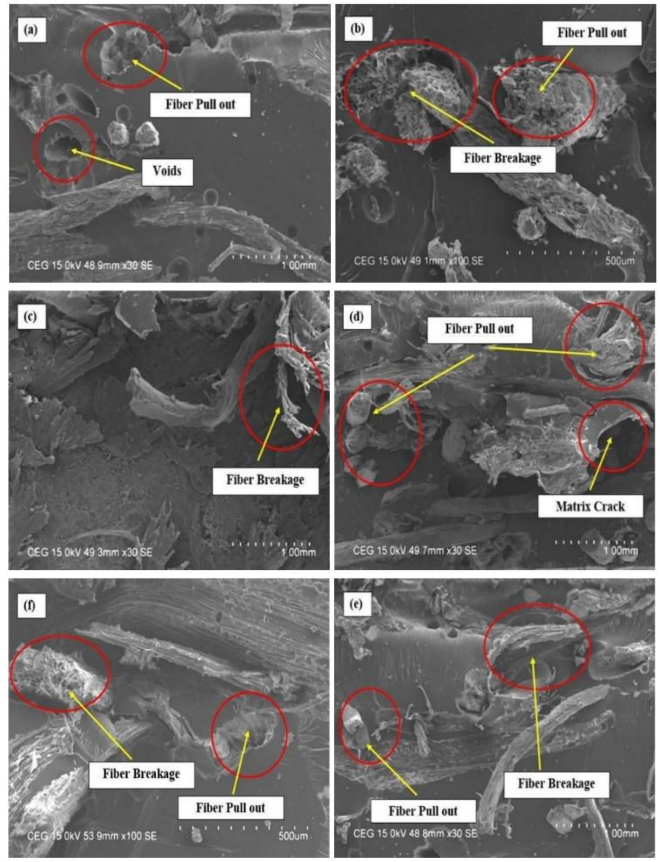


Tensile Micrographic Images Of Test Composites

FLEXURAL TEST

Flexural strength, also known as bending strength, was tested for the prepared samples. The flexural strength variations of the fabricated samples are shown in Figure 4.3. Figure 4.4 portrayed the surface topography of after test samples. The flexural test was conducted on the luffa fiber samples to understand the flexural strength. The results show that 50wt% added epoxy composite with luffa fiber as reinforcement yielded the maximum flexural strength value of 42.44 MPa. Generally, when the reinforcement luffa fiber is added with epoxy resin, the flexural strength reduces, and it may be due to the adhesive property of the natural fiber with the matrix being weak due to the hydrophilic and hydrophobic nature of the fiber and the matrix. Due to this factor, a weak fiber-matrix interface was formed and it reduces the reinforcing behavior of the fiber, and also it lacks the transfer of stress from the matrix to the load-bearing fibers.

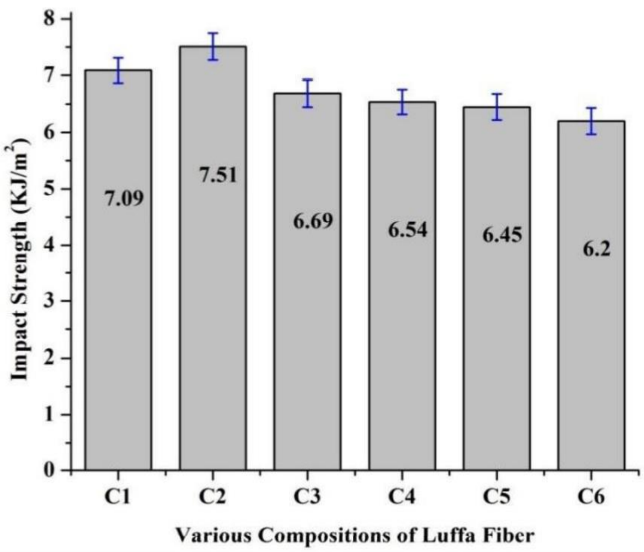


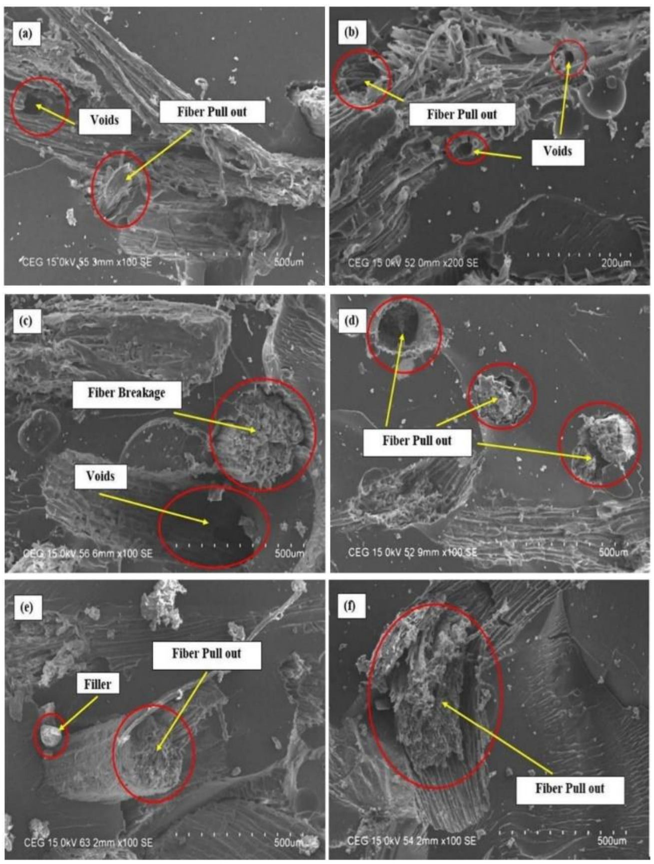


SEM images of **(a)** C1 **(b)** C2 **(c)** C3 **(d)** C4 **(e)** C5 **(f)** C6

IMPACT STRENGTH

The impact test was conducted on the luffa fiber composite samples to understand the impact strength and also to know the contributions made by matrix materials. The results show that 50 wt. % fiber added epoxy composite yielded maximum impact strength values of 7.51 kJ/m^2. The addition of fibers to the matrix increases the stiffness of the fabricated laminates and it may occur due to good adhesion between the fiber and the matrix resulting in better impact strength. Figure 4.6 shows the micrographic images if fabricated luffa fiber test sample composites.

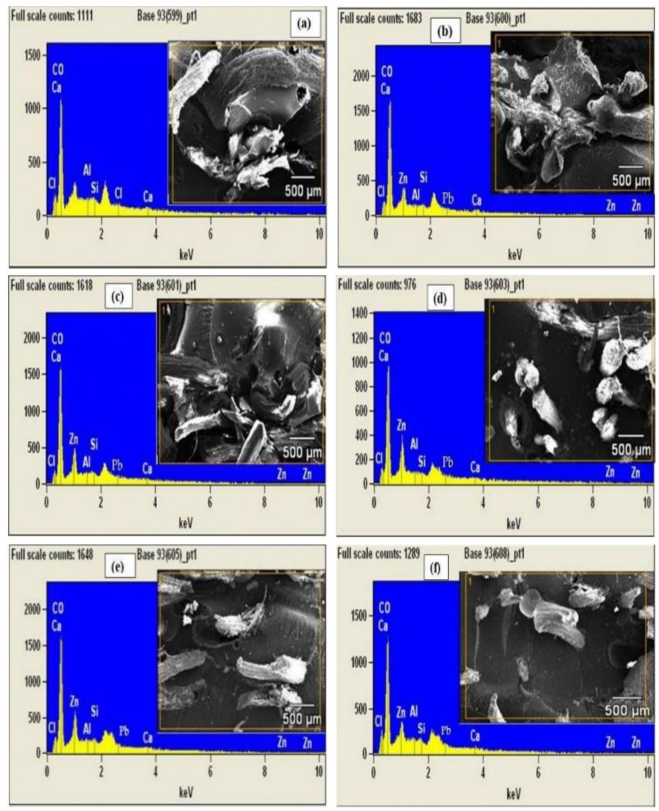




Micrograph images of test composites **(a)** C1 **(b)** C2 **(c)** C3 **(d)** C4 **(e)** C5 **(f)**

ENERGY-DISPRESIVE SPECTROSCOPY (EDS)

The elemental compositions of the fabricated composite samples were explored by scanning electron microscope equipped with energy dispersive X-ray analysis. The elemental compositions of all the prepared composite samples are shown in Figure 4.7 (a) – (f). Figure 4.7 (a) demonstrates the elemental compositions of luffa fiber without filler (sample C1). Sample C1 shows the higher amount of oxygen (O), carbon (C), and also the low amount of elements such as silicon (Si), aluminium (Al), calcium (Ca) and it confirms the removal of lignin, wax from the fiber surface due to surface treatment. The elements such as oxygen, carbon, silicon, and calcium were the major elements in luffa fiber and similar elemental compositions were observed in the present study. The atomic and weight percentages of elemental compositions in the prepared composite samples are listed in Table.



EDS analysis of composite samples

Samples	Weight (%)							Atomic (%)						
	C	O	Ca	Cl	Al	Si	Pb	C	O	Ca	Cl	Al	Si	Pb
C1	20.97	74.35	0.87	0.99	0.29	2.53	-	26.7	71	0.33	0.42	0.16	1.37	-
C2	14.47	78.42	2.96	0.53	0.50	2.81	0.31	19.07	77.58	1.17	0.24	0.29	2.81	0.08
C3	15.01	80.74	0.27	0.92	0.03	2.59	0.45	19.41	78.39	0.10	0.40	0.01	1.43	0.26
C4	17.41	77.36	0.53	0.74	0.29	3.03	0.65	26.69	70.69	0.11	0.31	0.40	1.51	0.29
C5	20.89	73.70	0.47	0.71	0.71	2.76	0.77	22.46	74.90	0.20	0.32	0.07	1.67	0.37
C6	16.55	78.57	0.26	0.71	0.47	2.60	0.84	21.52	76.71	0.10	0.31	0.27	0.62	0.47

Elemental compositions of fabricated composite samples

V. CONCLUSION

In conclusion, the experimental studies conducted on Luffa cylindrica fiber epoxy composites have provided valuable insights into the mechanical behavior and potential applications of this eco-friendly composite material. The key findings from the mechanical tests, including tensile, flexural, and impact properties, have been instrumental in understanding the performance characteristics of these composites. The results indicate that the incorporation of Luffa cylindrica fibers into epoxy matrices has a notable impact on the mechanical properties of the composites. The alkali treatment applied to the fibers has demonstrated its effectiveness in enhancing the adhesion between the fibers and the epoxy resin, resulting in improved tensile strength, flexural strength, and impact resistance.

The optimization of the fabrication process, including fiber treatment, composite formulation, and molding techniques, has played a crucial role in achieving composites with desirable properties. The choice of molding technique, such as compression molding, has proven effective in producing composites with consistent and predictable mechanical behavior. The optional post-curing step has shown promise in further enhancing the mechanical properties of the composites, providing an avenue for fine-tuning the material for specific applications.

The present study, luffa fiber used as reinforcement phase in improving the basic and functional properties of epoxy resin. A different percentage of fiber loading is used as a reinforcement material to improve the interfacial attraction of matrix phases; the conclude output results are as follows.

- The natural fibers incorporated with epoxy matrix phase using compression moulding technique produced better mechanical results.
- The fiber content 50 wt. % natural fber was observed with good mechanical properties.
- Maximum tensile properties of 15.31 MPa was observed by C2 composite sample.
- Flexural properties of C2 is 42.44 MPa. It is reveals that; the fabricated composite can be used as a light weight automobile application.
- Impact properties showed enhancement with the fiber addition.

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