Experimental Investigation and Finite Element Analysis of Mechanical Properties of Jute, Pineapple leaf, Jute-Pineapple leaf (Hybrid) Reinforced Polyester Composite

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Abstract - **There is a huge need for new materials in all fields of engineering, this leads to the investigation and development of new materials which suits the need. Utilization of biodegradable materials i.e. natural fibers for various applications to preserve the environment from synthetic fibres invites development of natural fiber reinforced polyester composites. In a country like India which is producing enormous amount of agricultural solid waste (in the form of leaf, fruits, stems etc.) there is lack of marketing for the above said wastes, if this can be improved the farmers may get benefited. Natural fiber reinforced composites are preferred than conventional materials because of their advantages like low density, light weight, high strength to weight ratio, low cost, high toughness and biodegradability. The present investigation deals with the preparation of jute, pineapple leaf fiber and jute-pineapple leaf fiber (Hybrid) reinforced polyester composite and to determine the tensile, flexural and impact properties with increase in percentage weight fraction of the fiber and to compare the properties of the composites. Further the experimental results will be validated through ANSYS software**.

Keywords: Natural fibres; Pine apple leaf fiber (PALF), Jute fiber, hybrid composite, Polyester resin, Catalyst, Accelerator.

1.Introduction

Materials scientists and engineers all over the world have focussed their attention on Natural fiber-reinforced polymer composites due to their attractive features like light weight, low material cost, moderate strength, high specific modulus, lack of health hazards, and environmentally friendly [1]. Many studies have been conducted to investigate the properties of natural fiber reinforced composite and to replace the conventional metals for certain applications [2]. Composite materials are composed of two or more phases one of the phases is termed as matrix phase, which is continuous and surrounds the other phase which is often called the dispersed phase or reinforcement phase. The reinforcement is usually much stronger and stiffer than the matrix, and gives the composite good properties [3]. Natural fibers offer good opportunities as a reinforcement material. Composites provides the positive benefit to the ecological and environmental advantage and the attractive mechanical properties [4]. Jute fibres are the natural fibres light in weight and many researchers have already identified the possibilities of fully biodegradable polymers with jute fiber reinforcement [5-6].

[7] These fibres often contribute greatly to the structural performance can provide significant reinforcement. The stiffness and strength can be further improved by structural configurations and better arrangement in the sense placing the fibers in specific locations for highest strength performance [8]. Fiber reinforced composites are used in almost in every advanced engineering structure, with their usage ranging from aircraft, helicopters, spacecraft through to boats, ships, offshore platforms and automobiles [9]. The use of natural fibers in matrices is highly beneficial because the strength and toughness of resulting composites are greater than unreinforced matrix. So, it is found good to use natural fibres in place of plastics and other environment unfriendly materials [10]. Natural fibres are of great importance, low availability of natural products like wood leads towards the need of alternatives with similar properties and these fibers are also a good alternative to plastics because of properties like bio-degradability and recyclability [11]. Natural fibers are introduced as a replacement to synthetic fibers in order to reduce the environmental impact of non-biodegradable materials [12].

Various natural fibres such as bamboo, sisal, jute, flax, hemp, Pineapple leaf fiber, coir etc are used as a reinforcement and thermo set or thermoplastic materials are used as a matrix [13]. Recently, the research community has shown great interest in using natural fibers as to reinforce thermoplastic and thermoset polymer composites due to their excellent mechanical properties compared to those of other natural fibers [14]. Natural fiber composites can also be very cost-effective material for application in building and construction areas (e.g. walls, window and door frames), storage devices (e.g. bio-gas container etc.), furniture (e.g. chair, table, tools, etc.) [15]. Natural fibers reinforced composite not only exhibits excellent mechanical and dielectric properties but also contribute to environmental safety such as recyclable, biodegradable, Hence, the use of natural fibers in composite materials industry can reduce environmental pollution and waste disposal problems [16].

2. Materials used, Fabricated & Testing:

The basic raw materials used to prepare the composites are jute and pineapple leaf fibers procured from GO Greenprodcuts,129, Cathedral Garden Road, Nungambakkam, Chennai, Tamilnadu, 600034, India.
Polyester Resin, catalyst and accelerator is purchased from BINDU AGENCIES H.NO 59-13-34/1, Shop No. 182, City Heart Towers, Main Road, Gayathri Nagar, Vijayawada – 520008.

2.1 Jute Fiber:

The industrial term for jute fibre is raw jute, the plants grow up to 1–4 meters (3–12 feet) long in two or three-month time, and such plants are cut, tied up in bundles and kept under water for several days for fermentation. It is a natural fiber popularly known as the golden fiber. It is one of the cheapest and the strongest of all-natural fibers Jute is the second most common natural fiber, cultivated in the world and extensively grown in Bangladesh, China, India, Indonesia and Brazil.

Table 1. Properties of Jute Fiber:

Fiber	*Density g/cm^3*	*Elongation %*	*Specific Modulus (Gpa)*
Jute	1.3	1.7	39

2.2 Pine apple leaf fiber (PALF):

Pineapple is the third most important fruit grown in the world after banana and citrus. Due to development of fruit production industries (jam industries), cultivation of pineapple is increased. The use of Pineapple Leaf fiber (PALF) as a reinforcement material can reduce environmental pollution, waste disposal problems and ecological concerns. Pineapple leaf fiber have excellent mechanical strength but due to lack of knowledge it is still not utilized properly.

Table 2. Pineapple Leaf Fiber (PALF) Properties

Fiber	*Density g/cm^3*	*Elongation %*	*Specific Modulus (Gpa)*
Pineapple Leaf	1.4	1.6	34

2.3 Polyester resin:

- ECMALON 4411 is an unsaturated polyester resin of orthophthalic acid grade with clear colourless or pale yellow colour. A large number of polyester structures that have found used in industry today, displays a wide variety of properties and applications.
- Polyesters are one of the most versatile synthetic copolymers. Polyesters are produced in high volume that exceeds 30 billion pounds a year worldwide.
- Most unsaturated polyester resins consist of a solution of a polyester in styrene monomer. The styrene serves two purposes: firstly, it acts as a solvent for the resin and secondly it enables the resin to be cured from a liquid to a solid by curing with polyester resin. This curing is achieved at room temperature by adding a catalyst (or initiator), and an accelerator (or promoter).

2.4 Catalyst:

- The catalysts used are invariably organic peroxides. Since these are chemically unstable as a class of compounds, of which some can decompose explosively in the pure form, they are mostly supplied as solutions, dispersions or pastes in a plasticiser or as a powder mixed with an inert filler to stabilise them.
- This indicates that they have been made safer to handle or stabilised with a plasticiser. Since organic peroxides are hazardous materials to handle, due note should be taken of the safety recommendations.

2.5 Accelerator:

The most commonly used accelerators are either based on a cobalt soap or tertiary amine. Other types of accelerators may be used for specific applications and those include quaternary ammonium compounds, vanadium, tin and zirconium salts. Accelerators usage (between 0.5 and 4%) is based on the resin weight.

2.6 Preparation of Composite specimens:

- Many techniques are available in industries for manufacturing of composites such as compression moulding, vacuum moulding, pultruding, resin transfer moulding etc. The hand layup process of manufacturing is one of the simplest and easiest methods for manufacturing composites.
- The primary advantage of the hand layup technique is to fabricate very large, complex parts with reduced manufacturing times. Additional benefits are simple equipment and tooling that are relatively less expensive than other manufacturing processes.
- Different steps involved in making of composites are collection of fibers and resin, mould making and preparation of the composite and extraction of composite from the mould. Initially the base plate (tile) has to be cleaned by scrubbing with a sand paper.
- Then the surface is allowed to dry after cleaning it with a thinner and later wax has to be applied to the mould (acrylate sheet) for the easy removal of the specimen. After that the fibers are cut down as per the ASTM Standards they are placed

in the mould. Polyester resin, catalyst, accelerator is mixed in the proportion of 100:1:1 and placed on the fibers which are already placed in the mould.

- This process is continuing up to 8-11 layers. After preparing the laminates a weight is placed on the mould. After 24 hours, the weight is removed, the cured specimens are removed and they are cleaned and inspected.

Figure. 1 Mould (acrylate sheet) for Tensile and Bending test specimens

Figure. 2 Mould (acrylate sheet) for Impact test specimens

Figure.3 Specimens of jute – Polyester- resin for Tensile, Flexural and Impact tests

Figure.4 Specimens of Pine Apple Leaf Fiber – polyester resin for Tensile, Flexural and Impact tests

Figure.5 specimens of jute-pineapple leaf fiber-polyester resin Hybrid Composite for tensile, flexural and impact

2.7. Tests for Mechanical Properties:

a. Tensile Test:

- The tensile test has been performed on A 2-ton capacity – Electronic tensometer, METM 2000 ER-I model is used to find the tensile strength of composites. Its capacity can be changed by load cells of 200kg is used for testing composites.
- Self-aligned quick grip chuck is used to hold the composite specimen. A digital micro meter is used to measure the thickness and width of composite, Tensile strength, tensile modulus is determined after conducting the tensile test.

Figure.6 Tensometer

b. Flexural Test:

The flexural test was performed on the same electronic tensometer is as shown fig. 6. The three-point bending test was conducted. Load, deformation values are noted and Flexural modulus and flexural strength values are determined.

c. Impact Test:

The impact test (Izod) on composite was performed. The cross section has a 45^{o} V-notch of 2mm deep. Each test is repeated three to four times and the average values are taken for calculating the impact strength.

Figure. 7 Impact Test

2.8 Validation of Results through Finite Element Analysis:

- In the study of the Micromechanics of fiber reinforced materials, it is convenient to use an orthogonal coordinate system that has one axis aligned with the fiber direction. The 1-2-3 Coordinate system shown in Figure 8 is used to study the behaviour of unit cell.
- The 1 axis is aligned with the fiber direction, the 2 and 3 axis is in the plane of the unit cell and perpendicular to the fibers. The isolated unit cell behaves as a part of large array of unit cells by satisfying the conditions that the boundaries of the isolated unit cell remain plane.

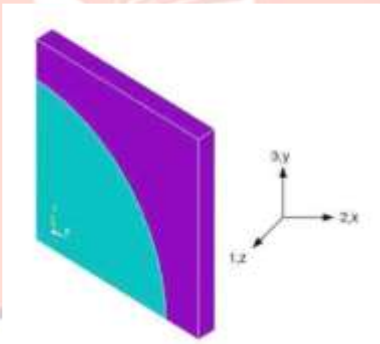


Figure.8: One fourth portion of Unit cell

Due to symmetry in the geometry, material and loading of unit cell with respect to 1-2-3 coordinate system it is assumed that one fourth of the unit cell is sufficient to carry out the present FE analysis.
The 3D Finite Element mesh on one fourth portion of the unit cell is shown in Figure 9.

Figure.9: Finite Element Mesh Model

2.9. Material Properties:

The materials properties that were used for the calculation of the Elastic properties of the resin-jute-pineapple composite are listed in table 3. The properties of resin, jute, pineapple leaf fibers are collected from literature

Table 3. Material Properties of Constituents for FEA

S No	Material	Young's Modulus E (Mpa)	Poisson's Ratio
1	Jute Fiber	26500	0.3
2	Pineapple Leaf Fiber	6260	0.3
3	Polyester Resin	36000	0.35

3. Geometry, Element type and Boundary conditions:

Geometry:
The dimensions of the finite element model are taken as

X = 100 units,
Y = 100 units,
Z = 10 units

Element type:
The element type SOLID 20 Node 186 is used for present analysis is based on a general 3D state of stress and is suited for modelling 3D solid structure under 3D loading. SOLID 20 node 186 is a higher-order version of the 3D 20-node solid element that exhibits quadratic displacement behaviour. It can tolerate irregular shapes without as much loss of accuracy. SOLID186 elements have compatible displacement shapes and are well suited to model curved boundaries. SOLID186 has plasticity, creep, stress stiffening, large deflection, and large strain capabilities. The element has 20 nodes having one degree of freedom with three degrees of freedom at each node: translation in the node X, Y, Z directions respectively.

Boundary Conditions:
Due to symmetry of the problem, the following symmetric boundary conditions are used:
At X = 0, $U_x = 0$
At Y = 0, $U_y = 0$
At Z = 0, $U_z = 0$
In addition, the following multi point constraints are used.

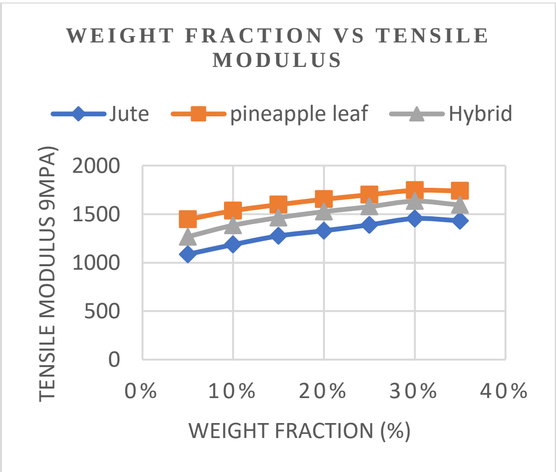
- The U_x of all the nodes on the area at X=100 is same.
- The U_y of all the nodes on the area at Y=100 is same.
- The U_z of all the nodes on the area at Z=10 is same.

3.1 Calculating Tensile Modulus:

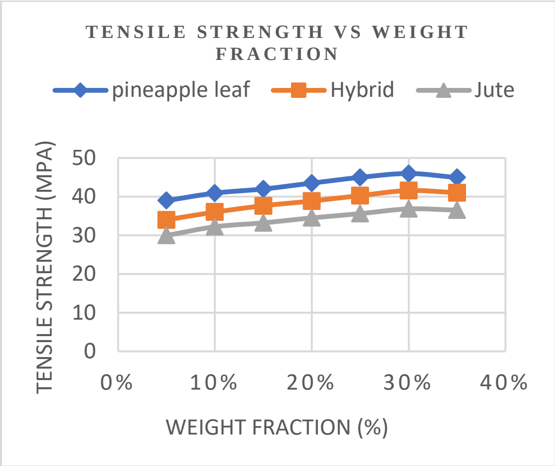
- For calculating the tensile modulus of the developed model, the deformation value in the fiber direction is to be considered.
- In this case the deformation value in Z-direction is considered for ε1 value by dividing it with its original value i.e. 10 units and divides the stress value with obtained strain value.
  Analysis of ε1 **values**:
  Tensile modulus is analysed with the help of finite element software ANSYS 17.2

3.2 Experimental Results:

a. Tensile Test:
From tensile test young's modulus and tensile strength of jute- polyester, pineapple leaf fiber – polyester and hybrid (jute – pineapple leaf fibers-polyester) composites are determined. The specimen dimensions for tensile test are160 mm x 12.5 mm x 3 mm as per the **(ASTM D638-89)** Standard.



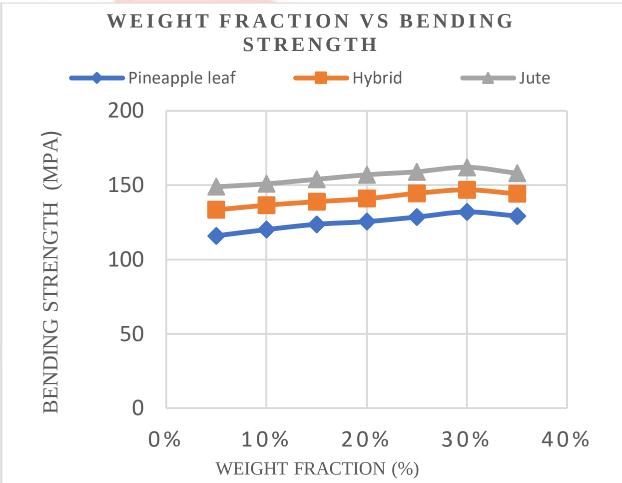
Graph 1: Weight Fraction Vs Tensile Modulus



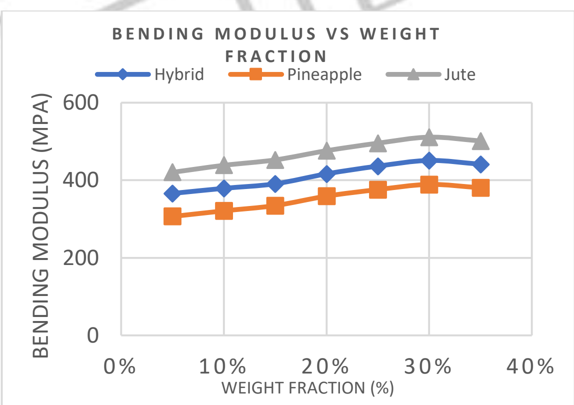
Graph 2: Weight fraction vs Tensile strength

b. Flexural Test:

By conducting flexural test, flexural modulus and flexural strength of jute- polyester, pineapple leaf fiber – polyester and hybrid (jute – pineapple leaf fibers-polyester) composite are determined. The specimen dimensions are 100 mm x 25 mm x 3 mm as per **(ASTM D79-86)** standard.



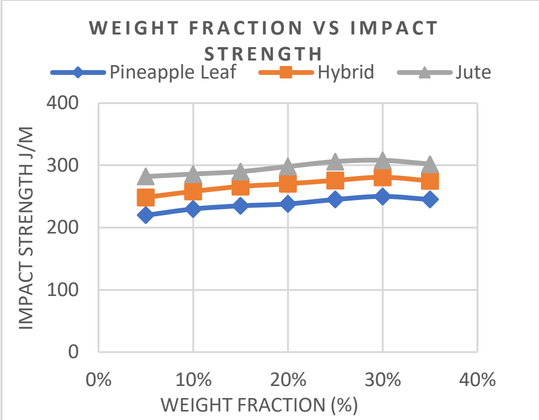
Graph 3: Weight fraction vs Bending strength



Graph 4: Weight fraction vs Bending Modulus

c. Impact Test:

Impact test is conducted on jute- polyester, pineapple leaf fiber – polyester and hybrid (jute – pineapple leaf fibers-polyester) composite. To determine impact strength as per the **(ASTM D 256-97)** standard. The specimen dimensions are 63.5 mm x 12.7 mm x 3 mm.



Graph 5: Weight fraction vs Impact Strength

3.3 RESULTS FROM ANSYS:

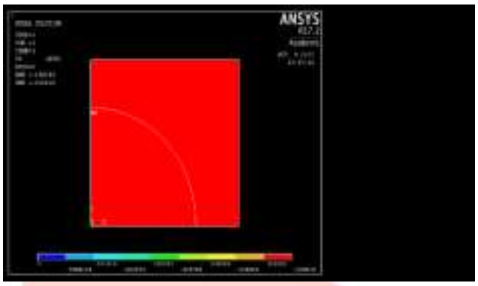


Figure.10 Results plot of E1 for sample Pineapple leaf fiber model

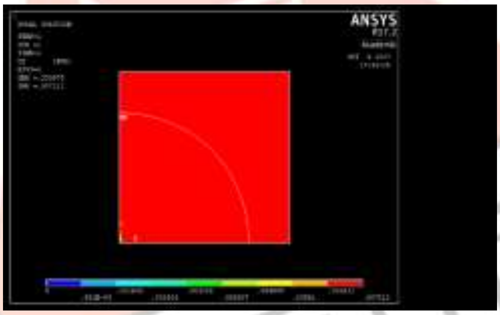
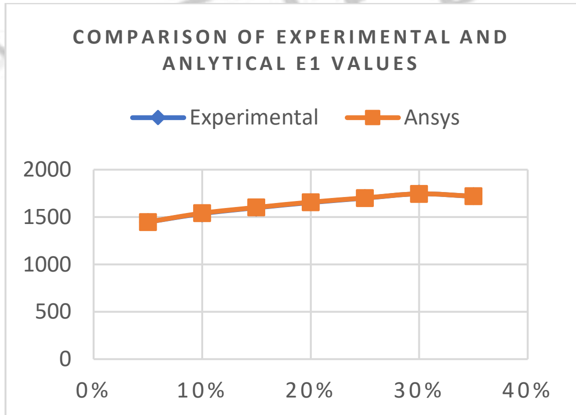


Figure.11 Results plot of E1 for sample Jute fiber model



Graph:6 Comparison of tensile modulus values determined experimentally with ANSYS results

Table 4 Comparison values of E1 for Pineapple Leaf fiber

S No	Fiber Weight Fraction	Pineapple Leaf Fiber Tensile Modulus (E_1) (Mpa) Experiment	Ansys
1	5%	1446.89	1445.51
2	10%	1536.48	1538.93
3	15%	1598.52	1599.48
4	20%	1653.58	1655.08
5	25%	1701.26	1699.81
6	30%	1745.68	1743.17
7	35%	1739.24	1737.57

Table 5 Comparison values of E1 for Jute fiber

S No	Fiber Weight Fraction	Jute Fiber Tensile Modulus (E_1) (Mpa) Experiment	Ansys
1	5%	1085.54	1086.11
2	10%	1185.26	1187.50
3	15%	1274.58	1275.18
4	20%	1327.82	1325.55
5	25%	1388.48	1386.57
6	30%	1453.38	1451.80
7	35%	1430.48	1432.04

Table 6 Comparison values of E1 for Hybrid:

S No	Fiber Weight Fraction	Hybrid Tensile Modulus (E_1) (Mpa) Experiment	Ansys
1	5%	1267.42	1269.52
2	10%	1385.62	1387.84
3	15%	1464.38	1465.28
4	20%	1526.53	1528.64
5	25%	1577.26	1579.32
6	30%	1634.72	1636.21
7	35%	1595.24	1596.47

Conclusions:

- The tensile strength, young's modulus, bending strength, bending modulus and impact strength of the composite are increase with increase in weight fraction of the fiber (up to 30%) and decrease with further increase in the weight fraction (35%).
- The Pineapple Leaf Fiber - Polyester composite has maximum young's modulus and tensile strength when compared to the jute-polyester and hybrid fiber composite.
- The Jute - polyester composite has maximum flexural modulus and flexural strength when compared to the Pineapple leaf fiber - polyester and hybrid composite.
- Similarly, impact strength of jute - polyester composite has maximum when compared to the pineapple leaf fiber and hybrid composite.

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