A STUDY ON ECO-FRIENDLY HYBRID EPOXY COMPOSITES WITH MIXED NATURAL FIBERS AND SYNTHETIC PARTICULATES

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ABSTRACT

The growing demand for sustainable materials in engineering applications has led to increased interest in hybrid composites that integrate natural fibers with recycled synthetic particulates. This study explores the mechanical and morphological properties of eco-friendly epoxy composites reinforced with a hybrid mixture of coconut fiber, bamboo fiber, and plastic particulates derived from post-consumer waste. The primary objective is to evaluate the potential of these bio-synthetic reinforcements in producing lightweight, durable, and environmentally responsible composite materials.

Specimens were fabricated using varying weight percentages of each reinforcement material within a consistent epoxy matrix, and tested for key mechanical properties such as tensile strength, flexural strength, impact resistance, and hardness. The results reveal that hybridization significantly improves load-bearing capacity and energy absorption, especially in compositions containing a balanced proportion of natural fibers and plastic fillers. Microscopic analysis also confirms effective interfacial bonding between the fiber surfaces and the epoxy matrix, with minimal voids or delamination.

The study concludes that the synergistic combination of renewable fibers and recycled plastics not only enhances the mechanical performance of epoxy composites but also promotes waste valorization and resource sustainability. These findings support the potential of such hybrid materials for applications in automotive interiors, construction panels, and consumer products, where strength-to-weight ratio and eco-friendliness are critical.

1. INTRODUCTION:

In the face of increasing environmental concerns and the global push for sustainable development, there is a growing demand for materials that combine high performance with eco-friendliness. Polymer matrix composites, particularly those reinforced with natural fibers, have emerged as promising alternatives to conventional synthetic composites due to their biodegradability, renewability, low cost, and low density. Among these, coconut fiber and bamboo fiber have garnered attention for their excellent mechanical properties and abundant availability, especially in tropical regions.

However, natural fibers alone often face limitations such as moisture sensitivity, poor thermal stability, and inconsistent quality. To overcome these drawbacks and further enhance the composite's characteristics, hybrid reinforcement strategies have been developed—combining natural fibers with synthetic materials or industrial waste. In this context, plastic particulates, particularly those derived from post-consumer waste, offer a dual benefit: improving composite toughness and contributing to plastic waste mitigation.

This study investigates the development of hybrid epoxy composites reinforced with a blend of coconut fiber, bamboo fiber, and recycled plastic particulates. The aim is to assess how these hybrid reinforcements influence the mechanical, thermal, and morphological properties of the resulting composites. The use of waste plastic not only enhances sustainability but also addresses one of the most pressing environmental issues—plastic pollution.

By leveraging the complementary properties of natural and synthetic reinforcements, the research seeks to design composite materials suitable for use in sectors such as automotive interiors, building components, and consumer products, where durability, lightweight characteristics, and environmental responsibility are increasingly prioritized. This investigation contributes to the ongoing development of green composite technologies, aligning material innovation with ecological and economic sustainability.

1. Plastic Shredder Machine

1.1 shredder machine

Plastic is one of the most common used materials in the world today, but, they cause serious environmental pollution and exhaustion of landfill space. The recycling of waste plastic recovers the material, which can be used to make new plastic products such as containers, plastic lumbers and particle boards. For this to happen, the waste plastic will first be shred into small bits making it ready for transportation and further processing. The shredder has the feeding unit, the shredding unit, power transmission unit and the machine frame.

The performance of the machine was evaluated and test results showed that there was a correlation between the machine speed with a regression less than 1 and there was a linear relationship with all variable parameters (the shredding time (t), the specific mechanical energy (sme), throughput (tp) and recovery efficiency (re)) and the variable operation speeds . The throughput of the machine is 27.3 kg/hr and the efficiency is 53% for all type of plastic and 95% for polyvinylchloride type of plastic. The machine is user friendly and the cost of producing one unit of the machine as at the time of fabrication was estimated to only making it affordable to acquire for small and medium scale entrepreneurs in waste plastic recycling business

Plastic have become an essential part of our day to day life since their introduction over hundred years ago. It is one of the most commonly used materials in the world today. They come in five major categories; the polyethylene terephthalate (pet), the high density polyethylene (hdpe), the polyvinylchloride (pvc), the polypropylene (pp) and the low density polyethylene (ldpe). The huge quantities of these plastic categories currently being marketed will ultimately find their way to the waste dump sites. This is creating waste products problems due to its high amount of waste generated, non-biodegradability and the fastest depletion of natural resources regarding its short life cycle, therefore increased amount of material utilized in its production, and waste generated.

plastic bottles make up approximately 11% of the content landfills, causing serious environmental consequences. The plastic waste globally constitutes more than 60% of the total global municipal solid waste (msw), 22% were recovered and 78% disposed. In united states, the waste of plastics in 2005 was calculated as 11.8% of the 246 million tons of msw generated. Some states in the us like michigan have a recycling rate that is close to 100% and in brazil, some potential in recycling have been raised where around 15% of all plastics consumed are recycled and returned to industry. Locally in nigeria and for nigerian cities and towns, different researches have been carried out on the challenges of solid wastes in nigeria. India and africa generally, but works on plastic wastes in nigerian cities and towns are still limited. Developing countries like nigeria have to import virgin plastic at high cost because recycling activities are usually low in these countries.

Machinery available for recycling activities in these countries are usually of very high cost and bulky and as such, recycling activities are restricted by these challenges in these countries. Therefore, to overcome these challenges, it was necessary to develop a low cost waste plastic shredding machine using available local materials that can easily be operated without much skill for low and medium income earner. This will prepare the recycled plastic for the production of new products in nigeria. Plastic recycling or reprocessing is usually referred to as the process by which plastic waste material that would otherwise become solid waste are collected, separated, processed and returned to use.

Waste plastic shredder is a machine that reduces used plastic bottles to smaller particle sizes to enhance its portability, easiness and readiness for use into another new product. The design principle of this machine was got from the ancient tradition method of using scissors to cut materials into reduced form and scratching used by rabbits when digging or tearing. These two traditional methods were applied in the design of the machine by fabricating cutting blades to cut the waste plastic while some of the cutting blades have sharp curved edges to draw-in the plastic into the cutting blades teeth. The waste plastic shredder comprises of four major components, namely; the feeding unit, the shredding unit, the power unit and the machine frame. The machine can be powered by electric motor of 10 hp.

1.2 machine description and operation:

The waste plastic shredder has four main components; the feeding unit, the shredding unit, the power unit and the machine frame. The feeding unit is made of 16 – gauge mild steel sheet of 9 mm thick plate and a dimension of 200 mm × 550 mm through which the waste plastic are fed into the shredding unit. The shredding unit is where the waste plastic are been cut into smaller sizes. The unit consists of a shaft, 50 mm length made up of 30 mm mild steel rod and a cylinder of 55 mm length and 200 mm diameter. Attached to the shaft are cutters made of 12 mm mild steel having nine serrated teeth welded 2 mm apart. The cylinder equally has same cutters with sharp edges to shred the waste plastic. Underneath the shredding unit is the outlet made of 16-gauge mild steel. The shredded waste plastic discharge freely from the shredding unit through the outlet. The machine is powered by 10 hp electric motor with the aid of belt and pulley arrangement which has 110 mm diameter driven pulley and 60 mm driver pulley

1.3 design consideration:

Some of the factors considered in the design of the recycled plastic waste shredding machine are safety, power requirement, compactness, ease of operations and overall cost of production. Material selection based on availability, durability, cost and ease of fabrication were also considered.

Machine components:

Volume of the hopper = area of cross-section of the hopper × width of hopper= ½ (a + b) h × width…

Volume of pet bottle (coca cola) in the shredding chamber:

No of bottle to fill the hopper = volume of hopper/ volume of pet bottle

Volume of pet bottle (Coca-Cola bottle) =

$$\text{Area} \times \text{height} = \frac{\pi d^2}{4} \times h \ldots(2)$$

Determination of shaft diameter

$$d^3 = \frac{16}{\pi \tau}\sqrt{(k_b m_b)^2 + (k_t m_t)^2} \ldots (3)$$

Where,

D = diameter of the shaft = 30 mm

t = allowable shear stress of metal with key way = 40 × 106 n/m^2

Mb = maximum bending moment = 25.61 nm

Mt = torsion moment = 22.3 n

Kb = combined shock and fatigue factor applied to bending moment = 2.0 (sudden loading)

Kt = combined shock and fatigue factor applied to tensional moment = 2.0 (sudden loading)

1.4 performance evaluation procedure:

One kilogram (1 kg) each of the four different plastic types (polyethylene terephthalate (pet), the high density polyethylene (hdpe), the polyvinylchloride (pvc) and the polypropylene (pp) were shredded at varied motor speed using 10 hp three-phase electric motor as the prime mover.

The shredded waste plastic, q, was weighed to determine the quantity of the actual shredded waste plastic before sieving into three different sizes in order to determine their average size and area using excel 2014. The shredding time (t), the specific mechanical energy (sme), throughput (tp) and recovery efficiency (re) of the machine were also determined using the relationship below:

Specific mechanical energy = power (p) × time (t)

Output mass (q)

Throughput (tp)=output mass of recycled waste plastic (q)

Time taken for recycling (t)

Recycling efficiency (re)= output mass of recycled waste plastic (q) × 100

2. INTRODUCTION OF COMPOSITES

2.1 composites:

The ideas of composites materials is not a new or recent one. Nature is full of examples where in the idea of composite materials is used. The coconut palm leaf, for example, is nothing but a cantilever using the concept of fiber reinforcement. Wood is a fibrous composite: cellulose fibers' in a lignin matrix. The cellulose fibers have high tensile strength but are very flexible (i.e. Low stiffness), while the lignin matrix joins the fibres' and furnishes the stiffness. Bone is yet another example of a natural composites that supports the weight of various members of the body. It consists of short and short collagen fibers embed in a mineral matrix called apatite. In addition to these naturally occurring composites, there are many other engineering materials that are composites in a very general way and that have been in use for very long time. The carbon black in rubber, portland cement or asphalt mixed with sand, and glass fibers in resin are common examples. Thus, we see that the idea of composite materials is not that recent. Nevertheless, one can safely mark the origin of the distinct discipline of the composites materials as the beginning of the 1960s. It would not be too much off mark to say that a concerted research and development effort in composite materials began in

1965. Since the early 1960s, there has been an increasing demand for materials that are stiffer and stronger yet lighter in fields as diverse as aerospace, energy and civil constructions. The demands made on materials for better overall performance are so great and diverse that no one material can satisfy them. This naturally led to a resurgence of the ancient concept of combining different materials in an integral-composite material to satisfy the user requirement. Such composites material system results in a performance unattainable by the individual constituents, and they offer the great advantage of a flexible design; that is, one can, in principle tailor make the material as per specifications of optimum deign.

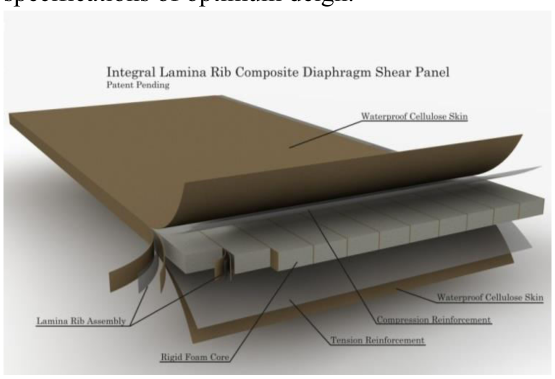


fig: hybrid epoxy composite

2.2 preparation methods:

Hand lay-up technique:

Hand lay-up technique is the simplest method of composite processing. The infrastructural requirement for this method is also minimal. The processing steps are quite simple. First of all, a release gel is sprayed on the mold surface to avoid the sticking of polymer to the surface. Thin plastic sheets are used at the top and bottom of the mold plate to get good surface finish of the product. Reinforcement in the form of woven mats or chopped strand mats are cut as per the mold size and placed at the surface of mold after perspex sheet. Then thermosetting polymer in liquid form is mixed thoroughly in suitable proportion with a prescribed hardener (curing agent) and poured onto the surface of mat already placed in the mold. The polymer is uniformly spread with the help of brush. Second layer of mat is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer present. The process is repeated for each layer of polymer and mat, till the required layers are stacked. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mold plate which is then kept on the stacked layers and the pressure is applied. After curing either at room temperature or at some specific temperature, mold is opened and the developed composite part is taken out and further processed. The schematic of hand lay-up is shown in figure 1. The time of curing depends on type of polymer used for composite processing. For example, for epoxy based system, normal curing time at room temperature is 24-48 hours. This method is mainly suitable for thermosetting polymer based composites. Capital and infrastructural requirement is less as compared to other methods. Production rate is less and high volume fraction of reinforcement is difficult to achieve in the processed composites. Hand lay-up method finds application in many areas like aircraft components, automotive parts, boat hulls, dias board, deck etc. Generally, the materials used to develop composites through hand lay-up method

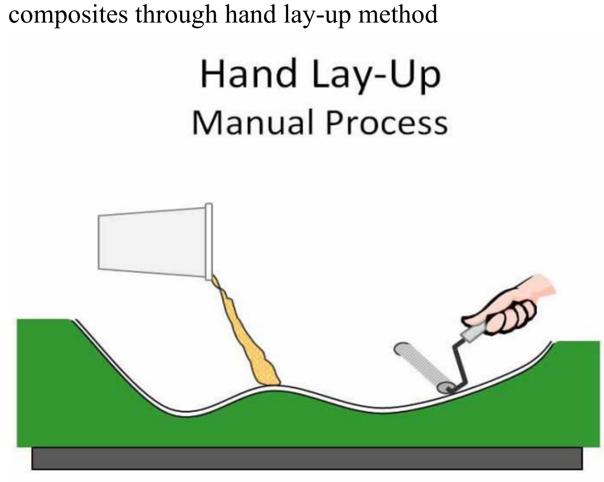


Fig: handmade lay-up process

3. Epoxy resin

Epoxy resins are formed from a long chain molecular structure similar to vinylester with reactive sites at either end. In the epoxy resin, however, they these reactive sites are formed by epoxy groups instead of ester groups, the absence of ester groups means that the epoxy resin has particularly good water resistance. The epoxy molecule also contains two ring groups and at its center which are able to absorb both mechanical and thermal stresses better than linear groups and therefore give the epoxy resin very

good stiffness, toughness and heat resistant properties.
Epoxies differ from polyester resin in that are cured by a hardener rather than a catalyst. The hardener , often an amine, is used to cured the epoxy by an addition reaction where both materials take place in the chemaical reaction.

density	1.35 g/cc
young's modulus	3200 mpa
poisson's ratio	0.35

design of plastic shredder blade:
Properties and specifications of plastic shredder blade:

- Typ e of material = en31 material
- Dia meter of blade = 80 mm
- Thi ckness of blade = 10 mm
- Hei ght of blade = 120 mm
- The rmal conductivity = 46 w/m k
- Che mical composition = c (0.25—29%),cu (0.20%), fe (98%), m n (1.03%)
- Mel ting point = 2570 degree fahrenheit
- Imp act strength = 31 j
- Ulti mate tensile strength = 841 m pa
- Spe cific gravity = 7.75 – 8.05 gm/cm3

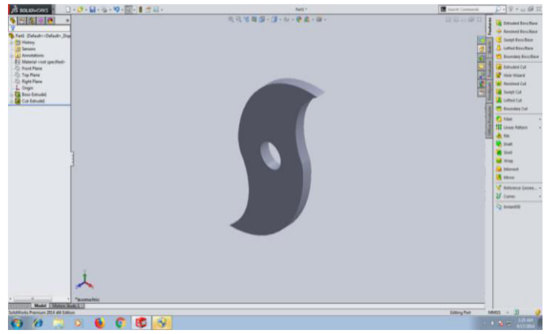


Fig: plastic shredder machine cutting blade

Design of plastic shredder box (mechanism holding head box):
Properties and specifications of plastic shredder box (mechanism holding head box):

- Typ e of material = mild steel
- Dia meter of hole = 25 mm
- Thi ckness of box = 10 mm
- Wi dth of box = 200 mm
- Len gth of box = 380mm
- Imp act strength = 31 j
- Ulti mate tensile strength = 290 m pa

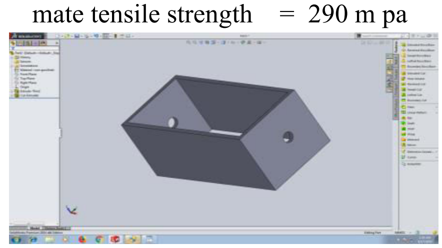


Fig: design of plastic shredder box (mechanism holding head box):

design of pulley:
Specifications and properties of pulley:

- Typ e of material = aluminum
- Dia meter of pulley = 50 mm (inside diameter)
- Ulti mate tensile strength = 290 m pa
- Spe cific heat = 0.900 j/ gm k

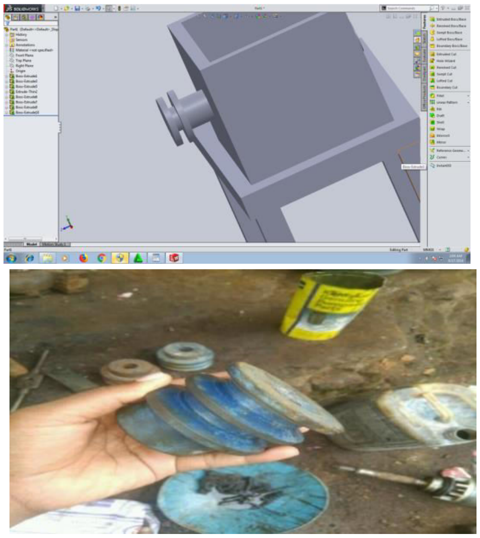


Fig: pulley

Design of electrical motor

Specifications of electrical motor:

- Speed = 1440 rpm
- Single phase motor
- Power = 230v
- Foot mounted
- Psc = 2.5amps
- 90s frame
- Aluminum body
- Model = 710
- Sakthi industries,coimbatore

specification of resins and hardner:

Type of material	Property	Specification	Units
Araldite ly 556 resin	Viscosity (at 25 degree centigrade)	10000 - 12000	M pa. S
Araldite ly 556 resin	Density (at 25 degree centigrade)	1.15-1.20	Gm/cc
Araldite ly 556 resin	Flash point	>200	C
Aradur hy 951 hardener	Viscosity (at 25 degree centigrade)	10-20	M pa. S
Aradur hy 951 hardener	Density (at 25 degree centigrade)	0.97-0.99	Gm/cc
Aradur hy 951 hardener	Flash point	>180	C

WEIGHT FRACTION OF THE FIBER:

The weight of the matrix was calculated by multiplying density of the matrix and the volume. Corresponding to the weight of the matrix the specified weight percentage of fibers is taken. For hybrid combination weight of fiber obtained is shared by two natural fibers

Volume ratio;

Fiber = 30%

Resin = 50%

Plastic = 20%

Volume of resin = 210x0.5 = 105g

Volume of plastic = 196.98x0.2 = 39.396g

Volume of fiber = 193.6x0.3 = 58.086g

Density of resin = 1.2g/cc

Density of fiber = 10g/cc

Density of plastic = 0.92g/cc

weight of the fiber = density of the fiber x volume of the mould

Weight of the fiber = volume of the fiber x density of the fiber

= 58.086 x 10

= 580.86 g

Weight of the resin = volume of resin x density of resin

= 105 x 1.2

= 126g

Weight of the plastic = volume of plastic x density of plastic

= 39.396 x 0.92

Weight of the plastic = 36.24456g

Density of composite = volume of fiber x density of the fiber = (0.3x58.086) + (0.5x1.2)

= 18.018g

Flexural test:

Flexural test is also known as bending test and consists in applying a point load at the center of composites material specimen. The flexural tests were done on the universal testing machine according to astmd790 with the crosshead speed of 10 mm/min. According to the astmd790 standard the dimensions of specimen used are shows the flexural testing astdm-d790 size of (100x12.5x10) machine with specimen.

$$\text{Flexural stress} = 3pl/2bd^2$$

Where;

p = brake load

b = width of specimens (mm)

d = thickness of the specimen

Fig: flexural testing machine

Tensile Test:

The tensile test specimen is prepared according to the astm d6368 standard and the machine specifications are also chosen according to the astm d6368.

Fig: tensile testing machine

4. RESULTS AND DISCUSSIONS

4.1 mechanical characteristics of composites:

The usage of natural fiber reinforced hybrid composites in different fields like aerospace, automobiles and other light weight applications has been increasing day by day due to their improved properties. In this part the investigation of the mechanical properties of reinforced hybrid composites of long continuous of different fiber weight fractions and their influence on the mechanical properties is carried out. The mechanical tests performed on the samples are:

A. Impact test
B. Flexural test

Results of mechanical properties of hybrid composites:

Table4.1: tensile properties of coconut fiber/ plastic hybrid composites

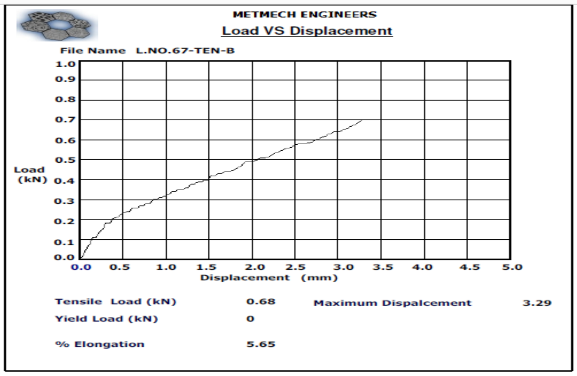
orientation	maximum strain (mpa)	% elongation	Tensile strength (mpa)
90^0	117.7	118.7	56.3

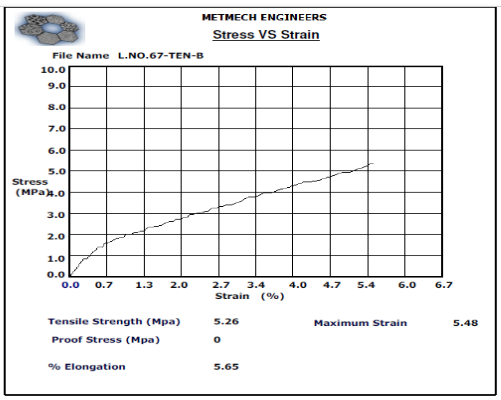
Table4.2: tensile properties of coconut fiber and bamboo / plastic hybrid composites

% weight fraction (p/b)	orientation	maximum strain (mpa)	% elongation	Tensile strength (mpa)

40/60	90^0	54.8	56.5	52.6

Tensile test graphs generated directly from computer





Comparison graphs of tensile test

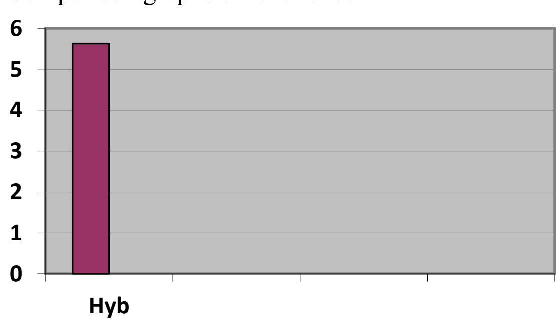


Fig: graph of tensile strength of 90^0 orientation fibers with coconut fiber / plastic

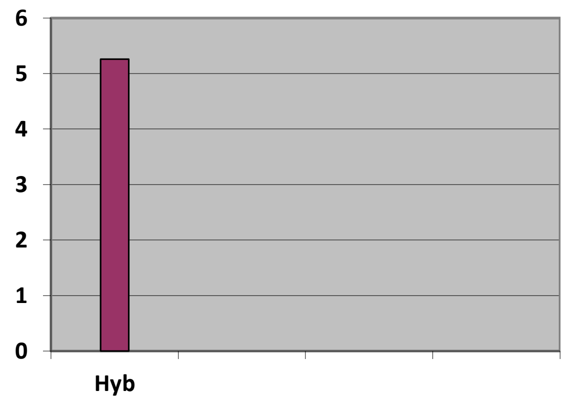
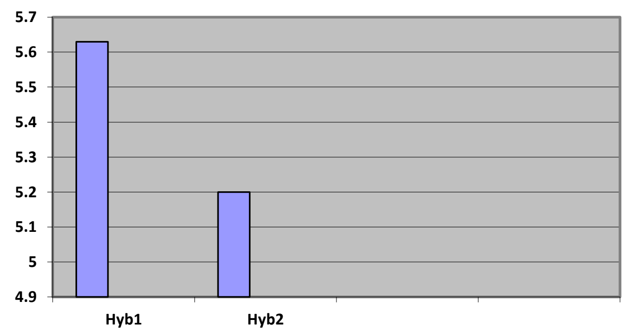


Fig: graph of tensile strength of 90^0 orientation fibers with coconut fiber and bamboo / plastic

Combination of both graphs:



From shows the tensile strength behavior of various composites with 40/60 weight fractions. It can be observed that tensile properties of coconut fiber / plastic hybrid composites shows a tensile strength of 5.63 mpa and tensile properties of coconut fiber and bamboo / plastic hybrid composites shows a tensile strength of 5.21 mpa respectively in 90^0orientation . Which is high when compared other fiber like banana and pine apple

Table4.3: flexural properties of coconut fiber/ plastic hybrid composites

% weight fraction (p/b)	Orientation	brake load (n)	flexural strength
40/60	90^0	540.000	575

table4.4: flexural properties of coconut fiber and bamboo / plastic hybrid composites

% weight fraction (p/b)	Orientation	brake load (n)	flexural strength
40/60	90^0	200.000	433.15

Flexural tests graphs generated directly from computer

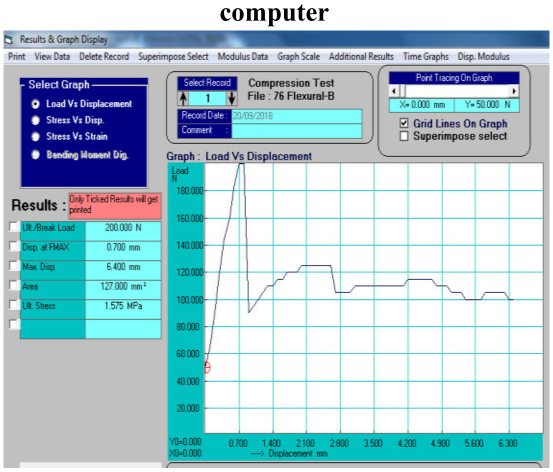


fig: graph of flexural strength of 90^0 orientation fibers with coconut fiber / plastic

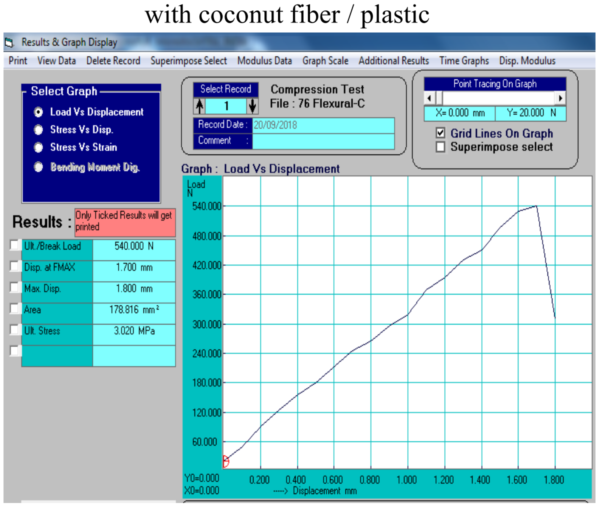


Fig: graph of flexural strength of 90^0 orientation fibers with coconut fiber / plastic

Comparison graphs of flexural test;

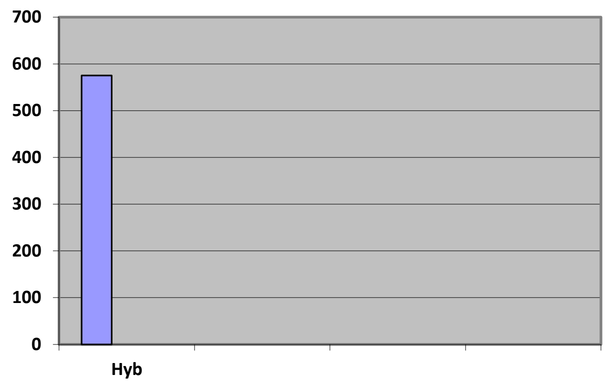


Fig: graph of flexural strength of 90^0 orientation fibers with coconut fiber / plastic

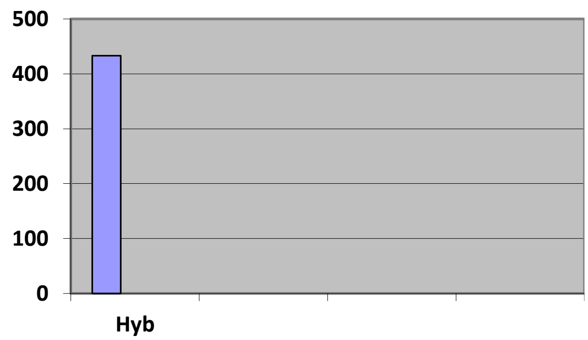
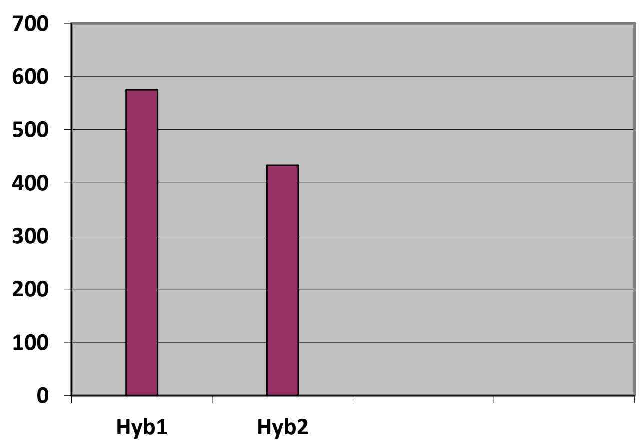


Fig: graph of flexural strength of 90^0 orientation fibers with coconut fiber / plastic

Combination of both graphs:



From shows the flexural strength behavior of various composites with 40/60 weight fractions. It can be observed that flexural properties of coconut fiber / plastic hybrid composites shows a flexural strength of 575 mpa and tensile properties of coconut fiber and bamboo / plastic hybrid composites shows a flexural strength of 433.75 mpa respectively in 90^0orientation . Which is high when compared other fiber like banana and pine apple

5. CONCLUSION

This study successfully demonstrated the potential of hybrid epoxy composites reinforced with coconut fiber, bamboo fiber, and recycled plastic particulates as sustainable alternatives to conventional synthetic composites. Through experimental investigation, it was observed that the incorporation of these hybrid reinforcements significantly improved the mechanical properties of the epoxy matrix, including tensile strength, flexural strength, and impact resistance. The optimal combination of natural and synthetic fillers yielded a synergistic effect, enhancing overall performance while maintaining lightweight characteristics.

The hybrid composites also showcased good interfacial bonding and structural integrity, as confirmed through microscopic and mechanical analyses. The addition of plastic particulates not only enhanced the material's toughness but also supported plastic waste reutilization, offering an eco-friendly pathway for waste management and material innovation.

Furthermore, the findings highlight the feasibility of utilizing agricultural by-products and non-biodegradable waste to create value-added materials suitable for automotive panels, interior components, furniture, and construction applications. The approach aligns with circular economy principles, addressing both environmental challenges and the need for resource-efficient material development.

Future research can explore chemical treatments to further optimize fiber-matrix adhesion, long-term durability assessments, and scaling-up production for industrial use. Ultimately, this hybrid reinforcement strategy paves the way for the next generation of eco-composites that balance performance, sustainability, and economic viability.

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