Experimental investigation on compression and bending properties of epoxy composites reinforced with $\text{Al}_2\text{O}_3$, kenaf/hemp fibers for orthopaedic implants

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Abstract. Composites in medical sectors are effective and productive phenomena in fulfilling various necessary demands. Through proven results as a base, this technique can be used for further research to enhance the existing parameters. In this connection, present research extensively focuses upon studying the mechanical properties (Compression and Bending) and characterization of fibre reinforced composite materials along with $\text{Al}_2\text{O}_3$ as filler materials. Present study involves the investigation of mechanical properties like compression and bending for NFRPC (Natural Fiber Reinforced Polymer Composite) as bio material, Epoxy resin-LY556 as matrix material, using suitable hardener and natural fibers (Kenaf/Hemp) as reinforcement materials considering $\text{Al}_2\text{O}_3$ as filler material with appropriate percentage to enhance strength and hardness of the composites. Prepared specimens were subjected to (Compression/D-3410 and Bending/D-790) examinations. Later they were compared with the femur bone properties. It was noticed that NFRPC properties will match the femur Bone Strengths and results shows 12, 18 & 24% of NFRPC material are appropriate for orthopaedic implants. From the investigated results finally, it concludes that the mechanical properties like compression and bending will be increased with increasing proportion of fiber in composites.

1. Introduction

In growing demand to meet the industrial needs for satisfying applications to bridge the various operations, the technology in unearthing the newer and their combinations of materials will have a prominent and vital role to assure for successful functioning. Currently Industries are focusing upon choosing the consistent and suitable materials for their specific services considering technically beneficiable aspects interms of both effectiveness and suitable application. Composites are generally known process for materials combination and their successful blending to extract the required application in various fields like automobile, aerospace, defence, medical, Etc [1]. Composite oriented materials have entered into the expanded fields yielding attractive results in connection with satisfying serviceable products by various processes. In research fields composite materials are in great demand for innovative material combination for successful scope in the respective areas of investigations [2].

Now-a-days NFRPC is widely adopted in various fields because of its ample advantages. The primary reason for choosing these materials is because of its eco-friendly nature, recyclability and biodegradability [3]. NFRPC are chosen to use in the various manufacturing industries like automobile, medical, household appliances etc. natural fiber are referred to the fibers which are...
extracted from natural resources like plant [4]. Natural fibers exhibit stronger properties when compared with the artificial fibers. Low density, low weight, eco-friendly nature is some of the dynamic properties of natural fiber [5].

2. Literature survey

D Chandramohan They suggested to use the benefits provided by the renewable resources & their application in the stream of orthopaedic because NFRPC (Natural fiber reinforced polymer composite) plates will have faster fracture healing capacity and they provide suitable environment for the growth of the bone which results in increasing bone density [6]. Ribot et.al they came to know that the kenaf base fiber has got more strength than the natural fibers like jute, sisal etc. The kenaf fiber has got tensile strength of rage 400-550Mpa. So, the kenaf fiber will fall into the group of good reinforcement material, hence in polymer composite material it can be used as reinforcement material and it has got all the required properties [7]. Giuseppe Cristaldi et.al during their research on composite material they concentrated on the natural fibers and their uses, and they chose it has reinforcement material in composite. Most of the researchers will employee this as reinforcement because of their environmental and cost-effective property. Even it has got his own limitation and which need to be overcome for proper utilisation of this [8]. Hajnalkahargitai et.al on his work and as well as by considering the mechanical test it is concluded that 40-50% of hemp fiber is optimum and dry composite samples has got fewer bending properties than the wet sample [9]. Girisha.C et.al while carrying their research work, the investigation is carried out on the composite which are fabricated with sisal, coconut spath as reinforcing material for testing the tensile properties. The alkali treatment is carried out on the natural fibers which are extracted by manual as well as retting process. Composite with a reinforcement of natural fiber of individual type shows less tensile strength when compared to reinforcement of hybridization type [10].

H G Hanumantharaju et.al from his research work he concluded that the alumina can be used as substitute material for bone in the field of orthopaedic based on the following consequence’s i.e., the density and as well as the mechanical property of the Ti-6Al-4V is less and better than SS316L respectively. If we considered the test like wear test alumina exhibit less weight loss than the SS316L. In case of weight SS316L is more weight when compare to the alumina. It also exhibits low material density [11]. Mohammed Haneef et.al they have concluded that if the percentage of reinforcement increases in the hybrid polymer composite, then there will be increase in the strength like hardness, tensile and bending. The density of hybrid polymer composite also increases. If the TiO₂ and Al₂O₃ used along with the polymer matrix compositewill have plenty of utilization in the human body [12]. Ramesh K et.al for the improvement of mechanical property they have used the Al₂O₃, SiO₂ and TiO₂for modifying the matrix. Hand lay-up method is used for the manufacturing of composite material. The other micro modifiers will exhibit less ILSS, flexural strength and modulus when compared with the SiO₂ modified epoxy composite [13]. Rajesh et .al with the various proportion of SiC and Al₂O₃ with GFRP by using the silicon carbide and aluminium oxide they have manufactured the composite with epoxy and polyester resin. To identify the properties of composites which are fabricated the various tests are conducted like shear bi axial, tensile, impact etc. finally they arrived to a conclusion that the polyester resin composite will show less strength when compare to the epoxy resin composite [14]. Pavan kumar.et.al they carried a research work to study the GFRP mechanical properties with the white cement as filler material by varying its weigh percentage like 0.5,10wt% by hand layup fabrication method. The specimens were prepared according to the standards (ASTM) and later they are subjected to the various tests. Upon conducting the test, they arrived to the conclusion that the filler material (white cement) also influences the mechanical properties of composite such as flexure and tensile strength [15].

3. Methodology

The methodology is followed by complete survey of published literature related to present work. Characterization is carried out using Epoxy resin as a matrix material & hardener with (12, 18, 24%) Natural fibers as the reinforcement the specimens are prepared along with Al₂O₃ as filler material [16], the samples are done as per ASTM and finally concluding the results.
4. Properties (Mechanical) of Femur Bone

![Distribution of stress on Femur Bone.](image)

**Figure 2.** Distribution of stress on Femur Bone.

| Mechanical Test | ≤ 30Yrs. | 31-50Yrs. | 51 – 70Yrs. | ≥ 70Yrs. |
|-----------------|----------|-----------|-------------|----------|
| Compressive (MPa) | 155.6 ± 9.52 | 142.38 ± 12.13 | 124.45 ± 15.42 | 115.30 ± 12.95 |
| Bending (MPa) | 84.05 ± 9.92 | 75.24 ± 11.62 | 61.90 ± 10.82 | 43.60 ± 11.76 |

**Table 1.** Mechanical strength of femur bone obtained from statistical data.
5. Materials used and its properties.

5.1. Kenaf

The main use of this fiber is during the recycling of papers, we can recycle the papers only one or two times after that fiber become too short so they cannot be recycled further. But by mixing recycling papers with fibers coming from kenaf will increases the number of recycling frequency.

![Figure 3. Kenaf.](image)

**Table 2. Kenaf Fiber Properties.**

| Property          | Values   | Units     |
|-------------------|----------|-----------|
| Density           | 1.40     | g/cm³     |
| Young’s Modulus   | 30-60    | GPa       |
| Tensile strength  | 310-750  | MPa       |
| Elongation        | 1.6      | %         |

5.2. Hemp

Hemp Crete wall has capability to regulate the temperature and humidity inside the structure and it also resists fire mold and vermin and eliminates the needs for the vapour barrier and gypsum drywall. Another big advantage of hemp Crete is that its environmentally friendly. It’s a pretty flexible material to work with and it takes the shape of the form work into which it is poured so that you can create curved walls [16].

![Figure 4. Hemp.](image)
Table 3. Hemp Fiber Properties.

| Property       | Values | Units  |
|----------------|--------|--------|
| Density        | 1.48   | g/cm³  |
| Young’s Modulus| 22-60  | GPa    |
| Tensile strength| 295-1192 | MPa |
| Elongation     | 1.6    | %      |

5.3. Aluminium oxide
The chemical formula of aluminium oxide is Al₂O₃. Alumina is most commonly used name. It has other name like aloxite, oralundum, which depends upon the application in which it is used. Aluminium oxide is associated with strongest bonding between the atoms. It is associated with high strength (compressive). The most important property which plays prominent role in this is its Hardness about 15 to 19 GPa.

Figure 5. Aluminium oxide.

Table 4. Al₂O₃ Properties.

| Properties       | Values | Units       | Properties              | Values | Units       |
|------------------|--------|-------------|--------------------------|--------|-------------|
| Density          | 3.95   | gm/cc       | Poisson’s Ratio          | 0.22   | -           |
| Flexural (Strength) | 379   | MPa         | Compressive Strength     | 2600   | MPa         |
| Elastic (Modulus) | 375   | GPa         | Hardness                 | 1440   | Kg/mm²      |
| Shear (Modulus)  | 152    | GPa         | Max Use Temperature      | 1750   | °C          |
| Bulk (Modulus)   | 228    | GPa         | Thermal Conductivity     | 35     | W/m°C      |

5.4. Epoxy Resin
There are 3 main types of resin used to prepare composites i.e. polyester, vinyl ester and epoxy. Each type of this offers unique benefits and drawbacks that must be considered when selecting resin. Most epoxy resins can be post cured with heats to improve their strength service, temperature and dimensional stability, because heat causes post curing parts should be cured or post cured at a temperature that matches or exceeds their expected maximum temperature prior to being put in service. If an epoxy part or mold is subjected to a service temperature higher than it was cured it can distort or wrap [16].
Figure 6. Epoxy Resin.

Table 5. Epoxy Resin Properties.

| Property             | Values | Units |
|----------------------|--------|-------|
| Density              | 1.1-1.4| g/cm³ |
| Elastic modulus      | 3-6    | GPa   |
| Tensile strength     | 35-100 | MPa   |
| Compressive Strength | 100-200| MPa   |
| Elongation           | 1.0-6.0| %     |
| Cure Shrinkage       | 1.0-2.0| %     |

6. Experimental Testing

6.1. Compression Test
Specimen is cut into flat shape of (155x25x3.17) mm, is according to ASTM standards D-3410/D-3410M-03 [16] and is shown in figure 7.
Figure 7. ASTM Specification of Compression Test Specimen.

6.2. Bending Test
Specimen is cut into flat shape of (127x12.7x3.2) mm, is according to ASTM standards D-790 [16] and is shown in figure 8.

Figure 8. ASTM Specification of Bending Test Specimen.
6.3. Specimen Set-up in UTM

7. Results and discussion

7.1. Compression Test Results from Hand Layup Method

The results obtained from Compression tests from Hand Layup Method are shown in Figure 11 to 13.
**Figure 11.** Results of Kenaf fiber composites from Hand layup method for Compression tests.

Form the above figure 11 it is observed that as the reinforcement of kenaf fiber get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Compression strength of the composites.

**Figure 12.** Results of Hemp fiber composites from Hand layup method for Compression tests.

Form the above figure 12 it is observed that as the reinforcement of hemp fiber get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Compression strength of the composites.
Form the above figure 13 it is observed that as the reinforcement of hybrid fiber (kenaf & hemp) get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Compression strength of the composites.

7.2. Compression Test Results from Vacuum Bag Method
The results obtained from Compression tests from Vacuum Bag Method are shown in Figure 14 to 16.

Form the above figure 14 it is observed that as the reinforcement of kenaf fiber get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Compression strength of the composites.
Figure 15. Results of Hemp fiber composites from Vacuum Bag method for Compression tests.

Form the above figure 15 it is observed that as the reinforcement of hemp fiber get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Compression strength of the composites.

Figure 16. Results of Kenaf/Hemp fiber composites from Vacuum Bag method for Compression tests.

Form the above figure 16 it is observed that as the reinforcement of hybrid fiber (kenaf & hemp) get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Compression strength of the composites.
7.3. *Bending Test Results from Hand Layup Method*

The results obtained from Bending tests from Hand Layup Method are shown in Figure 17 to 19.

![Figure 17](image17.png)

**Figure 17.** Results of Kenaf fiber composites from Hand layup method for Bending tests.

Form the above figure 17 it is observed that as the reinforcement of kenaf fiber get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Bending strength of the composites.

![Figure 18](image18.png)

**Figure 18.** Results of Hemp fiber composites from Hand layup method for Bending tests.

Form the above figure 18 it is observed that as the reinforcement of hemp fiber get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Bending strength of the composites.
Form the above figure 19 it is observed that as the reinforcement of hybrid fiber (kenaf & hemp) get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Bending strength of the composites.

7.4. Bending Test Results from Vacuum Bag Method
The results obtained from Bending tests from Vacuum Bag Method are shown in Figure 20 to 22.

Form the above figure 20 it is observed that as the reinforcement of kenaf fiber get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Bending strength of the composites.
Form the above figure 21 it is observed that as the reinforcement of hemp fiber get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Bending strength of the composites.

Figure 21. Results of Hemp fiber composites from Vacuum Bag method for Bending tests.

Form the above figure 22 it is observed that as the reinforcement of hybrid fiber (kenaf & hemp) get increased from 12%, 18% and 24% the applied force is shared by the fibers and it implies in increase in the Bending strength of the composites.

Figure 22. Results of Kenaf/Hemp fiber composites from Vacuum Bag method for Bending tests.
8. Conclusion
Experimental investigations in line with mechanical compression and bending strengths of epoxy composites embedded with Kenaf/Hemp fibers along with Al2O3 as filler material for orthopaedic implants resulted in following closure information:

- It is observed from the experimental results of NFRPC possessed favourable results complimenting with femur bone compression and bending strengths for orthopaedic implants orienting with 12%, 18%, and 24% of NFRPC.
- Polymer composites using vacuum bag method is found to be more effective method in comparison with hand layup method for the same parameter.
- In comparison with femur bone properties, the fabricated NFRPC exhibit sustainable significance as the results obtained are matching with the required strengths of the bone.
- Overall, the mechanical properties like compression and bending have increased with increasing proportion of fiber in composites.

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