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# EVALUATION AND COMPARISON OF MECHANICAL PROPERTIES OF NATURAL FIBRE COMPOSITES

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**ABSTRACT**
Natural fibre composites are gaining interest as a replacement for more conventional composites, as they are easily available, cheap, environmental friendly and possess excellent strength. The present study deals with evaluating the mechanical properties of natural fibre epoxy composites made up of jute and banana fibres separately. These natural fibres were subjected to alkali pre-treatment in NaOH solution, following which they were ground into smaller fibres. Three distinct lengths of banana fibres were separated by sieving, whereas, this was not possible for jute in which the fibres could not be separated. Moulds for the composites were created as per ASTM standards. Fibres were mixed with appropriate quantities of epoxy and hardener and poured into their respective moulds to create the composites. After curing, specimens were removed from their moulds and subjected to tensile and flexural testing. It was found that in both tensile and flexural tests, short banana fibre reinforced epoxy composite performed better than long and medium banana fibre reinforced epoxy composites as a result of high surface area -to-volume ratio. Jute also showed good mechanical strength due to the spun-like fibres produced after grinding, also resulting in higher surface area-to-volume ratio, and thus, better adhesion with the epoxy matrix.

**Keywords:**
Natural fibre reinforced composites, jute fibre, banana fibre, mechanical properties, epoxy matrix

## INTRODUCTION

Composites are materials that are made up of two or more different substances, in a manner such that the components are distinct in the resulting material. The main purpose of composites is to combine advantageous properties of two or more materials such that the composite formed from their combination has properties superior to those of the parent substances.

### Natural Fibre Composites

Natural Fibre Composites (NFCs) are polymer composites, which use natural fibres as the reinforcement phase, embedded into a system of polymer resin as matrix. A variety of natural fibres are available, which include sisal, jute, banana, cotton, wool, bamboo, abaca, and wood.

The increase in environmental consciousness, new regulations on natural resources, and an unsustainable consumption of petroleum and other conventional resources has led the world to make a shift over to the use of natural fibres, and Natural Fibre Composites (NFC) in general.

Although much lower in strength, when compared to the synthetic fibres like carbon and graphite, when used in proper proportion with respect to epoxy in the matrix, and appropriate size, these natural fibre composites have a strength comparable to their synthetic counterparts, and plus have an added advantage of being 100% biodegradable, causing no harm to the environment. The synthetic fibres like carbon in some cases could be of corrosive nature to other reinforced phases, like steel, which could be an expensive option to go for. Apart from this, natural fibres are cheaper and more easily available than synthetic fibres.

### Literature review

Chandramohan et al. (2017) performed a study of hybrid polymer composites made of powdered coconut shells, walnut shells and rice husk was performed in a bio-epoxy resin. On performing tests to ascertain tensile, flexural, shear and impact strengths as per ASTM standards, it was found that, across the board, hybrid walnut shell and coconut shell composites performed better, and hybrid composites, in general, had better performance than single material composites.

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Willems and Bonten et al. (2015) studied the influence of processing on fibre length degradation and fibre reinforced plastics. A very low significant influence of process parameters on mechanical properties were found , also for specimens with higher fibre content, the fibre length degradation is dominated by fibre-fibre interaction.
Ferreira et al. (2010) performed tensile and flexural tests based on ASTM D638 and ASTM D790 respectively, on hemp fibre reinforced composites and pine sawdust reinforced composites. The matrix used was polypropylene and studied the effect water immersion on mechanical properties. It was found that in 4 point flexural testing, the stiffness modulus increases with an increase in fibre content, and in tensile testing the strength shows a decreasing tendency with increasing fibre content. Water degradation effect was observed in pine sawdust composites only after 20 days.
Md. Ashraful Alam et al. (2017) reinforced the concrete beam with NFRP ( Natural Fibre Reinforced Polymers ) laminates , and studied the change in properties , this was done in place of CFRP laminates,which are expensive and lead to corroion of steel plates. The beams with natural fibre composite plates had shown higher ductility and higher failure load when compared to CFRP laminates.
Mejri et al. (2017) studied the effect of hygrothermal ageing on natural composite made of high density polyethylene (HDPE) and 40%wt of short birch fibres. Flexural quasi-static tests showed no significant change in flexural mechanical properties between aged and unaged specimens. Bending fatigue tests showed that ageing reduced high cycle fatigue strength of the composites. A possible cause for this is the swelling of birch fibres due to immersion in water.

**Knowledge Gained from Literature**

From the literature review, it was possible to ascertain that it is feasible to produce and study natural fibre reinforced polymer composites as they are viable alternatives to conventional ones. Natural fibre composites are environmental friendly, strong, easily available and cheap. The requirement of alkaline treatment for natural fibres, with 5% NaOH solution in order to enhance the mechanical properties and interfacial bonding between fibres and epoxy was understood. The fact that the characteristics of the natural fibre composite would change depending on the fibre length was identified. It was also found that hybrid composites, comprising of natural and synthetic fibres considerably enhance mechanical properties of the composites, while balancing the economy of production of the composites. Suitable raw materials, particularly jute and banana fibres, apart from carbon fibres were also identified. The ASTM D790 standard for tensile testing and flexural testing were found to be suitable for the project.

**Gaps in Literature**

From the literature reviewed on natural fibre reinforced polymer composites, it was found that scarce work has been done to study the variation of mechanical properties of the composites by varying the fibre length. Further, there is also a lack of quantitative comparison of mechanical properties between the natural fibre composites. It was also found that the most common fabrication process for these composites was by hand lay-up. Thus, the present work aims to address these important factors as it will be beneficial to understand and compare the variations of mechanical properties of natural fibre reinforced polymer composites particularly by varying the fibre length, by using the method of moulding instead of the hand lay-up process.

**Problem Statement**

To process, fabricate and perform tests on moulded epoxy composites made up of natural fibres, particularly jute and banana fibres and compare their respective mechanical properties. Further, determine relationship between fibre length and mechanical strength in banana fibre reinforced epoxy composites and study the fibres under a microscope. Also to apply a different method of fabrication, namely moulding, instead of the hand lay-up technique which is most often used in fabrication of composites.

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**METHODOLOGY**

This section deals with the understanding of the methodology and procedures implemented in this project. The project execution stages are enlisted in the flowchart depicted in Fig. 1.

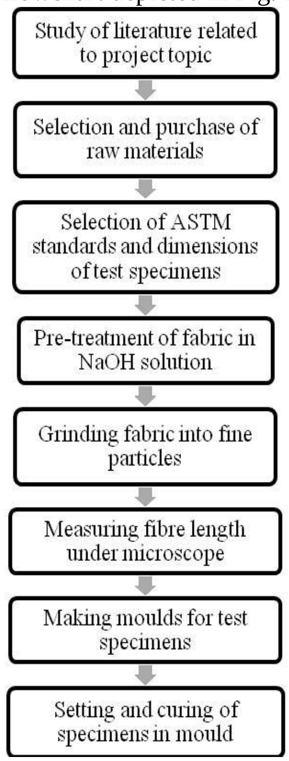


***Fig. 1: Flow-chart of project execution stages***

Literature related to the topic were identified and read in order to understand the project topic in depth and to possibly identify steps that would be involved in project execution. Following this the raw materials required were finalized and purchased. Appropriate ASTM standards were found as per the project requirements and dimensions of the tensile and flexural test specimens were determined. All the natural fibres were pre-treated by soaking in NaOH solution of 5% concentration. Samples were dried and ground into fine particles and sieved to appropriate lengths. Fibre lengths were then measured with the help of microscope. 2% wt of fibre with respect to epoxy was measured and mixed with 10% vol of hardener and poured into moulds of appropriate dimensions of tensile and flexural testing. Moulds were allowed to cure and tests were carried out.

**ASTM Standards and Specimen Dimensions**

ASTM D7205 standard has been used for tensile specimens of jute fibre, short banana fibre, medium banana fibre and long banana fibre reinforced epoxy composites prepared in the project. Fig.2 shows the tensile samples prepared. The dimensions used for tensile testing have been mentioned below. Overall length : 250 mm

Width : 25 mm
Thickness : 2.5 mm
Span length : 150 mm

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*Fig. 2: Tensile specimens prepared as per ASTM D790*

Flexural testing samples of jute fibre, short banana fibre, medium banana fibre and long banana fibre reinforced epoxy composites have been prepared on the basis of ASTM D790 standard. Fig. 3 shows the prepared flexural samples. The dimensions used for flexural testing have been mentioned below. Overall length: 80 mm
Width : 10 mm
Thickness : 4 mm
Span length : 70 mm

**Alkali Pre-Treatment of Natural Fibres**

Woven fabric of both banana and jute fibres were cut into 25 $cm^2$ sheets. The sheets were washed in water and dried. Subsequently, they were soaked separately in 5% wt NaOH solution in water for 3 hours. On completion of this duration, they were removed from the solution and washed once again in water. The fabrics were allowed to dry overnight under ambient conditions.

**Grinding of Fibres and Measurement of Fibre Length**

The pre-treated fabric is cut into smaller pieces and ground in the mixer-grinder.Grinding resulted in the breakdown of fabric into smaller particles, suitable for moulding in epoxy. The fibres were further sieved in a sieve shaker in order to get different sizes. After the natural fibres are ground and sieved into various sizes, the fibre-length is measured using microscope. Fig.4, Fig.5 and Fig.6 are the microscopic images of the three different sizes of banana fibres produced by sieving.

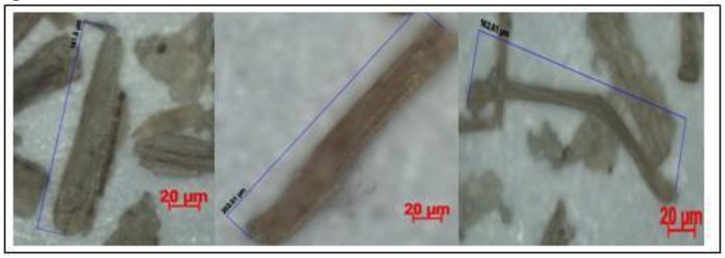


*Fig. 3: Microscopic images of short banana fibres*

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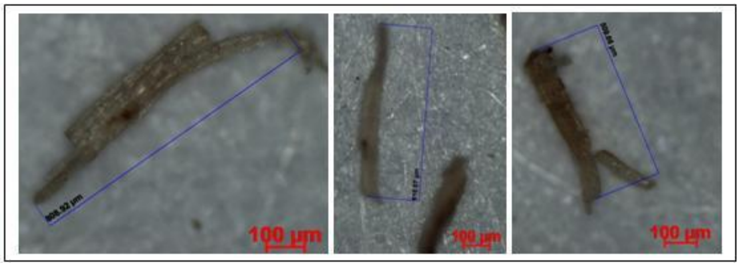


*Fig. 4: Microscopic images of medium length banana fibres*

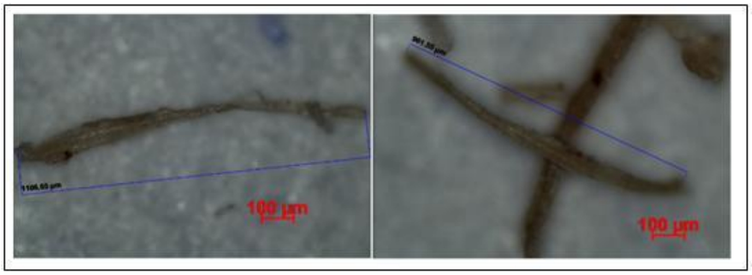


*Fig. 5: Microscopic images of long length banana fibres*

The average fibre length of short banana fibre is found to be 168.81 micrometer. The average length of medium length banana fibre is found to be 648.88 micrometer. The average length of long banana fibre is found to be 1034.1 micrometer. On viewing jute fibre under the microscope, it was clear the grinding and sieving resulted in spun-like fibre being formed where distinct fibres could not be isolated to measure fibre length. Fig.7 is the microscopic image of jute fibre.

*Fig. 6: Microscope image of jute fibre*

**Setting and Curing of Test Specimens in Mould**

On the creation of moulds, 2% wt of ground fibre (both banana and jute, separately) with respect to a given volume of epoxy was weighed and kept aside. Hardener at about 10% volume of epoxy was measured and poured into the epoxy and stirred vigorously. The epoxy-hardener mixture was then poured into a bowl, along with the weighed fibres. Stirring was continued till a homogeneous mixture was created. Fig. 2.9 is a representation of tensile and flexural specimens being cured in their moulds. Simultaneously a very thin layer of wax was applied on the walls of the moulds in order to allow for easy removal of cured specimens. The mixture thus created, was poured into the moulds evenly. The moulds were allowed to set for 48 hours, following which the specimens were removed from the moulds and tested.

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## RESULTS AND DISCUSSION

The results generated from tensile and flexural testing have been elaborated in detail. Corresponding stress-strain graphs have been plotted for each specimen. In addition, a comparative study of the results obtained with respect to jute and banana fibres in epoxy composites is attempted. Finally, the results obtained are discussed in depth to understand the properties and their variations in the different materials being tested.

### Tensile Test

The results from tensile testing of all the specimens are represented graphically and mechanical properties have been tabulated in this section.

#### Tensile Test on Jute Fibre Epoxy Composite

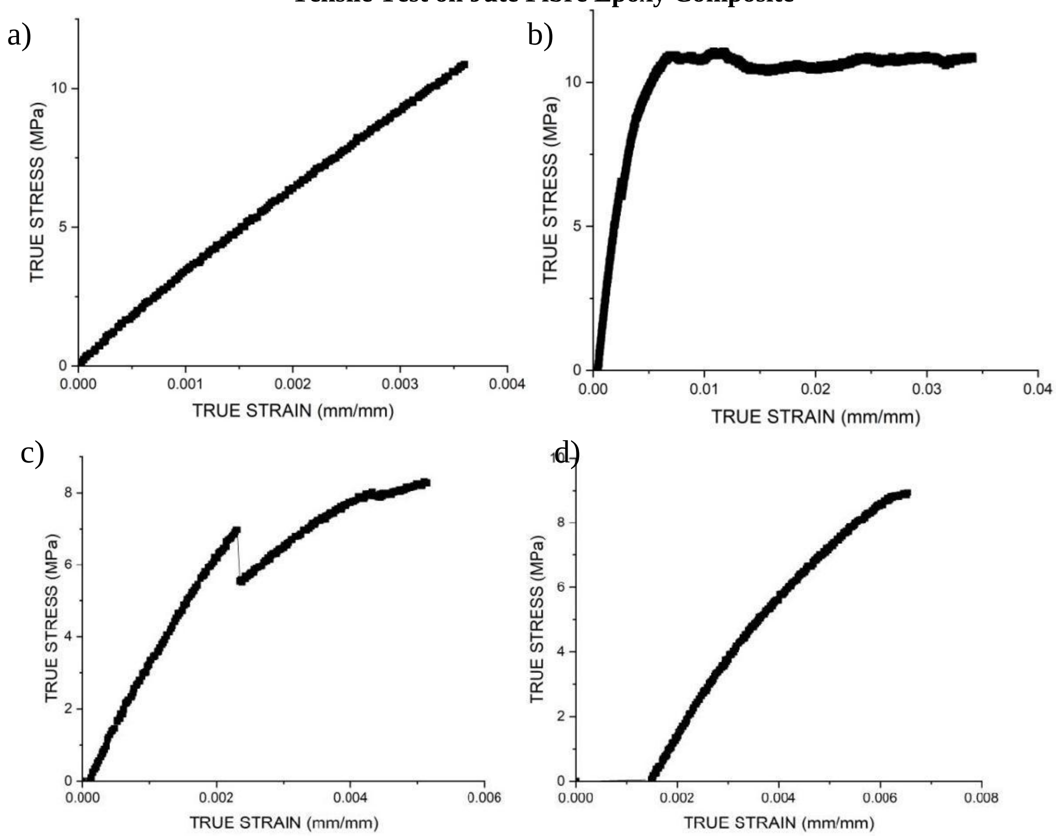


*Fig. 8: Stress-strain graphs for jute specimens a) Jute 1 b) Jute 2 c) Jute 3 d) Jute 4*

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*Table 1: Tensile test results for jute specimens*

| | ULTIMATE TENSILE STRESS (MPa) | YIELD STRENGTH (MPa) | DUCTILITY (%) |
|---|---|---|---|
| **JUTE 1** | 10.855 | 6.408 | 0.36 |
| **JUTE 2** | 11.075 | 5.173 | 1.08 |
| **JUTE 3** | 8.299 | 6.199 | 0.51 |
| **JUTE 4** | 8.933 | 5.375 | 0.65 |

**Tensile Test on Short Banana Fibre Epoxy Composite**

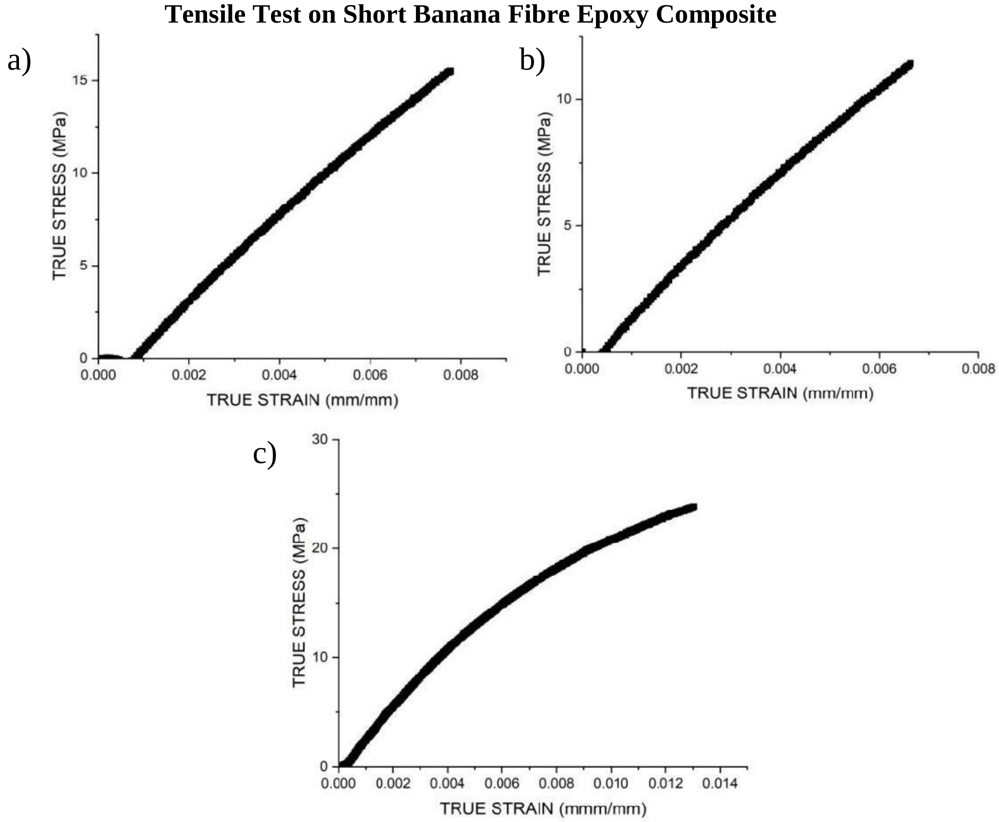


***Fig. 9: Stress-strain graphs for banana (short fibre) specimens a) Short 1 b) Short 2 c) Short 3***

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*Table 2: Tensile test results for banana (short fibre) specimens*

| | ULTIMATE TENSILE STRESS (MPa) | YIELD STRENGTH (MPa) | DUCTILITY (%) |
|---|---|---|---|
| **SHORT 1** | 15.531 | 3.084 | 0.77 |
| **SHORT 2** | 11.424 | 3.421 | 0.66 |
| **SHORT 3** | 23.822 | 5.489 | 1.3 |

**Tensile Test on Medium Banana Fibre Epoxy Composite**

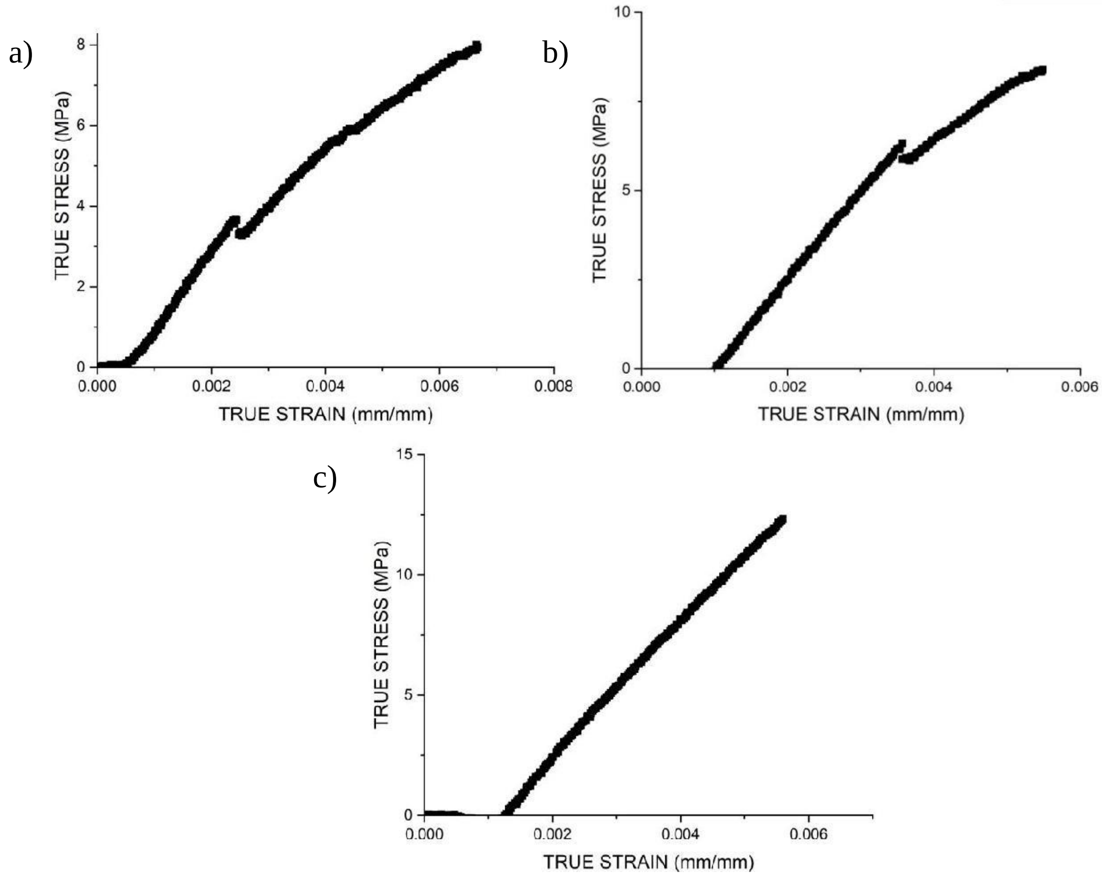


***Fig.10: Stress-strain graphs for banana (medium fibre) specimens a) Medium 1 b) Medium 2 c) Medium 3***

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*Table 3: Tensile test results for banana (medium fibre) specimens*

| | ULTIMATE TENSILE STRESS (MPa) | YIELD STRENGTH (MPa) | DUCTILITY (%) |
|---|---|---|---|
| **MEDIUM 1** | 7.9967 | 2.8654 | 0.66 |
| **MEDIUM 2** | 8.3836 | 2.4969 | 0.55 |
| **MEDIUM 3** | 12.3302 | 2.4134 | 0.56 |

**Tensile Test on Long Banana Fibre Epoxy Composite**

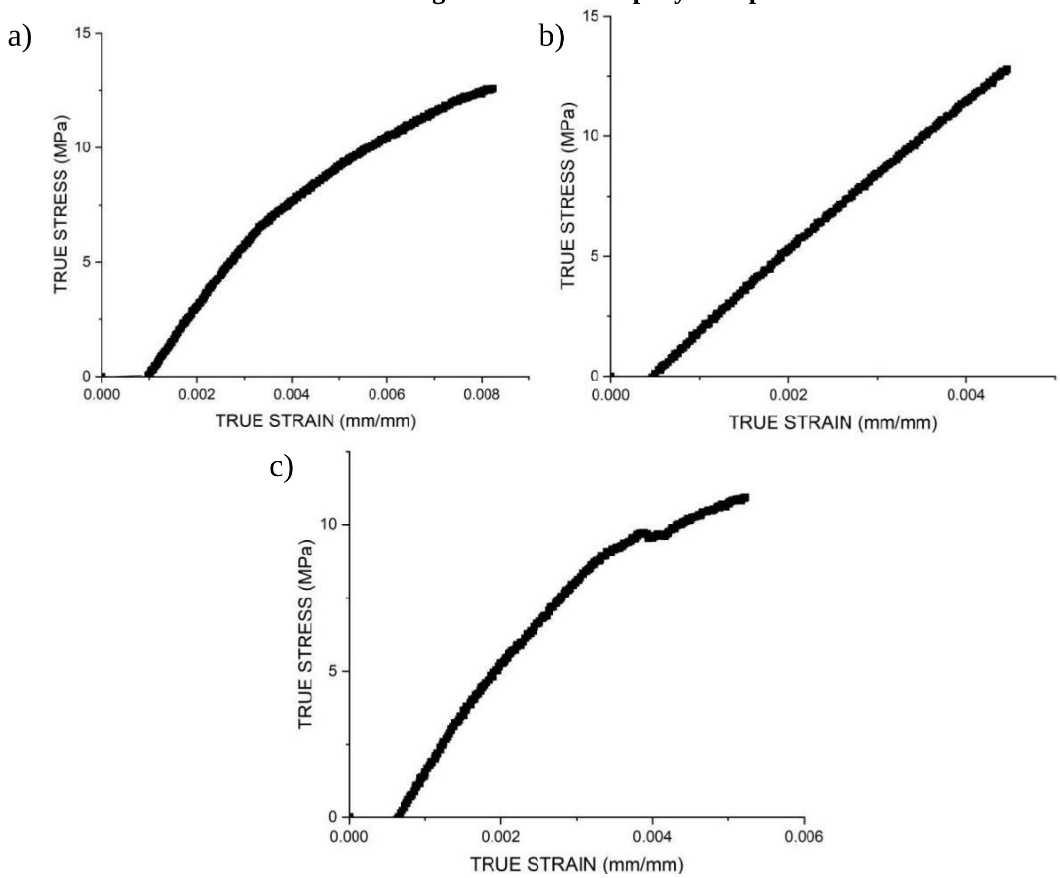


***Fig. 11: Stress-strain graphs for banana (long fibre) specimens a) Long 1 b) Long 2 c) Long 3***

*Table 4: Tensile test results for banana (long fibre) specimens*

| | ULTIMATE TENSILE STRESS (MPa) | YIELD STRENGTH (MPa) | DUCTILITY (%) |
|---|---|---|---|
| **LONG 1** | 12.577 | 3.061 | 0.82 |
| **LONG 2** | 12.769 | 5.25 | 0.44 |
| **LONG 3** | 10.939 | 5.489 | 1.3 |

**Flexural Test**

The results from flexural testing of all the specimens are represented graphically and mechanical properties have been tabulated in this section.

**Flexural Test on Jute Fibre Epoxy Composite**

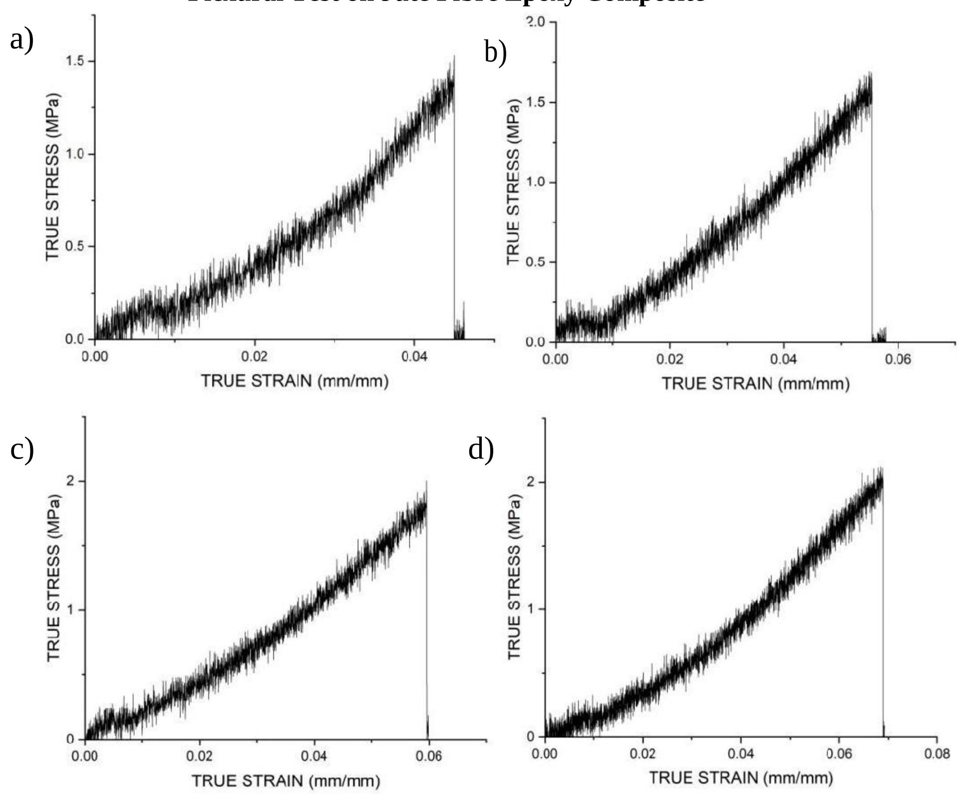


*Fig. 12: Stress-strain graphs for jute specimens a) Jute 1 b) Jute 2 c) Jute 3 d) Jute 4*

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*Table 5: Flexural test results for jute specimens*

| | ULTIMATE FLEXURAL STRESS (MPa) | YIELD STRENGTH (MPa) | DUCTILITY (%) |
|---|---|---|---|
| **JUTE 1** | 1.5314 | 0.11956 | 4.4498 |
| **JUTE 2** | 1.6887 | 0.0898 | 5.495 |
| **JUTE 3** | 2.0022 | 0.160207 | 5.95 |
| **JUTE 4** | 2.121 | 0.0937 | 6.85 |

**Flexural Test on Short Banana Fibre Epoxy Composite**

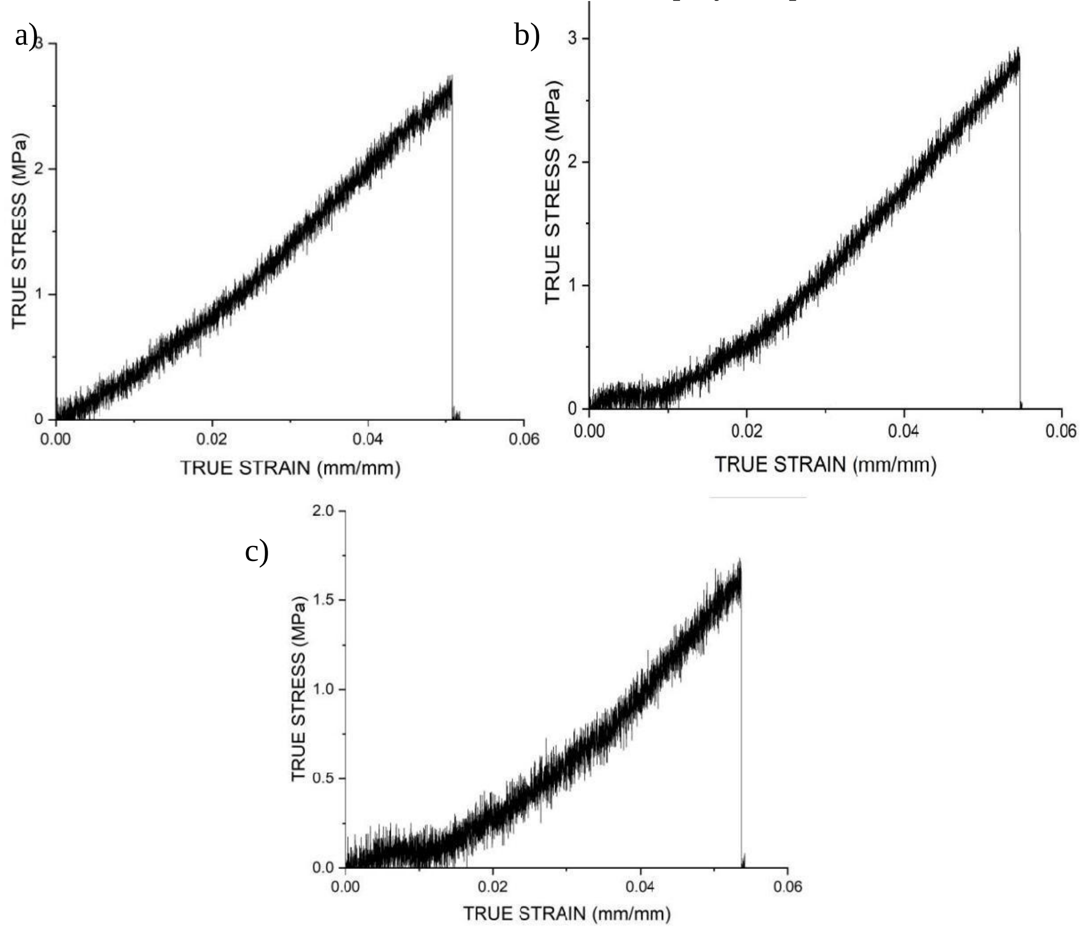


*Fig. 13: Stress-strain graphs for banana(short fibre) specimens a) Short 1 b) Short 2 c) Short 3*

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*Table 6: Flexural test results for banana(short fibre) specimens*

| | ULTIMATE FLEXURAL STRESS (MPa) | YIELD STRENGTH (MPa) | DUCTILITY (%) |
|---|---|---|---|
| **SHORT 1** | 2.75 | 0.0507 | 5.07 |
| **SHORT 2** | 2.933 | 0.0544 | 5.44 |
| **SHORT 3** | 1.7367 | 0.0534 | 5.34 |

**Flexural Test on Medium Banana Fibre Epoxy Composite**

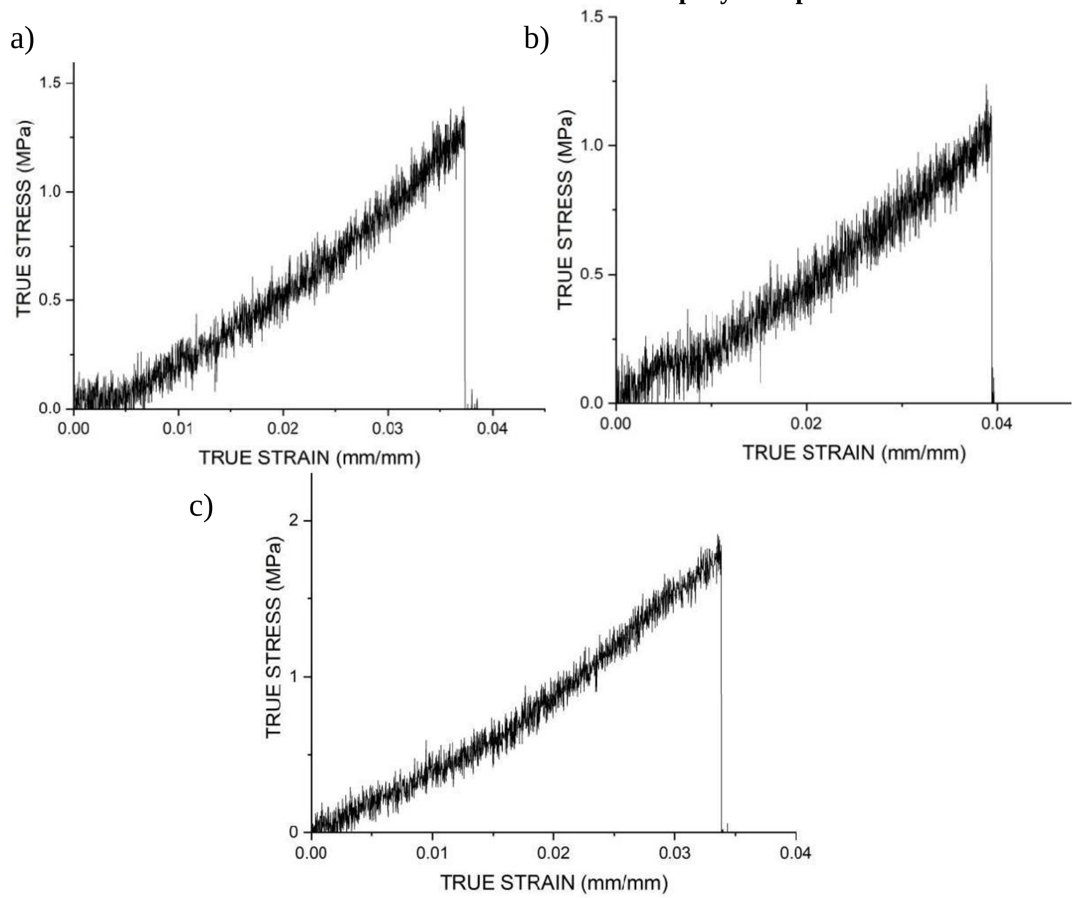


*Fig. 14: Stress-strain graphs for banana (medium fibre) specimens a) Medium 1 b) Medium 2 c) Medium 3*

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*Table 7: Flexural test results for banana (medium fibre) specimens*

| | ULTIMATE FLEXURAL STRESS (MPa) | YIELD STRENGTH (MPa) | DUCTILITY (%) |
|---|---|---|---|
| **MEDIUM 1** | 1.39285 | 0.11702 | 3.72 |
| **MEDIUM 2** | 1.2375 | 0.1128 | 3.88 |
| **MEDIUM 3** | 1.9138 | 0.1374 | 3.35 |

**Flexural Test on Long Banana Fibre Epoxy Composite**

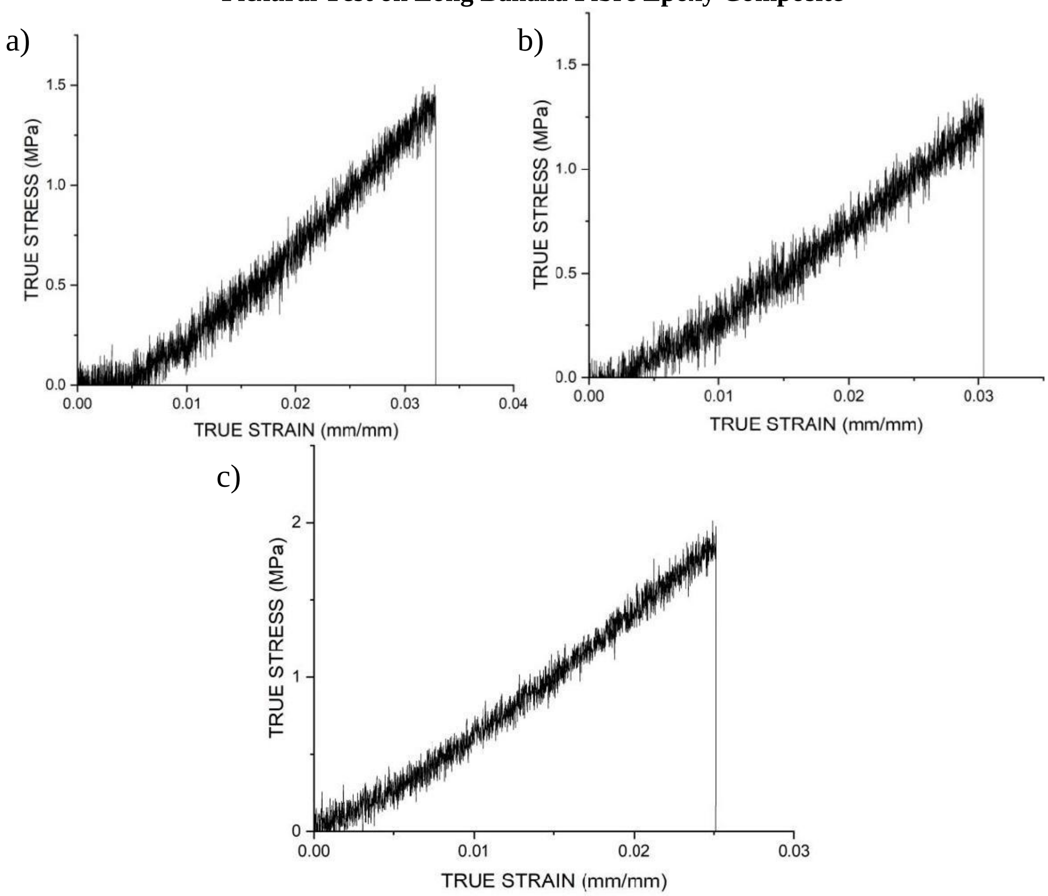


*Fig.15: Stress-strain graphs for banana (long fibre) specimens a) Long 1 b) Long 2 c) Long 3*

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*Table 8: Flexural test results for banana (long fibre) specimens*

| | **ULTIMATE FLEXURAL STRESS** (MPa) | **YIELD STRENGTH** (MPa) | **DUCTILITY** (%) |
|---|---|---|---|
| **LONG 1** | 1.5017 | 0.0328 | 3.28 |
| **LONG 2** | 1.3635 | 0.0298 | 2.98 |
| **LONG 3** | 2.0125 | 0.0249 | 2.49 |

## Discussion

Having performed the requisite testing on the samples, it is important to infer the reason behind the results that have been generated. This section is an attempt to discuss the test results in detail and provide and explanation as to why the results are as they are. It is important to add that the use of the moulding technique instead of the hand lay-up technique for fabrication was found to be easy, requiring no special equipment and machining and is also less time consuming.

### Tensile Test Results - Discussion

From the tensile test results, it is found that on an average, the Ultimate Tensile Stress of short banana fibre reinforced epoxy composite is much higher than that of long and medium banana fibre reinforced epoxy composites. This is a result of the high surface area-to-volume ratio of the short fibres, resulting in better adhesion with epoxy matrix, causing improved mechanical properties. The Ultimate Tensile Stresses of long and medium banana fibre reinforced epoxy composites are comparable because if the length of fibre is increased beyond a threshold value, changing fire length has negligible effect on the mechanical properties of the material. Jute fibre reinforced epoxy composite is also found to possess high Ultimate Tensile Stress because of the spun-like nature of the fibres produced. This is attributed to high surface area-to-volume ratio of the spun-like fibres.

The ductility of short banana fibre reinforced epoxy composite is found to be higher than both long and medium banana fibre reinforced epoxy composites. This is, once again, be a result of high surface area-to-volume ratio of the former.

### Flexural Test Results - Discussion

It has been found from the results that the Ultimate Flexural Stress of short banana fibre reinforced epoxy composite on an average is considerably higher than that of medium and long banana fibres. This can be attributed to the fact that the short fibres have high surface area-to-volume ratio, resulting in improvement of mechanical properties of this material with respect to longer fibres. The Ultimate Flexural Stresses of long and medium banana fibre reinforced epoxy composite are comparable in nature as beyond a certain threshold of fibre length, the mechanical properties do not show a significant difference. Further the Ultimate Flexural Stresses of long and medium banana fibre reinforced epoxy composites are much lower than that of short banana fibre reinforced epoxy composites. Jute fibre reinforced epoxy composite shows high flexural strength as a result of the spun-like nature of the fibre produced, leading to high surface area-to-volume ratio and thus, better adhesion of fibres to the matrix.

With respect to ductility too, a similar trend has been observed, wherein short banana fibre reinforced epoxy composite shows higher ductility than medium and long banana fibre reinforced composite. The results can be attributed to the fact that as fibre length decreases, the surface area-to-volume ratio increases, resulting in better adhesion of the fibre reinforcement with the matrix, and thus, improved mechanical properties. Also, beyond a certain threshold of fibre length, any increase in fibre length does not necessarily equate to considerable changes in the measured properties.

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## CONCLUSION

In the experimental study of natural fibre composites, the processing, fabrication and testing (tensile and flexural) of the composites made up of jute and banana fibres as reinforced phase, and epoxy as matrix was carried out by moulding them, and a number of properties observed. Pure epoxy samples were fabricated and tested likewise to be used as a reference for testing. While banana fibres with three different lengths of fibres, were used for fabrication and testing, only one kind of jute fibre was used, as it was not possible to obtain different fibre lengths for jute, because of the spun formation of jute fabric while grinding. The results of tensile and flexural testing show a trend where the banana fibre composites with short length (150-200 microns) have a higher strength than all other kinds of fibres tested. This can be attributed to the high surface area-to-volume ratio of these fibres. The strength of long and medium length banana fibre composites was found to be comparable. This can be attributed to the fact that beyond a certain threshold of fibre length, any increase in the length would have no substantial effect on the mechanical properties of the material. Jute fibre reinforced epoxy composites were found to show good mechanical properties which is a result of the spun formation of the fibres on grinding. This increases the surface area-to-volume ratio of the fibres, resulting in better adhesion to the epoxy matrix.

The fabrication process used in this project is distinct from those previously used. From literature, it was found that the most popular fabrication process was the hand lay-up technique. However, in the current study, moulding technique was used, wherein fibres along with the requisite amounts of epoxy and hardener were mixed together and poured into their respective moulds and allowed to cure. This fabrication process was found to be considerably less time consuming, requiring very little pre or post-processing of the composites that were formed at the required dimensions with good surface finish, without the need for further machining.

As a result of this project, it was found that natural fibre reinforced polymer composites can play an important role in the material sciences with further improvements and fine-tuning of their fabrication and design procedure. In fact, they can closely compete with synthetic fibre reinforced polymer composites in certain applications. In a world moving towards ecological sustainability and minimum-wastage production and design practices, the use of natural fibre reinforced composites can be a big step towards a more environmental friendly planet.

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