Mechanical investigations on Neem/Banyan fibers reinforced with ceramic powder particulates hybrid polymer composite helmet

Thandavamoorthy Raja, Palanivel Anand
Department of Mechanical Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, 400 Feet Outer Ring Road, Avadi, Chennai, India-600062.

Abstract. The major investigation of this work is to replace the synthetic fiber polymer composite helmet to natural fiber reinforced polymer helmet. This study examines the mechanical properties such as impact strength, impact modulus, flexural strength, hardness and water absorption capacity. It is performed to develop the natural fiber hybrid composite helmet. The fiber reinforcements are short neem fiber and alkali treated banyan woven fabric is used. The weight percentage of laminates contain as matrix 85% (510g) and reinforcement 15% (90g), the matrix consists of epoxy resin (450g), hardner (45g) and the granite powder is used as a filler material (15g), which is fixed for all samples and varied in the fiber weight ratio of Neem/Banyan (grams), natural fibers are 15/75, 30/60, 45/45, 60/30, 75/15. The result shows the weight fraction of neem fiber 12.5% (75g) and banyan 2.5% (15g) gives high impact strength and it can be applied for fabricating the motorcycle driving helmet.

Keywords. Natural fiber hybrid composite helmet, Neem/Banyan fibers, granite nano particles, impact energy absorption, flexural strength.

1. Introduction
The Developed polypropylene composite reinforced with different natural fibers such as sisal, kenaf, hemp, jute and coir with compression molding process. When the impact velocity is increased with increasing of liner thickness and it reduced generally in the acceleration peak head. Therefore, the impact velocity of 6 m/s used for 10 certified helmet models lesser the 300g for bicycle helmet, [1]. The mechanical properties shows that the hemp fiber reinforced polypropylene composite shows an improved flexural and tensile strength when compared to other natural fibers, [2]. Similarly, sisal fiber reinforced polypropylene composite shows a better impact resistance when compared to other fibers. Overall, this study reveals that the specific demeanor of the most of natural fibers reinforced composites has shown a favorable properties with glass fiber reinforced hybrid composites, [3]. The testing of protection system for human head needs to adequate awareness in terms of impact velocity, brain tolerance limit and angle was carried out in this developed composite bicycle helmet. This well-defined interface and unique combination offer numerous favorable properties such as light weight, high stiffness and strength, better corrosion behavior, improved thermal stability, etc. Further, these composites can be designed for specific applications with desirable properties in the required directions, [4].

The composite materials are evolving into the many categories based on the matrix, reinforcement, fillers, etc. However, the synthetic fiber reinforced composites are predominantly used in many
applications reaching from the automobile to aviation industries and the natural fibers are used for alternate reinforcement of synthetic fiber composite with polypropylene to fabricate the natural composite helmet, also conducted the flexural strength and real time drop test of bio composite helmet, [5, 6]. The dissimilar types of synthetic fibres are widely used for reinforcement, particularly glass, carbon, kevlar, ceramic fibres etc, To optimize the fiber volume fraction of natural fiber reinforced composite to achieve the good mechanical strength of composite helmet. It can create the theories related for developing the composite helmet and gives significant strength and specific modulus of composite helmet, [7]. Despite the unique advantages, these synthetic fibres based composite shows a server threat to the environment, since these synthetic fibres are highly non-biodegradable in nature, [8].

The developed a novel vakka fiber reinforced polymer composite and characterized for mechanical strength and dielectric properties vakka fibres are locally called as royal palm with a scientific name of Roystonearegia. This experimental investigation revealed that the increase of the vakka fibre volume fraction positively influences the strength of the vakkafibre reinforced composites, [9,10]. Further, the tensile behavior of vakka fiber reinforced composite is significantly better than banana and sisal fiber reinforced composite and at the same time, it is comparable to the bamboo fiber reinforced composite, [11]. Unlike bamboo, sisal and banana fiber reinforced composites, vakka fibre reinforced complex shows an upsurge in dielectric strength with the increase of fiber volume fraction, which makes it as a potential material for electrical insulation application.

Mention in another work, experimentally characterized jowarfiber reinforced polymer composite and compared the same with sisal and bamboo fiber reinforced composites. Jowar fibre reinforced polymer composite shows an effective density of about 922 kg/m$^2$ and tensile strength of about 302 MPa with the tensile modulus of 6.99 GPa. The comparative evaluation revealed that jowar fiber is similar in strength when compared to bamboo fibers, however when compared to sisal fibers, jowar fiber show significant improvement of about 1.89 times, [12,13]. In another work, a grass broom fiber based polymer composite and characterized for tensile behavior. When compared to the neat polymer composites, grass fiber reinforced polymer composite shows 22.2 % increase in the tensile strength and 40% fiber volume fraction, [14]. Similarly, the tensile modulus is also increased for about 17.3% when compared to the pristine. Further, it is observed that the tensile behavior of grass broom fiber reinforced polymer matrix composites considerably increased with increase of grass fiber volume fraction, [15].

In this current work, a granite waste filled Neem/Banyan natural fiber reinforced hybrid composite helmet is fabricated. The impartial of this work is to develop the natural fiber hybrid composite helmet from the effect of fiber weight fraction of two fibers on the impact and flexural behaviour of natural composite. To optimize the different samples and to develop the fabrication of hybrid composite helmet and the SEM analysis was conducted for revealing the flop mode of Neem/Banyan hybrid composite helmet.

2. Materials and methods

Two fibers used for this fabrication work of natural fiber reinforced polymer composite are Neem and Banyan. Neem fiber is supplied from go green pvt. Ltd, Chennai (India). Banyan fiber mat is supplied from N fabrics New Delhi (India). Epoxy resin is used as matrix, which is supplied by Javanthi enterprises, Chennai. The granite waste is used as a filler material for this hybrid composite. The fiber-matrix composition is given in table-1

| Table 1. The composite laminates and their weight fraction. |
### Table

| Sample Name | Epoxy Resin and Hardner Weight (g) | Granite powder Weight (g) | Neem Fibre Weight (g) | Banyan Fibre Weight (g) | Neem/Banyan weight ratio in percentage (15%) | Fiber weight fraction ratio of Neem/Banyan |
|-------------|-----------------------------------|---------------------------|-----------------------|------------------------|---------------------------------------------|------------------------------------------|
| Sample A    | 510                               | 15                        | 15                    | 75                     | 2.5/12.5                                    | 1:5                                      |
| Sample B    | 510                               | 15                        | 30                    | 60                     | 5/10                                        | 1:2                                      |
| Sample C    | 510                               | 15                        | 45                    | 45                     | 7.5/7.5                                     | 1:1                                      |
| Sample D    | 510                               | 15                        | 60                    | 30                     | 10/5                                        | 2:1                                      |
| Sample E    | 510                               | 15                        | 75                    | 15                     | 12.5/2.5                                    | 5:1                                      |

### 2.1. Fabrication Process

This work is done by Hand lay-up technique for fabricating of composite specimens, the NFRP hybrid composite helmet. Open mold steel board is used for the laminating of hybrid composite, epoxy matrix is mixed thoroughly with hardener by ratio of 10:1 (resin/hardener). Then the granite powder is used as a filler material, the filler material (15g) is constant for all the samples and it is mixed with the matrix. The neem fiber is in the form of loose fiber and the alkali treated banyan fiber is in the form of a woven fabric mat, a layer of banyan woven mat is 15g, the same weight of 15g is used for a layer of chopped neem fiber and the ratio layer weight is equal to this hybrid composite. As an initial step steel board is encased by non-rushed thin cover sheet to give a superior surface completion. At that point the form delivering operator was applied for adhering of polymers to surface. A layer of gum is applied by brush and the hacked Neem fiber is situated on the steel board shape. Again the network is applied, at that point Banyan woven fiber is set as second layer of the principal succession. This cycle of creation is rehashed for five different sequences (i.e) 15/75, 30/60, 45/45, 60/30, 75/15. Each sequence is considered as the different weight ratio of Neem/Banyan hybrid fibers are 1:5, 1:2, 1:1, 2:1, 5:1. It is applied by the mold releasing agent (liquid Wax) and the roller is used for removing the air gap between the layers of polymers. The steel board mold is located then the weight of 15-20 kg is applied. The process of curing to this place at room temperature for about 36-40 hrs, [16]. Once, the developed hybrid composite is removed from the mold, the plaster of Paris(POP) technique is used for helmet molding to produce the fabrication of natural fiber reinforced polymer composite hard hat (helmet) as shows in figure 1.
3. Mechanical Properties of hybrid composite helmet

3.1. Flexural Test
This study, to assess the flexural strength of this hybrid composite by conducting 3 point bending flexural test. The test specimen is prepared by the ASTM D790 STD. The bend test is done by UTM (Universal Testing Machine) and the load is functional gradually at the rate of 5mm/min, [16]. This load rate is applied till the fracture of hybrid composite. The same procedure is consistent for each composition and the each composition is performed for 3 times and their average value is taken. The same test is also conducted for the other samples and the average flexural value is taken.

3.2. Impact Test
The Izod impact test is done and the test specimen is prepared as per ASTM D256. In this specimen, the standard dimension for izod impact test 13x10x64 is followed, v-notch was created as per the standard and the pendulum hammer to impact that v-notch specimen by releasing the pendulum from its position, [17]. The impact energy consumed is shows in dial gauge, it is used to find the impact strength and impact modulus of the hybrid composite. The maximum impact energy is 50 Joule in Izod impact testing machine with 5kg pendulum weight and the impact velocity is 5.25m/s, [18]. The procedure is repeated for other composition. Each example is performed multiple times, and their normal worth is taken.

3.3. Surface Morphological Study
The surface morphology, identification of hybrid composite is done by Scanning Electron Microscope (SEM) S-3700N HITACHI model is used, [19-22]. This analysis is used to study the surface fracture, blow hole, fiber fracture, matrix bonding between the fibers of hybrid composite.

3.4. Hardness Test
This work as examines, the hardness of the hybrid composite by conducting Rockwell hardness test. The specimen is prepared as per the ASTM E 18-07 standard. The Rockwell hardness testing machine is having 1/16 inch steel ball indenter; the load range is 60 kgf-150 kgf. In this study, the load value of 60 kgf is applied and the impression is found in the hybrid composite. Based on the impression, the hardness value of hybrid composite is noted from the dial gauge present in the testing machine. Three trial is done for each sample of the natural fiber hybrid composite by repeating the same procedure and the average hardness values of hybrid composite, the three trial list samples are taken.

3.5. Water Absorption Test
The major physical property of NFRP hybrid composite is moisture absorption. The material absorbs water from the surroundings through hydroxyl domain that exists in the composite. The moisture absorption capacity mechanisms transports H2O molecules, diffusion and capacity. This work, conducts water absorption test by ASTM D570 standard, [23]. The initial weight of hybrid composite sample is noted and then the sample is entirely immersed in water for 24 hrs at atmospheric temperature. After 24 hrs the weight of hybrid composite is checked. The same process is repeated for all the five samples. To calculate the water absorption capacity of the samples is varied to apply the initial and final values of hybrid composites into the water absorption formula. Water absorption capacity = [(final wt. – initial wt.) / initial wt.], [23].

4. Result and Discussion

4.1. Flexural Strength
As a result, the flexural strength of developed hybrid composite is revealed in figure 2. The flexural value of the different sequence of hybrid composite, in these sequences given the maximum flexural value is 31.24 MPa (75g of banyan fiber and 15g of neem fiber). The lower value of flexural strength
is 14.12 MPa for 15g of banyan fiber and 75g of neem fiber. It is observed from this hybrid composite, that the flexural strength and modulus is increased when the weight percentage of banyan fiber to be increased and flexural strength and modulus of this hybrid composite is decreased when the weight percentage of neem fiber to be increased. The maximum flexural value of hybrid composite of Banyan/Neem hybrid composite has the weight ratio of 75g/15g. Then the lower flexural value weight percentage Banyan/Neem of hybrid composite has the weight ratio of 15g/75g. This may tends to the improper impregnation fibers and matrix. The fiber properties of neem and banyan also leads to improper adhesion between fiber and matrix of this hybrid composite.

Figure 2. Flexural strength of banyan/neem fibers reinforced hybrid polymer composite.

4.2 Impact Strength and Impact Modulus

Figure 3. Impact strength of the banyan/neem fibres reinforced hybrid polymer composite.

Figure 4. Impact modulus of the neem and banyan fibre reinforced hybrid polymer composite.

The impact strength and impact modulus of this hybrid composite is revealed in figures 3 and 4, the maximum impact energy absorption is 24.3J and the impact modulus is 0.00292 J/mm$^3$ for 75g of
neem fiber and 15g of banyan fiber of hybrid composite. The minimum value of impact energy absorption is 16J and impact modulus is 0.0019 J/mm$^3$ for 15g of neem fiber and 75g of banyan fiber. The similar work is done for the glass/jute fiber composite, [23]. From this hybrid composite, impact strength is improved with the increases in neem fiber and the decreased neem fiber gives low impact strength of banyan/neem/epoxy hybrid composite. Increasing the weight percentage of neem fiber to proper interface between the fiber/matrix of hybrid composite gives high impact strength. It is observed that the neem fiber has high ductile property and it give more reinforcement to the matrix. Hence it gives high impact strength of this hybrid composite. The eventual helmet was done by the above impact strength of the hybrid polymer composite. The sample sequence 75g of neem fiber and 15g of banyan fiber is used. This combination of hybrid composite is given an high impact strength. Hence, it is selected for fabricating the motorcycle driving helmet that has to the replaced with the old synthetic helmet.

4.3. Morphological Analysis
The surface morphological analysis by SEM test is performed to learn the failure analysis of the NFRP hybrid composite helmet. From this SEM analysis the fracture mode, matrix crack, fiber weakens are determined. The figure 5 shows its failure region of fracture mode and weak bonding of the hybrid composite.

![Figure 5. SEM image of Banyan/Neem/Epoxy Hybrid Composite helmet.](image)

4.4. Hardness Test
The hardness values of composite samples is shown in figure 6 from this graph maximum value of hardness is 80.3 for the sample C, the sequence of 45g neem fiber and 45g banyan fiber hybrid composite. The minimum hardness number of hybrid composite is 75 for the sample D and the weight fraction is 60g neem fiber and 30g banyan woven fabric. Therefore, the equal weight fraction ratio of Neem/Banyan hybrid composite is gives high hardness value when compared to the other sequences,
also when increasing or decreasing the weight fraction of Neem/Banyan fiber it gives positive and negative results. So, the equal ratio of Neem/Banyan hybrid composite gives the positive influence of the hardness value of hybrid composite.

4.5. Water Absorption Capacity
All common strands are hydrophilic in nature. This is the primary downside of characteristic filaments, as this makes them have high water ingestion and to be contrary with hydrophobic polymer grids, [23]. In this work, five different specimens of Neem/Banyan hybrid composite is prepared as per the weight fraction that is given in table 1. To calculate the water absorption capacity of hybrid composite of 100x15 mm², then the specimens are subjected to water for 24hrs and their weight ratios are calculated, all the five samples are in same weight and sequence layer is varied of hybrid composite. The water absorption capacity of hybrid composite is given in table 2. From the result, the equal amount weight fraction of hybrid compsite is gives the maximum value of water absorption capacity, at the same time Water absorption capacity is decreased with increasing the neem fiber weight portion. Therefore, the addition of neem fiber gives good resistance to the water absorption.

Table 2. Water absorption capacity of hybrid composite.

| Sl. no. | Samples | Before subjected to water in grams | After subjected to water in grams | Water absorption capacity in % |
|--------|---------|----------------------------------|----------------------------------|------------------------------|
| 1.     | A       | 11                               | 11.12                            | 1.09                         |
| 2.     | B       | 11                               | 11.10                            | 0.9                          |
| 3.     | C       | 11                               | 11.14                            | 1.2                          |
| 4.     | D       | 11                               | 11.05                            | 0.4                          |
| 5.     | E       | 11                               | 11.02                            | 0.1                          |

Water absorption capacity % = [(final wt. – initial wt.) / initial wt.] X 100
\[ \frac{11.02 - 11}{11} \times 100 = 0.1\% \]

5. Conclusion
Finally this work investigates the flexural and the impact strength of Banyan/Neem fibre reinforced hybrid composite. The chief observations of the findings are given below.

- The flexural strength is enhanced by adding banyan fiber to the hybrid composite and at the same time, the impact strength is enhanced by adding Neem fiber to hybrid polymer composite.
- The hardness standards of hybrid composite is enhanced by the equal weight ratio of Neem/Banyan fibers.
- The composition of Neem 75g and banyan 15g (5:1) has produced higher impact strength and less water absorption capacity of hybrid composite. The created bio composite protective cap was manufactured by Reinforcement of normal strands, for example, sisal, areca, coconut, banana with the grid of epoxy gum and tried the effect retention, [23].
- Based on the findings, the above composition of Neem/Banyan (5:1) hybrid composite was utilized to fabricate the motorcycle driving accessories (Helmet).

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