Natural Fibre Reinforced Hybrid Composite: Thermal & Mechanical Characterization

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Abstract. The waste material can be used for the development of different composite materials after their use for their prime objectives viz. Bagasse fibre, human hair, egg shell etc. These waste materials have some specific mechanical & thermal properties such as tensile and compressive strength, hardness, toughness, moisture content etc. Millions of tonnes of chicken feather is continuously extracted by poultry industry and small proportion of this waste material is utilised while the rest amount considered as waste. Bagasse fibre consist of cellulose, hemi-cellulose and lignin with their respective percentage of 40%, 30% and 15% to offer tensile strength and increases due to formation of quinones constituent of the fibre and its adhesiveness also increases after treatment in furfural alcohol solution. By holding their specific properties, these are biodegradable so the hybrid composite made with the help of these fibres, also biodegradable and Eco-friendly. In this paper, polymer thermostet epoxy resin was used as matrix, Bagasse fibre and chicken feather as reinforcement in definite proportion of 55%, 40% and 5% respectively. The hybrid composite was fabricated with the help of hand lay-up technique. Specimens were prepared as per ASTM standard for tensile and compressive strength, hardness and toughness, the present work also carried out thermal characterization such as TGA and water absorption test having analysis of 72 hrs. After evaluation of their mechanical and thermal properties, this work also present comparison in between neat epoxy polymer composite with natural fibre reinforced hybrid composite.

1. Introduction
The contemporary world is search intensively about the alternate material fabricated by the natural fibre because of their easily availability at very low cost such as sugarcane bagasse, chicken feather, human and animal hair etc. Unlike other synthetic or man-made fibres, natural fibres are light weight, low density, and good specific properties, low cost, non-abrasive, biodegradable and readily available but also some negative traits such as hydrophilic behaviour, poor interfacial adhesion and their properties may also vary with time. natural fibre may be obtained by the residue of crops, plant etc. which have as much as strength of synthetic fibre [1]. A composite comprises of one or more major elements in which one of the elements, known as the reinforcing agent, in the shape of net, fibres or particulate form is bonded into the other element called the matrix agent. Obtained Composite normally has a fibre or particulate agent that is more stiff and tough than the continuous matrix agent [2-3]. The properties of resultant material i.e. composite has more enhanced characteristics than the characteristics of the parent materials that make the composite. The resin performs as intermittent of load transfer between fibres whereas reinforcement provides strength and stiffness to the matrix. The resin or matrix even shields the fibres to decay due to environment within processing and after processing of composite. Srivastava AK, & Shukla Ravi [4] defines as “Composites are the compound materials that are differentiated from alloys because their individual constituents retain their characteristics.”
Kumar et al. observed composite as dissimilar materials which consist of two or more solid medium, are mixed at microscopic level to the constituent’s [5].

Ahmed K [6] said that “Composites are those multi utility material systems that provide attributes which are unobtainable from any other material. They are made physically by combining two or more than two compatible materials which are different in composition, characteristics and form”.

Sharma et al. clearly stressed that composites must not only be regarded simply as a combination of two materials. Instead in broader perspective; the composite has its own separate properties [7].

1.1 Hybrid Composite

The composites that involve the reinforcement of two or more fibers in a common matrix are called hybrid composites [8-9]. Hybrid composites are specifically employed in those conditions which require a combination of different set of properties of different fibers or when both lateral and longitudinal mechanical performance of composite is required. Hybrid Composites provide us with the advantage of using the properties of one fiber to compliment that is deficient in the other. The properties of the hybrid composites depends upon many factors which are- fiber density, fiber length, fiber quality, fiber orientation, nature of interface between fibers, fiber to matrix bonding capacity etc.

The fibres which are obtained directly from nature like bagasse, sisal, pineapple leaf fibre animal hair, egg shell, chicken feather etc. are reinforcing element in the composite when compared to the other artificial fibre, the natural fibre based composite put inherent properties and directly disposable in the atmosphere. Polymer composites are used at everywhere of our surroundings such as automobile, constructional purpose, accessories and machinery used for medical purpose etc. thermoset and thermoplast composites would cast easily any type of complex shaped by extrusion, injection moulding, vacuum forming or foaming. It is durable, reliable, weather resistance, resilient enough and insubstantial. For developing hybrid composite bagasse used as a fibre and chicken feather in particulate form. Bagasse is the residue of sugar mill while chicken feather residue from poultry form [10-12]. Chicken Feathers prevents temperature transfer due to presence keratin protein there are two forms of microcrystalline keratin in the feathers. Resilient and cushioning are the basic property of chicken feather [13]. Both are going to be wasted in millions of tonne, rarely bagasse is used in furnaces and chicken feather is used in textile industry [14].Epoxy resin is a thermoset type polymer, is popularly choose for developing composites because of their easily presence and cured at NTP.

1.2 Elements of Composites

The composite material primarily comprises of two elements:

a) Reinforcement

The reinforcement generally provides strength to the composite and append its mechanical properties. It is generally found in fibrous or particle form and provides stiffness to the composites. For majority of applications, the fibres are organized into some form of sheet. Many ways of arranging fibres into a packed structure and the diversity of fibre orientation helps the reinforcement to obtain different characteristics.
b) Matrix
The matrix component generally comprises the major part of a composite. Materials in fibrous form resemble good mechanical properties and for achievement the fibres characteristics must be embedded by the resin. There are three basic division of matrix for material– Polymer, metals and ceramics as we know. The matrix sets apart the fibres from one another and holds the fibres in position. The matrix must hold good capability to get elongate or contract without difficulty against variable load; manipulate the direction of load to the fibre so that the concentration of stress spread out evenly.

1.3 Natural Fibres
Fibres can be of two types: - natural and manmade or synthetic. Natural fibres refers to the fibres obtained from Natural sources i.e. such as jute, sisal, sugarcane stalks, wheat/paddy leftovers, hemp, sisal, ramie, bamboo, flax, banana, cotton, pineapple leaf fibre, etc. whereas synthetic fibres involve glass, carbon, aramid, etc. Unlike other synthetic or man-made fibres natural fibres are light weight, low density, good specific properties, low cost, non-abrasive, biodegradable and readily available but also some negative traits such as hydrophilic behaviour, poor interfacial adhesion and their properties may also vary with time. According to the sources of origin natural fibre can be broadly classified into following categories [11].
   a) Flora fibres
   b) Fauna fibres
   c) Mineral fibres

1.4 Applications of Natural Fibre Composites
The application areas of natural fibre composites are:
   a) In Electrical industry and for manufacture of storage devices.
   b) In manufacturing of daily use products such as helmets, lamp shades etc.
   c) In automobile, aviation, packaging, paper and pulp industries, etc.
   d) In manufacturing of hulls of boats, seats and cabins in railway coaches
   e) In manufacture of door panels and dashboard of car by luxury car companies such as BMW, Mercedes, Audi etc.

2. Materials and Methods
The materials required for fabrication of composites are:
2.1. Natural fibres (Reinforcement)
   1) Bagasse fibre
   2) Chicken feather

2.1.1. Sugarcane Bagasse
The Bagasse fibers utilized in this work were obtained from local market. Sugarcane bagasse (as shown in Fig. 1) is a one of the main crop for the production of sugar as well as ethanol. The harvesting of sugarcane is mainly in tropical region like India, Cuba, Brazil and China. Bagasse which is left after the juice has been extracted from the sugar cane biodegrades in 25-65 days. Each 10 tons of sugarcanes processed in a sugar factory produces approximately 3 tons of moist bagasse. After crushing sugarcane Bagasse is secondary employed combustible agent in the furnace of various mills. Near about 10% of sugarcane bagasse used in the production of ethanol.
Bagasse fibre consist of cellulose, hemicelluloses and lignin with their percentage
40%, 30% and 15% respectively for offering tensile strength and is increased due to formation of quinones in lignin constituent of the fiber and by treating with the furfural alcohol its adhesion increased. Lignin works as a binding agent for the cellulose fibers [12].

2.1.2. Treatment of fibre
Bagasse is extracted from sugarcane when the juice extracted by the crusher then after Bagasse is cleaned by fresh boiled water and again by the distilled water then dried properly in so that moisture content evaporate. Fig. 2 (a) and (b).

2.1.3. Chicken feather
Chicken feather was collected from the poultry form then it would be cleaned properly by boiled water then fresh water lastly treated with NaOH solution. After cleaning the feather was chopped properly with the chopper. Now the feather showed their fracture toughness of has proved around 10 kJm obtained due to β-keratin played their important role in this composite. Since the chicken feather has good thermal resistance properties due to their keratin structure [15-16]. Fig. 3 (a) and (b) illustrates the chicken feather and chopped chicken feather.
2.2. **Epoxy Resin**

The formation of Epoxy resins are by consisting few monomers that chemically react and composed a molecule of high molecular weight known as polymers. Epoxy resins comprise a group of cross-linkable material occurs through the reactions of epoxide group. The epoxy resin possesses excellent features to achieve specific performance characteristic as the matrix material.

- a) Outstanding adhesiveness to a variety of substance.
- b) Excellent protection to chemical and physical abuse.
- c) More tensile, compressive and flexural strength.
- d) Ability to cure at normal temperature and pressure.
- e) Remarkable electrical insulation properties and resistance to corrosion.
- f) Odourless and completely nontoxic.
- g) Very low curing contraction.

Bondtite Super Strength is a high strength two component epoxy adhesive system. These systems are tailor made to bond similar and dissimilar materials such as metal, ceramic, wood, leather, rubber, marble, glass etc. Bondtite super strength is made the Resinova chemie ltd, Kanpur. The Ratio of epoxy (AY-105) and hardener (HY-951) is 10:8 as per manufactures percentage of Epoxy system (800gm epoxy + 640gm hardener). Matrix part A designated as AY-105 and part –B Hardener as HY-951 as shown in Fig. 4.

![Epoxy resin with hardener](image1)

**Figure 4.** Epoxy resin with hardener [1]

2.3. **Preparation of Hybrid Composites**

There are many techniques to develop or Fabricate composite materials to meet their specific objectives and manufacturing challenges, some of them are listed below:

- Open moulding
- Resin infusion processes
- High-volume moulding
- Autoclave moulding
- Hand lay-up technique

Hand lay-up technique is basic and popular technique to fabricate thermoset polymer composite in which the reinforcement of fibre (layer form or particulate form or mat type) takes place manually.

As illustrated in Fig. 5 (a), the dimension of Mould 650mm ×450mm ×10mm for the preparation of composite material by Hand Lay-up technique is used. Wax pasted on the inside f of mould face for avoiding matrix and the mould surfaces bonding. For the
450x300x10 mm³ composite sheet, two plywood frames are prepared each of 5mm thick. Preparation of hybrid composite sheet, bagasse fibre, chicken feather and epoxy resin mixture by the percentage of weight 40% bagasse, 5% of chicken feather and remaining 55% of epoxy resin. So there was mixture of 848 gram epoxy system (472gm epoxy + 376gm hardener) and 54 gram of chicken feather (particulate form) was prepared. The orientation of bagasse fibre is reinforced longitudinal in the middle of the sheet. So there is hybrid composite sheet having desired dimension (450x300x10 mm³) prepared as illustrated in Fig. 5 (b).

3. Results and discussion

3.1. Tensile Analysis

Tensile test work piece are prepared as per ASTM D638 as shown in Fig. 6 (a). To evaluate the value of Young’s modulus, deformation and ultimate stress of the sugarcane bagasse & chicken feather hybrid composite material, the tensile test is performed on Universal testing machine (Model No-AST 40) as shown in Fig. 6 (b), and the following result is obtained.

![Figure 5](image1.png)

**Figure 5.** (a) Mould (b) Bagasse/chicken hybrid composite sheet

3.1.1 Result of Tensile test

Tensile Test Specimen (ASTM D638) – The specimen’s dimensions are 165 x 57 x 6 mm³.

**Average Value of Young’s Modulus** = 0.203KN/mm²

**Average Value of Deformation** = 1.43%

**Average Value of Ultimate stress** = 0.03 KN/mm²

3.2. Impact Analysis

The work piece for impact test is prepared as per ASTM D256 as shown in Fig 7. Three work piece are prepared for experiment for calculate an average value.

To examine the impact behaviour of this hybrid composite Izod test is conducted as per standard ASTM D256. The average value of impact strength of the hybrid composite is obtained 28.233 J/m which shows better impact behaviour to the neat epoxy sheet and chicken feather composite as illustrated in Table. 1.
Table 1. Izod Test Results

| S. NO. | TEST     | STANDARD  | TESTED VALUE (J/m) | TESTED VALUE(CFC) (J/m) |
|--------|----------|-----------|---------------------|-------------------------|
| 1      | IZOD     | ASTM-D256 | 28.40               | 23.455                  |
| 2      | IZOD     | ASTM-D256 | 28.40               | 24.360                  |
| 3      | IZOD     | ASTM-D256 | 27.90               | 24.561                  |

3.2.1 Result of Izod test
Average Value of bagasse fibre chicken feather hybrid composite strength = 28.233 J/m
Average Value of chicken feather composite (CFC) strength = 24.125 J/m.

3.3 Rockwell hardness Analysis
Hardness test is conducted on Digital hardness tester machine with model RBHT, M scale, 100 kgf load capacity, 1/4” ball indenter as shown in Fig 8. The hardness of sugarcane bagasse fibre & chicken feather hybrid composite 62.26HRM (Average Value) is more than hardness value of natural fibres composite.

Table 2. Hardness Test Results

| S. No | TEST VALUE |
|-------|------------|
| Sample 1 | 62.2 |
| Sample 2 | 62.7 |
| Sample 3 | 61.9 |

3.3.1 Result of Hardness test
From Table 2, it is clearly shown that the hardness of the particulate form of Bagasse fibre and chicken feather hybrid composite 62.26 HRM is more than hardness value of chicken feather composite.

3.4 Thermo Gravimetric Analysis
Thermo gravimetric analysis or thermal gravimetric analysis (TGA) is a thermal analysis in which chemical as well as physical features are analyse with the temperature variation.
keeping rate of heat is fixed, or as time variable (with definite temperature and/or definite mass loss).

![Thermal Gravimetric Analysis Thermographs](image)

**Figure 9.** Thermo Gravimetric Analysis Thermographs

### 3.4.1 Result of TGA

TGA test-Curves of bagasse fibre & chicken feather composite are shown in Fig. 9. Thermal treatment covered of bagasse fibre & chicken feather composite gave an initial weight loss below 200 °C because of moisture loss. The loss of weight obtains with hybrid because of the molecular mass under gravity of the compounds. The starting loss of mass is due to complex composite reaction and development of volatile product.

It is obvious, TGA thermographs that no decay occurred until 200 °C for the sample the onset being above 200 °C. The highest rate of loss of weigh is seen in between of 200°C–500°C. The amount of residue left is 9%.

The specimen passes through bi-stage degradation process shown on thermographs. In which first step, thermal degradation process took place in between the temperature of 200°C-390°C. The first step followed by another degradation process in between the temperature of 450°C-500°C and because of hybrid composite fibre and matrix degradation.

The above graph shows thermal behaviour variation of hybrid composite significant thermal behaviour of the compound was determined from the starting decay temperature started and the residue weight percentage denoted as chart.

### 3.5 Water Absorption Test

For Water absorption test, specimen is fully submerged into a water beaker for 72 hours at room temperature under normal condition and every 4hours their weight would be measured by a digital weighing machine and this process is repeated for two consecutive days. Finally water absorption test is done for 72 hours. As the epoxy resin doesn’t form any hydrogen
bond so that there is lean possibility to increase in their weight but by natural fibres absorbed some moisture content initially but later its weight become in variant.

![Image](image_url)

Figure 10. (a) Specimen dipped in beaker (b) Water Absorption Test

3.5.1 Result of water absorption test
20 grams weighted a cubic specimen is taken for this test. First 24 hours its weight became 20.70 grams. In first 24 Hours the specimen tested every 4 hours and the graph which is drawn between times and weight shows that gradual increase in weight and then its weight get stagnant. The hybrid composite hold only 0.70 grams of moisture in 24 hours and then failed to obtain moisture any more for next 48 hours as shown in Fig. 10 (a) and (b).

4. Conclusions
4.1 Conclusion on the basis of tensile test
Values of chicken feather composite (CFC)
Average value of modulus of elasticity = 0.136 KN/mm²
Average value of elongation = 3.296 %
Average value of ultimate stress = 0.02 KN/mm²

Values of bagasse fibre chicken feather hybrid composite
Average value of modulus of elasticity = 0.203 KN/mm²
Average value of elongation = 1.43 %
Average value of ultimate stress = 0.03 KN/mm²
The tensile test is performed on chicken feather composite and bagasse fibre & chicken feather composite and it is found that the modulus of elasticity and ultimate stress of bagasse Fibre & chicken feather composite is slightly increases than the chicken feather composite and elongation percentage is decreases in case of fibre form of composite.

4.2 Conclusion on the basis of Hardness test
Average hardness of bagasse fibre & chicken feather hybrid composite = 62.26 HRM
Average hardness of chicken feather (CFC) composite = 54.06 HRM [14]
From Table 2, it is clearly shown that the hardness of the particulate form of Bagasse fibre and chicken feather hybrid composite 62.26 HRM is more than hardness value of chicken feather composite.

1. The Izod test shows their impact strength 28.233J/m of hybrid Composite by adding waste bagasse fibre and chicken feather as compared to neat thermoset polymer (Epoxy Resin).
2. The Rockwell hardness (62.20) of hybrid composite sheet, made up by fibre composite reinforcement method is good enough as compared to particulate reinforcement.
3. The hybrid composite hold only 0.70 grams moisture in first one day and then there is no moisture content obtained further.

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