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# DEVELOPING AND ASSESSING ECO-FRIENDLY MUNTINGIA CALABURA FIBER REINFORCED COMPOSITE

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## ABSTRACT
A composite material is a material made from two or more different materials that are stronger together than they are individual component. It boosts high strength-to-weight ratio, making them light yet strong. Natural fibres are considered a renewable resource with numerous advantages including high stiffness, strength and biodegradable properties. Muntingia Calabura is one type of interesting fibre due to its large population, which is considered as agricultural waste. Muntingia bark is easy to dry, elastic, and soft. Owing to its potential characteristics, it can be used as a composite. This study focusses on using the Muntingia Calabura fibre for making reinforced composite. For procuring the fibre, water retting process was followed which is an eco-friendly method. Four proportions of laminate composites were developed from Muntingia Calabura bark fibre by hand lay-up method. These fibre reinforced composites when selected to mechanical tests, revealed good tensile and elongation, compression, hardness and flexural. They were also tested for FTIR and visual evaluation for its laminated structure was also well appreciated by the experts.

**Key words:**
Muntingia Calabura, Natural fibre, Fibre reinforced, Laminate, Composite, Eco-friendly.

## I. Introduction
A composite, the shortened form for composite material, is a material fabricated from a combination of two or more disparate materials in terms of physical or chemical properties with the intention to produce a new material with more robust structure conveys Halip *et al* (2019). A composite is a material structure that consists of atleast two macroscopically identifiable materials that work together to achieve a better result express Nijssen (2015). Composite materials are the combination of two or more materials in such a way that certain improved or desired properties are achieved suggest Balasubramanian (2014). George Lubin (1982) claim the components of a composite do not dissolve or otherwise merge completely into each other, but nevertheless do act in concert. Ismal and Paul (2017) explains composite materials have taken an essential place and a wide spread use in daily life and industry. High-performance plastics and composites have become the substitutes for conventional materials because of their excellent performance and improved properties.
Natural Fibre Composites (NFCs) are bio-based composites with a natural fibre reinforcement and matrix. Natural fibre composites have various advantages, such as low cost, high flexibility, high impact resistance, low specific gravity, less equipment abrasiveness, eco-friendliness explains Saha *et al* (2024). Natural fibre composites offer excellent thermal and sound insulation, serving as eco-friendly alternatives to traditional construction materials like plastic or metal. They are particularly advantageous for reinforcing thin-walled structures, contributing to the principles of eco-design convey Abbasi (2024). Natural fibres are any fibres that exist as fibres in their natural state refer Wilson (2011). According to Parasakthibala and Monisha (2022), the natural fibres provide many significant advantages and potentials such as low cost when compared to synthetic fibres, low density, light weight, excellent mechanical properties, biodegradability, renewable source, high specific stiffness, acoustic insulation and non-toxicity. In terms of reinforcement, natural fibres are a viable eco-friendly alternative signifies Elfaleh *et al* (2023) for both common applications, technical parts and due to their carbon balance and recyclability.

Muntingia Calabura (MC) is a neo-tropical tree. It is a reforestation tree that grows quickly. It has been neglected as a forest tree for various reason estimates Nivetha *et al* (2023). It is also known as Jamaica cherry tree, that is commonly found in nurseries, streets and residences. Vinod *et al* (2021) says the Muntingia Calabura is a fast-growing tree native to Mexico, North America and South America which grows upto 12m high and thrives well in tropical climate as well as in poor soil conditions like acidic, alkaline, and drought but not in saline environment. Savitha and Grace Annapoorani (2017) says Muntingia Calabura fibre has high cellulose content, and high tensile properties of fibre. The moisture content of Muntingia Calabura fibre is better than other natural fibres, which lead to better dimensional stability, reduced porosity and improved adhesion between the fibres. The bark of the Muntingia Calabura tree is soft, elastic, and easily dried. Based on the characteristics, the bark of the tree has a potential to be used as a reinforcing material for composites with a fibre composition consisting of hemicellulose, cellulose and lignin. The amount is around 65–70% of the dry weight of the plant containing hydroxyl which is important in water adsorption through hydrogen bonds. As a water absorber, holocellulose absorbs moisture and has hydrophilic properties. The Muntingia Calabura bark fibre is considered as a sustainable, renewable, and a potential source of raw material from agro-waste which can be used as potential sustainable replacement of synthetic reinforcement in composites for clean production of eco-friendly composites in lightweight structural applications. This study was focussed on developing by using the Muntingia Calabura bark fibre as a sustainable composite fibre for preparing a laminate eco-friendly composite structure and assessing its strength.

## II. Methodology

The methodology comprises the following steps:

### 2.1 Selection of Natural Fibre

Natural fibres are fibrous plant material produced as a result of photosynthesis. Natural fibres (NF) are fibres that aren't man-made or synthetic explains Abdelbary and Mohamed (2021). Plant-based natural fibres boast many advantages, including biodegradation, renewability, low cost, high strength, low density, ease of partition, recyclability and carbon dioxide seizure affirm Thapliyal (2023). The moisture content of Muntingia Calabura fibre is better than other natural fibres, which lead to better dimensional stability, reduced porosity and improved adhesion between the fibres. Muntingia Calabura fibre has been introduced as a stem fibre for the development and production of an acoustic non-woven fabric for the use of any lightweight structure. So, the investigator selected Muntingia Calabura (Plate 1) as a natural source fibre for the study.

### 2.2 Collection of Muntingia Calabura (Jamaica Cherry) Bark

The Muntingia Calabura tree (Plate 1) was found in Michael Palayam, Dindigul, Tamil Nadu. The Muntingia Calabura stems were cut into required length for bark peeling. Then, the bark was removed away from the wood by using a knife. Now, the bark of Muntingia Calabura was collected (Plate 2). Then, the collected Muntingia Calabura bark was taken for retting process.

### 2.3 Selection of Retting Process for Muntingia Calabura Bark

Retting is a process resting on the (random) action of microorganisms to remove non-cellulosic components from natural fibres and separate fibres from the plant stem structure so as to obtain cellulose-rich fibres estimates Liu *et al* (2017). Kokila Manchanda (2024) conveys water retting is a fibre extraction method that involves submerging bundles of plant stalks in water to separate the fibres from the plant. Ventorino *et al* (2024) shares the retting time is important for obtaining high fibre quality and also it can increase the mechanical performance of fibres. This method is simplest and eco-friendly describes Kumar *et al* (2023). So, the investigator selected the water retting process for the study.

### 2.4 Procedure for Retting Process of Muntingia Calabura Bark

Muntingia Calabura bark which was collected (Plate 2), was cleaned in soft water before water retting process started. For this process, the cleaned Muntingia Calabura bark was taken and steeped into the soft water in a tub. The tub should be in the size that when the Muntingia Calabura bark was steeped,

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it immerses inside fully such that the water is above the bark. This immersion is carried for one week for extraction (Plate 3). During this water retting process, the barks are completely wetted and fully soaked. The gums present in the fibres are separated (Plate 4). Thus, the extracted Muntingia Calabura fibres were washed thoroughly to remove the unwanted materials, dried in shade atleast from two to four hours to remove the water content. Finally, from the water retting process, Muntingia Calabura bark fibres were obtained (Plate 5) to make a composite for the study.





**PLATE 1 PLATE 2 PLATE 3 PLATE 4 PLATE 5**
**MUNTINGIA CALABURA TREE PEELED OFF MUNTINGIA**
**SOAKING OF MUNTINGIA MANUAL EXTRACTION OF EXTRACTED MUNTINGIA**
**CALABURA BARK**
**CALABURA BARK MUNTINGIA CALABURA CALABURA BARK FIBRE**

**FIBRES**

### 2.5 Selection of Type of Composites for Muntingia Calabura Bark Fibre

The obtained Muntingia Calabura bark fibres were taken to make an eco-friendly laminate composite. This eco-friendly laminate composite is produced by fibre reinforced composite or polymer matrix composite type.

### 2.6 Preparation of Fibre Reinforced Composite from Muntingia Calabura Bark Fibres

The composite for lamination from Muntingia Calabura bark fibre is produced by fibre reinforced composite method or which is also known as polymer matrix composites.

For the preparation of laminate composites, raw materials such as Muntingia Calabura bark and epoxy (resin) is needed. Resin here is called as matrix and Muntingia Calabura bark fibre is known as reinforcement.

The Muntingia Calabura bark (MC) (reinforcement) and epoxy (R) (resin) both are taken in four different quantities of MC : R such as 10 : 90, 20 : 80, 30 : 70 and 40 : 60 proportions. The selected four proportions were taken in separate vessels and mixed well in a wooden rod at room temperature and taken separately in each compartments. Simultaneously, the cavity were created on the bottom plate which having four compartments and a size of 5 x 5 inches totally 20 x 20 inches (Plate 6). The wax was coated on the both bottom and upper plates. The wax coated on the surface of plate prevents sticking of the composites on plate. Then the mixer of four different proportions are poured in the cavity. A roller the was used to roll on top to give some presser to remove the open pores and gaps on the cavity (Plate 7) and upper plate was placed on the bottom plate and closed with the help of fasteners and kept for curing for 24 hours. Then after 24 hours, the prepared Muntingia Calabura fibre reinforced composite were removed (Plate 8) and the specimen was removed using switch board cutter. Finally, the laminated composites, which was obtained in four different proportions (Plate 9) was named as 10 $NFCL^{MC}$, 20 $NFCL^{MC}$, 30 $NFCL^{MC}$ and 40 $NFCL^{MC}$.

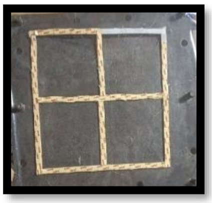


**PLATE 6 PLATE 7 PLATE 8 PLATE 9**
**CAVITY ON THE BOTTOM PLATE SETTING UP OF CAVITY AFTER CURING 24 HRS ECO-FRIENDLY MUNTINGIA CALABURA**

**FIBRE REINFORCED COMPOSITES**

**2.7 Evaluation**
Evaluation is the process of assessing the value or merit of the developed product. There are two types of evaluation. Subjective evaluation is an assessment that is based on personal feelings, tastes or opinions, rather than objective criteria. Objective evaluation refers to the impartial assessment of information or performance, relying on measurable criteria and data without personal biases.

**2.8 Visual Evaluation of Developed Fibre Reinforced Muntingia Calabura Fibre Laminate Composites**
The developed four 10 $NFCL^{MC}$, 20 $NFCL^{MC}$, 30 $NFCL^{MC}$ and 40 $NFCL^{MC}$ were shown to 250 students of Chikkanna Government Arts College, Tiruppur to get the feedback of the composites. The feedback was obtained for its surface finish, feel, laminate texture, durability, stress, overall evenness of the composite and general appearance of the composite was recorded under results and discussion.

**2.9 Mechanical Evaluation of Developed Fibre Reinforced Muntingia Calabura Fibre Laminate Composites**
The developed four 10 $NFCL^{MC}$, 20 $NFCL^{MC}$, 30 $NFCL^{MC}$ and 40 $NFCL^{MC}$ were subjected to mechanical evaluation for Tensile and Elongation tests, Compression test, SHORE D Hardness Test, Flexural test and FTIR tests.

## III. Results and Discussion
The assessed results for the developed eco-friendly fibre reinforced 10 $NFCL^{MC}$, 20 $NFCL^{MC}$, 30 $NFCL^{MC}$ and 40 $NFCL^{MC}$ composites are discussed below:

**3.1 Analysis of Visual Evaluation of Developed Fibre Reinforced Muntingia Calabura Composites**
The developed four Muntingia Calabura 10 $NFCL^{MC}$, 20 $NFCL^{MC}$, 30 $NFCL^{MC}$ and 40 $NFCL^{MC}$ composites which were shown to 250 students of Chikkanna Government Arts College, Tiruppur, to evaluate for their surface finish, feel, laminate texture, durability, stress, overall evenness of the composite and general appearance of the composite. From the Fig, 1, the results of the visual evaluation of developed Muntingia Calabura natural fibre composites show that 90% of the respondents rated as good for the surface finish. 100% of the respondents rated as smooth for the top and moderate for the bottom under feel of the composites; good for the laminate composite texture; has strong durability and the composite has good stiffness under stress. All the respondents rated moderate for the overall evenness of the composite and good for the general appearance of the composite.

**3.2 Analysis of Tensile and Elongation Tests**
The developed Muntingia Calabura natural fibre composites, for tensile and elongation tests for composites is a destructive test method that measures the strength and ability of a composite material to stretch (elongate) under tension. From Fig. 2, for tensile strength of composites 40 $NFCL^{MC}$ has the best tensile strength of 16.9 $N/mm^2$ followed by 30 $NFCL^{MC}$ and 20 $NFCL^{MC}$ having 12.83 $N/mm^2$ and 12.72 $N/mm^2$ respectively. The least tensile strength was noted in 10 $NFCL^{MC}$ as 12.23 $N/mm^2$. When elongation percent was noted, from Fig. 2, the best elongation was seen in 40 $NFCL^{MC}$ which had 36.80 % followed by 30 $NFCL^{MC}$ and 20 $NFCL^{MC}$ which had 26.64 % and 19.68 % elongation respectively. The composite 10 $NFCL^{MC}$ had more elongation of 18.20 %. Based on the results, 40 $NFCL^{MC}$ had the best tensile strength and good elongation percent.

**3.3 Analysis of Compression and Shore D Hardness Test**
The developed Muntingia Calabura natural fibre composite, for compressive strength test measures how much compressive force a material can withstand before breaking. From Fig. 3, it shows that 40

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NFCL$^{MC}$ has the best compression strength of 6.82 N/mm$^2$ before breaking followed by 30 NFCL$^{MC}$, 20 NFCL$^{MC}$ having 6.07 N/mm$^2$ and 5.31 N/mm$^2$. The least compression strength was noted in 10 NFCL$^{MC}$ showing 4.23 N/mm$^2$. Based on the results shown Fig. 3, in composite as fibre percentage increases and resin percentage decreases the compression strength increases. The developed Muntingia Calabura natural fibre composite in SHORE D hardness test measures the hardness of the composite materials, providing an indication of their resistant to indentation. From Fig. 3, it reveals that 40 NFCL$^{MC}$ has the best SDH of 69.2, followed by 30 NFCL$^{MC}$ having 67.8 SDH. The moderate hardness was seen in 20 NFCL$^{MC}$ having 47.9 SDH. The least hardness in composites was noted in 10 NFCL$^{MC}$ showing 43.9 SDH. Based on the results for composites seen in Fig. 3, as fibre percentage increases and resin percentage decreases the SHORE D hardness also increases.

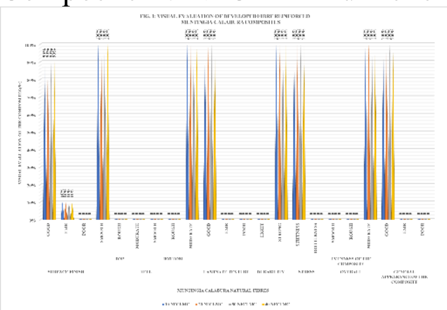
**3.4 Analysis of Flexural Test**

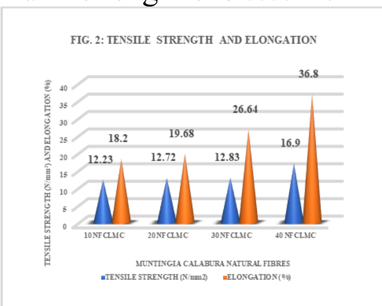
The results obtained for the developed four Muntingia Calabura 10 NFCL$^{MC}$, 20 NFCL$^{MC}$, 30 NFCL$^{MC}$ and 40 NFCL$^{MC}$ composites are shown in Table I.

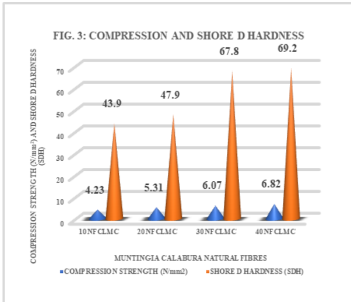
**TABLE I: FLEXURAL TEST**

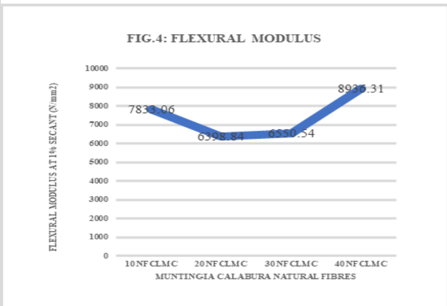
| MUNTINGIA CALABURA NATURAL FIBRE COMPOSITES | FORCE AT 1% (N) | DEFLECTION AT 1% (mm) | M (SLOPE) (N/mm) | FLEXURAL MODULUS AT 1% SECANT (N/mm$^2$) | MAX. FORCE (N) | FLEXURAL STRENGTH (N/mm$^2$) |
|---|---|---|---|---|---|---|
| 10 NFCL$^{MC}$ | 1.11 | 0.01 | 111.40 | 7833.06 | 193.65 | 96.83 |
| 20 NFCL$^{MC}$ | 0.91 | 0.01 | 91.01 | 6398.84 | 306.33 | 153.17 |
| 30 NFCL$^{MC}$ | 0.93 | 0.01 | 93.16 | 6550.54 | 401.69 | 200.85 |
| 40 NFCL$^{MC}$ | 1.27 | 0.01 | 127.09 | 8936.31 | 252.20 | 126.10 |

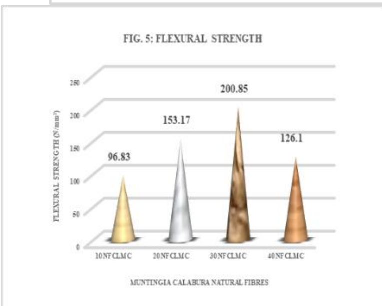
The relationship between flexural modulus and flexural strength, is that flexural modulus is the relationship between flexural strength and deformation. From the Table I and Fig. 4, bending modulus / flexural modulus shows that 40 NFCL$^{MC}$ had the best stiffness of 8936.31 N/mm$^2$, followed by 10 NFCL$^{MC}$ and 30 NFCL$^{MC}$ having 7833.06 N/mm$^2$ and 6550.54 N/mm$^2$ respectively. The lowest stiffness at 1% secant was seen in 20 NFCL$^{MC}$ by 6398.84 N/mm$^2$. When the composites were tested for flexural strength, from the Table I and Fig. 5, 30 NFCL$^{MC}$ had the best flexural strength of 200.85 N/mm$^2$, followed by 20 NFCL$^{MC}$ and 40 NFCL$^{MC}$ of 153.17 N/mm$^2$ and 126.10 N/mm$^2$ respectively. Composite 10 NFCL$^{MC}$ had the least flexural strength of 96.83 N/mm$^2$.

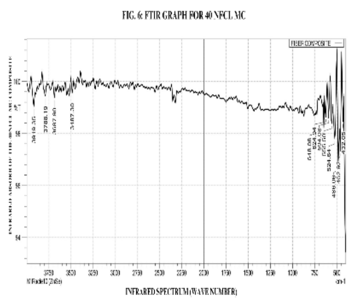





**3.5 Analysis of FTIR Test**

The FTIR test was conducted on the 40 $NFCL^{MC}$ composite which had the best tensile strength and good elongation to find out the chemical composition of a composite sample. 40 NFCL $^{MC}$ composite specimen was selected because it also showed best performance in compression strength, hardness, flexural modulus/bending modulus and flexural strength. Peak position indicates the type of chemical bond or functional group that absorbs light and the peak shape usually indicate a pure compound, while broad peaks may indicate a complex mixture. The peak intensity indicates the relative amount of a substance present. The FTIR result obtained for the 40 $NFCL^{MC}$ composite is depicted here in Fig. 6.
From Fig. 6, it reveals that the two peaks at 3687.90 cm-1 and 3487.30 cm-1 are associated with the O-H stretching. The bands at 648.08 cm-1, 624.94 cm-1, 594.08 cm-1 and 555.50 cm-1 are characteristics of C-Cl stretching. The peak at 524.64 cm-1 is attributed to the C-Br stretching. The FTIR test also revealed that the composite spectrum, for its absorbance peak refers the presence of O-H stretching of hydroxyl group, C-Cl stretching of chloride group and C-Br stretching of alkyl halide group.

## IV. Summary and Conclusion

A composite is a material made from two or more different materials that, when combined, are stronger than individual materials by themselves. A composite material can be referred to as any material consisting of two or more components with different properties and distinct boundaries between them. Moreover, the idea of combining several components to produce a material with properties that are not attainable with an individual component has been used by man for thousands of years. Correspondingly, the majority of natural materials that have emerged as a result of a prolonged evolution process can be treated as composite materials describes Vasiliev and Morozov (2013). Composite materials can possess a combination of properties from each of constituting materials (i.e., metals, ceramics, and polymers) or create new properties and hence exhibit superior or unique properties, usually as light but strong and stiff materials. Wang and Zhao (2018) asserts properties of composites can be controlled by changing the ratio of constituting materials, their features and the interface.
Engineers use flexural modulus to design safe and effective products and structures. Architects use flexural modulus to select materials for load-bearing applications. Fibre-reinforced composites have gained much importance now-a-days in the aerospace industry due to their low weight and superior mechanical properties. Natural fibre and bio-composite materials present considerable environmental benefits due to their biodegradability. Owing to their low cost and high specific mechanical properties, have future prospects in the aerospace industry, mainly in the interior parts of the aircrafts. Europe is expected to remain the largest market for natural fibre reinforced composites due to high acceptance of environmentally friendly materials by automotive, government, and small-scale industries. The growth of natural fibre reinforced polymer composites in electrical, electronics, and sporting segments is driven by improvements in materials performance. The potential for a strong market share in these sectors is significant.
Incorporating fibres or fabrics as reinforcement with resins is an effective approach for preparing high-performance composites that can be used as suitable replacements for traditional engineering materials such as steel and concrete. The resulting materials are called textile composites with excellent characteristics, such as lightweight, high specific strength, and high specific modulus claims Zhao *et al* (2023). Matveev and Long (2015) mentions textile composites, which are a combination of polymer matrix and textile reinforcements, provide an attractive alternative to unidirectional (UD) composites as they enable easier and automated manufacturing of complex component shapes. Ease of draping results in lower overall manufacturing costs. The large variety of available textile reinforcements, which includes woven, braided and knitted fabrics, offers a large choice of engineering solutions.
Fibre reinforced composites offer significant advantages due to their high strength-to-weight ratio, customizable mechanical properties, corrosion resistance, and design flexibility, making them ideal for diverse applications across industries like aerospace, automotive, construction, and medical devices;

however, careful consideration of the fibre-matrix interface, manufacturing processes, and potential environmental impacts is crucial for optimal performance and sustainable use.

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