Characterisation of Nano Aluminium Oxide Filled Hybrid Cotton Glass FRP Composite Structures

Sunil Kumar Jyothula[1*], *Chinna Maddaiah* K[2], *Veeresh Kumar* G B[3], and *Anaz Khan* Muhammed[1]

[1]Department of Mechanical Engineering, MLR Institute of Technology, Hyderabad, Telangana-500043, India.
[2]Department of Mechanical Engineering, CMR Engineering College, Medchal Road, Hyderabad, Telangana - 501401, India.
[3]Department of Mechanical Engineering, National Institute of Technology, Andhra Pradesh, Tadepalligudem, Andhra Pradesh, India.

Abstract. Natural fiber-based composite manufacturing is now an expanding field of study, and it is the preferred option not only because of its exceptional qualities such as light weight, rigidity, low density and superior mechanical properties, but also because it is affordable, biodegradable, fully or mostly recyclable and renewable. A Glass Fibre is a type of Reinforced Polymer (GFRP) made of tiny glass fibers embedded in a plastic matrix. Hybridization of natural and synthetic fibres has to be done to overcome the shortfall of these fibres. When compared to single Fibre Reinforced Polymer (FRP) composites, fibre-reinforced hybrid composites offer improved mechanical, thermal, and damping characteristics. The goal of this research is to see how Nano Aluminum Oxide (Al_2O_3) fillers affect the characteristics of hybrid cotton-glass FRP composites. The vacuum bagging technique was used to make nano Al_2O_3 particles - hybrid cotton-glass FRP composites out of glass fibre chopped strand mat, cotton fabric, epoxy resin, and nano-Al_2O_3 fillers. The nano Al_2O_3 fillers were integrated in different weight (wt.) ratios in the FRP and the effect on tensile, flexural and impact properties were examined.

1 Introduction

The modern research is concentrated on genesis and optimization of the nano Al_2O_3 filled hybrid cotton-Glass FRP composites. This paper reviews work which has already been done in the field, with a view to pointing out weaknesses and possible areas of development of the current project. Some of these parameters include stacking sequence, fiber volume, foam density, and fiber reaction of the fiber reinforced polymer composites made from cotton base fiber and glass for dumper application have also been examined. Introducing glass fibers with sisal fiber Polypropylene (PP) composites, the several researchers have reported that the inclusion of compatibilizers raised tensile, impact, and flexural properties due to the raised interfacial adhesion between the matrix and fiber. Although the addition of glass fibers seems to adopt moderate effects in the mechanical properties of these composites. On the other hand, the incorporation of glass fibers enhanced thermal stability and decomposition temperature of PP composites as loading of glass fibers increased [1].

The dry sliding wear characteristics of epoxy/jute composites reinforced with Al_2O_3/SiC filler in amounts of 5 wt% to 15 wt% of the resin volume using hand layup technique [2]. Other survey, for therapeutic epoxy/glass composites with fuller's earth filled by PBO, SiO_2, Al_2O_3 and $CaCO_3$ it analyzed that lead oxide (PbO) as filler give better tensile properties, whereas Al_2O_3 improve torsional strength and hardness [3]. Flexural and tensile strength of the epoxy- glass fiber composite has been examined frequently and the results indicate that flexural and tensile strength of the material depends on the orientation of fiber alignments; e.g., either 0°/30°/60°/90° or 0°/90°/0°/90°. As the glass fiber volume fraction increases they have increasing values of the ultimate tensile strength (UTS) and flexural strength [4]. Having also noted the damping characteristics of glass fibre reinforced composites (GRC) increases as the glass fiber content increases [5].

However, they also study the impact of epoxy modifiers including Al_2O_3, TiO_2 and SiO_2 on the mechanical performance of epoxy reinforced by glass fiber composite. It was observed that the composites containing SiO_2 had higher amounts of flexural strength, flexural modulus and inter laminar shear strength (ILSS) than the composite containing other micro modifiers [6]. Subsequent investigation has focused on investigating other types of polymer-natural glass fiber composites employing natural fiber which includes sisal, pineapple, jute, hemp, coir and cotton fibers. Modification of these fibers with glass fibers has revealed enhancements in different mechanical characteristics, notably when a silicon carbide filler is incorporated into the sisal fabrics [7]. Also, when incorporating cotton fibers into the polymer matrix composites, an enhancement in green strength and young modulus with increasing of the glass fiber percentage is observed [8].

* Corresponding mail: jyothula92@gmail.com

Other related studies include wear behavior and mechanical properties of the composites with filler reinforcement. For instance, incorporation of graphite fillers to cotton fiber polyester composites improved wear characteristics. Based on the aforementioned studies, common fiber reinforced polymers have been improved in most respects compared to typical glass fiber reinforced composites; particularly there has been an observed improvement of strength when a small proportion of cotton fiber has been incorporated [9]. As other hybrid composite material options for cue tip applications, glass fiber and coconut coir have also been researched because of their mechanical benefits over conventional glass fiber-reinforced composites [10].

2 Experimental Procedure

2.1 Fabrication and testing of composite laminate structures

The materials used in fabrication of the composite laminates: – Peel Ply, Woven E-Glass Fabric, Epoxy Resin Araldite CY230, Aluminium oxide nano-filler, Hardener Aradur HY951, Mold, Sealant tape, breather material, perforated, Release fabric and Vacuum bag and a Vacuum pump and fabricated samples shown in figure 1.

Fig. 1. Specimens for Tensile Test before testing

2.2 Tensile strength test

In tensile test, the following specimen ASTM standard dimensions are used 140 mm X 20 mm and gauge length is 80 mm. Here, the cross head speed of the Universal Testing Machine (UTM) of 2 mm/min has been used to conduct tensile tests. The readings that are obtained from this test are used in computing the UTS of the composite test samples. Three specimens are tested and the mean of the above obtained values is used to determine the UTS of the laminate. Some of the test samples of Cotton-Glass fibre reinforced laminates used for carrying out and fractured samples are presented in figure 2.

Fig. 2. Specimens of Tensile Test after testing

2.3 Flexural test

The flexural test was carried out on ASTM based test specimens of 140 mm length and 12.5 mm thickness. In the present study, a Universal Testing Machine (UTM) with a three-point bending test setup was used with a cross head speed of 2×10^{-2} mm / min and a maximum load carrying capacity of 30 kN. The data acquired from this test were incorporated in the potentiation of flexural strength of the composite samples. For statistical credibility, three samples of each composite configuration were used to test on the instrument. He noted the average as the flexural strength of the laminate between these three values. This serves to explain any small differences in sample preparation procedures, or testing conditions that we may encounter. The test samples which include composites of CFRP laminates were produced to the required size and are illustrated in figure 3. This figure supports the specimen sizes, shapes, and surface characteristics prior to the testing procedure as described above.

Fig. 3. Specimens after flexural test.

2.4 Impact test

The impact test was carried out based on the ASTM method using test specimens of dimensions 65 mm x 12 mm. This standard size helps keep the comparison and coordination of results from different works and different materials possible. The impact strength and the toughness of the composite specimens was carried out using an Izod impact-testing machine. Finally in this test, a pendulum of known mass is dropped from a fixed height so that it strikes the specified point of the specimen. The strength and toughness of the specimen is determined by the energy that was absorbed by it during the impact and fractured samples are shown in figure 4.

Fig. 4. Specimen after Impact Testing

2.5 Water absorption test

This test is performed for a span of 56 days. After taking down the values, the specimen's proportion of water absorption is found out using the below formula

$$\text{Water absorption (\%)} = \frac{(W_1 - W_2)}{W_1} \times 10 \quad \frac{(W_1 - W_2)}{W_1} \times 10$$

Where, W1 and W2 are the dry and wet sample weights, respectively.

3 Results and discussion

Cotton and E-Glass are employed as natural fibres in this project. Epoxy resin CY230 and hardener HY951 are employed as matrix ingredients. Flexural strength, impact strength, and Tensile strength, as well as water absorption qualities, density, and void fractions, are all tested.

3.1 Water absorption test analysis

To assess the ability of the developed hybrid cotton-glass fiber reinforced polymer (FRP) composites with varying nano-Al_2O_3 fillers the water absorption test was performed. The test was carried out for a total period of 56 days and the percentage of water absorbed was determined on a weekly basis. Three different compositions of hybrid composite laminates were analyzed: The three formulations incorporate 2 wt%, 4 wt% and 6 wt% of nano-Al_2O_3 fillers and are referred to as L1, L2 and L3. The results also show that the water absorption percentage of the composite specimens increases over time for all the specimens. The trend, which was obtained from the test data as shown in Table 1, reveals that water absorption occurs in a linear fashion up to 8 weeks where slight variations in water absorption were realised among the different composites.

- L1 (2% nano-Al_2O_3): Initially, the weight of the specimen was taken 7.6 gm, and the final weight was measured at the end of the 56 th day at 19.6 gm thus having absorbed 157.89% water.
- L2 (4% nano-Al_2O_3): This specimen initial weight began at 6.7 grams and weighed 20.2 grams at the end of the 56th day in the process of bacteria colonization The water absorbed percentage was 201.49%.
- L3 (6% nano-Al_2O_3): Starting from 6.4 grams L3 had the lowest water absorbing capacity and the final weight after the water absorption test was recorded as 15.6 grams, giving about 143.75 % water volatility.

Percent water uptake of the composite specimens significantly decreases with the nano-Al_2O_3 filler content with the specimen L1 having the highest percentage water uptake whereas L3 having the lowest percentage water uptake. This implies that the incorporation of extra nano-Al_2O_3 fillers can further decreases the porosity of the composite structure thereby limiting water accumulation. It is probably for the same reason that Nano-Al_2O_3 particles enhance the density and decrease the void fraction in the composite materials; the water absorption values of the L3 specimens are lower.
The filler content is identified as having significant influences on the water absorption performance. Low filler content composites, for example L1 with only 2 wt% of filler, had higher water absorption because they had higher void fraction and porosity. Conversely, in the L3 sample with 6% filler content, improvement in moisture resistance was observed because it had better filler-matrix interface adhesion, which decreased the void and microchannel availability for water transportation. The water absorption properties of all the composites were seen to rise consistently with time and, thus, it can be deduced that the hybrid composite structure enables controlled water absorption, particularly when filler fractions are comparatively low. This time dependency is common for polymer composites where the moisture diffusion is through the matrix and along the fiber/matrix interface.

It is concluded that the decrease of the water absorption capacity of increasing contents of nano-Al_2O_3 could be attributed to the improvement of the barrier properties of the composite material. From previous works, the authors have come to understand that the embedding of nanoparticles such as Al_2O_3 in polymer matrices increases the effectiveness of the material's resistance to water permeation by lowering the permeability paths within the composite system. Similar observations can be made from the test results presented here where higher filler content composites demonstrate better moisture absorption resistance. Greater water resistance at the higher filler levels is beneficial for conditions in which the composite may be exposed to conditions of humidity or wetting, as in boats or outdoors use. Thus, filling content of the composite can be made to have desired water absorption performance by adjusting the filler content.

Table 1. Water Absorption Test Results

% nano-filler	Initial weight of the specimen in grams	No. of Days							
		7	14	21	28	35	42	49	56
L1	7.6	3.9	14.1	15.2	15.9	16.2	16.9	18.5	19.6
L2	6.7	11.2	11.5	13.6	15.9	16.1	17.4	19.7	20.20
L3	6.4	3.9	4.2	9.6	11.2	11.6	13.8	14.1	15.6

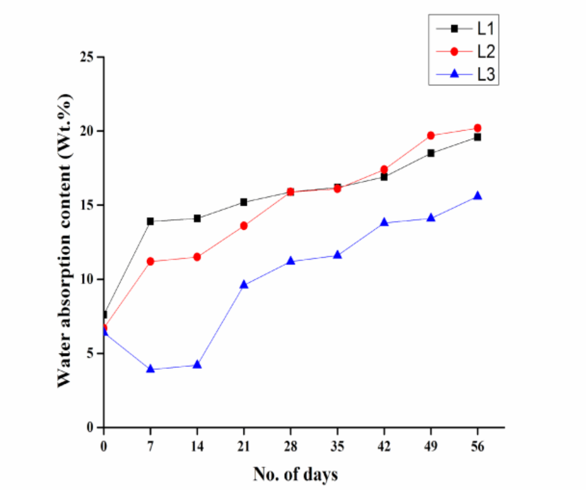

Fig. 5. Variation of water absorption content of different laminated specimens against no. of days.

3.2 Tensile test analysis

These properties were assessed by the tensile test on the hybrid cotton-glass fiber reinforced polymer (FRP) composite that contains different proportions of nano-Al_2O_3 particles. Three different compositions were tested: They include low addition nano-Al_2O_3 contents by weight of 2%, 4%, and 6% hence L1, L2 and L3 respectively. The test was performed on the UTM at different composite materials' specimens prepared according to ASTM requirements and then three specimens for each composite type were taken, and their mean values were used.

The UTS of the composite specimens changed with increase incorporation of nano-Al_2O_3 filler as shown in Table 2 to Table 5. The graph also illustrates the gradual increase of the tensile strength of composites containing nano-Al_2O_3 up to the definite amount of filler and slight decline in tensile strength at higher nano-Al_2O_3 concentrations.

- L1 (2% nano-Al_2O_3): The value of UTS obtained was 102.2 MPa, followed by a break force of 10.731 KN and average break age of 5.573mm. This composition of the polymer nanocomposite material proved to have the highest tensile strength among all the three variants presented in this work.
- L2 (4% nano-Al_2O_3): The composite material UTS for L2 was a little lower at 99.174 MPA and it has the break force of 10.413KN and the average break elongation of 4.607mm.
- L3 (6% nano-Al_2O_3): The value of UTS was further reduced to 93.7 MPa with a break force of 9.838 kN and the average break elongation was 4.424mm.

The tensile modulus which expresses the stiffness characteristic of the composite also increases, following the same trend. L1 or 2% filler had the highest tensile modulus of 15.353MPa followed by L2 or 4% filler with a tensile modulus of 15.28 MPa and the lowest tensile modulus was recorded with L3 which was a 6% filler of 13.07MPa. This suggests that the dimensional accretion or the shift to slightly more flexible composites occurred beyond the 2% fillers. The result obtained from the tensile strength test is that the nano-Al_2O_3 fillers improve the tensile characteristic of the composite up to an optimum weight percentage (2 wt%), beyond which the enhancement is reduced.

- L1 (2% filler): The ult tens strength as well as the modulus of the neat composite were found to be highest at this filler concentration and hence the 2 wt % nano-Al_2O_3 filler concentrations offers the best reinforcement for the composites structure. These particles should at this concentration increase the interfacial adhesion between the glass and the cotton fiber as well as the epoxy matrix through better load transfer reaction across the fiber-matrix interface.
- L2 (4% filler): The tensile strength has marginally reduced compared to L1, which may assume that as the filler content increases, the distribution of nano-Al_2O_3 particles is not homogeneous in nature. This could culminate in the formation of agglomerates which work as stress concentrators and thus decrease the overall strength of a composite.
- L3 (6% filler): The decrease in tensile strength and modulus at this higher filler content implies that excessive addition of nano-Al_2O_3 weakens the effectiveness of load transfer. Nano-filler clustering and increase in void content most probably degrade the matrix and decrease the strength of any ASYSA epoxy composite.

The percent increase in break elongation of the composites was highest with L1 having 5.573 mm and reduced with the increase in the filler content for synthesizing L2 of 4.607 mm and L3 of 4.424 mm. This suggests that the overall property of the composite becomes more brittle as the filler content increases. These data indicate that increased filler content results in greater tensile strength, but at the same time, decreased elongation. As shown the 2% nano-Al_2O_3 filler can increase strength and flexibility, however, increasing the filler content decreases the elongation to fracture capacity, making the material less ductile. The findings of the current study are in accordance with past studies suggesting that the incorporation of nanoparticles can enhance the mechanical characteristics of the fiber-reinforced composites up to a certain filler loading. More than this value, the incorporation of the filler incurs further declined properties because of particle coalescence, poor affinity between the filler and the matrix, and higher void volumes. The average tensile strength of the fabricated cotton-glass hybrid composite with 2% nano-Al_2O_3 filler (102.2MPa) is fall in the range found out by other workers in the area of hybrid natural-synthetic fiber composites.

Table 2. Tensile properties of sample with 2% nano- Al_2O_3 by wt.

Specimen	1	2	3	Average
Break force (kN)	9.499	11.117	11.577	10.731
Ultimate strength (MPa)	90.466	105.88	110.254	102.2
Break elongation (mm)	5.119	6.025	5.577	5.573
Tensile modulus (MPa)	15.03	15.38	15.65	15.353

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Table 3. Tensile properties of sample with 4% nano-Al_2O_3 by wt.

Specimen	**1**	**2**	**3**	**Average**
Break force (kN)	8.009	11.191	12.04	10.413
Ultimate strength (MPa)	76.271	106.583	114.669	99.174
Break elongation (mm)	3.894	4.933	4.996	4.607
Tensile Modulus (MPa)	15.03	15.1	15.71	15.28

Table 4. Tensile properties of sample with 6% nano-Al_2O_3 by wt.

Specimen	**1**	**2**	**3**	**Average**
Break force(kN)	11.318	7.696	10.502	9.838
Ultimate strength (MPa)	107.789	73.294	100.017	93.7
Break elongation (mm)	4.963	3.771	4.538	4.424
Tensile Modulus (MPa)	12.91	12.4	13.9	13.07

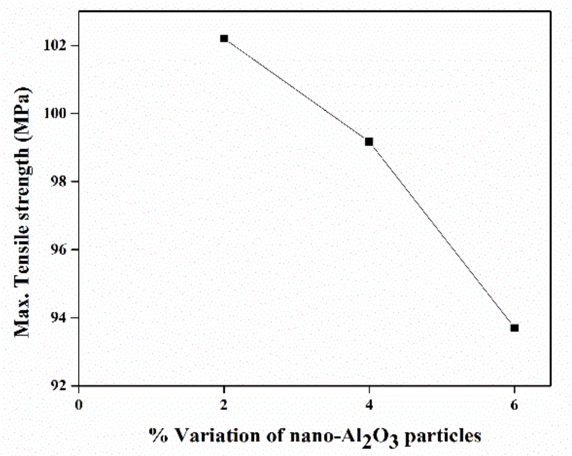

Fig 6. Variation of Tensile strength against nano Al_2O_3 fillers by wt%.

Table 5. Comparison of Tensile properties at different compositions of the specimens.

Tensile property	**2% Al_2O_3**	**4% Al_2O_3**	**6% Al_2O_3**
Max Tensile strength (MPa)	102.2	99.174	93.7
Tensile Modulus (MPa)	15.35	15.28	13.07

3.3 Flexural test analysis

The flexural test was then carried out on hybrid cotton-glass fiber reinforced polymer (FRP) composites containing nano-Al_2O_3 fillers with either 2% (L1), 4% (L2) or 6% (L3) by weight. CPI was carried out for the developed composites scaffolds for three point bending method using UTM machine following ASTM guideline and the results of the test were represented by the mean of three samples for each composition. The flexural strength results of the composite specimens are summarized in Table 6, 7 and 8. It also indicates that the flexural strength is dependent with the nano-Al_2O_3 filler content. L1 composite which had filler content of 2% yielded the best flexural strength but it was followed by a consistent drop off as we had composites with 4% and 6% fillers.

- L1 (2% nano-Al_2O_3): The maximum flexural strength was observed at 15.297 MPa with maximum force 1.338 KN and maximum deflection of 7.08 mm.

- L2 (4% nano-Al_2O_3): Equally for flexural strength this composition had a lower value of 15.266 MPa with a maximum force of 1.336 KN and a maximum deflection of 6.435mm.
- L3 (6% nano-Al_2O_3): The flexural strength of composite further reduced to 14.266 MPa at the maximum force of 1248.00 N and maximum deflection of 6.808 mmm.

The flexural modulus which is the measure of the material stiffness in bending state was highest for the composite with 2% nano-Al_2O_3 filler (L1). The slight decrease in the flexural modulus owed to the filler content variation, whereby the composite with the highest filler content exhibited slightly lower modulus than its corresponding composite with lower filler contents.

- L1 (2% nano-Al_2O_3): The composite with the highest weight fraction of particles attained the highest flexural modulus and therefore claimed the highest stiffness.
- L2 (4% nano-Al_2O_3): The values of the flexural modulus for this composition were in the same range as in the case of L1 but somewhat lower.
- L3 (6% nano-Al_2O_3): A similar trend in flexural modulus was also noted, and this indicated that the stiffness of the composite reduced with the increment of the filler content.

The flexural test results demonstrate a clear trend: at the 2% filler loading the incorporation of nano-Al_2O_3 fillers improves the flexural characteristics of the hybrid composite but at higher loading the flexural strength and modulus value decreases. Beyond this level, the amount of filler increases and this was found to reduce the flexural strength and modulus of the composite.

- L1 (2% filler): These findings showed that flexural strength and stiffness of this particular composition were the highest This research also revealed that the 2% nano-Al_2O_3 filler provides the best reinforcement. The nanoparticles probably also plug some of the microvoids and, therefore, increase the interfacial adhesion between the epoxy matrix and the CIF and GFs, which results in increased load-carrying capacity during bending.
- L2 (4% filler): The slight reduction in the flexural strength and modulus of L2 relative to L1 indicates that while the nano-Al_2O_3 particles remain beneficial for the composite, the raised filler proportion might cause agglomeration, which generates stress concentrations and weakens the reinforcement effect.
- L3 (6% filler): A further reduction in the flexural strength and modulus for L3 proves that, a high nano-Al_2O_3 filler content is detrimental to the flexural properties of the composites. At higher filler concentrations, the nanoparticles aggregate, reducing the strength of the matrix and the capacity of the composite to resist bending loads. Also, the higher filler content is likely to decrease the flexibility of the composite such that it may fail in a brittle manner especially under flexural loads.

The maximum deflection in a typical flexural test was reduced as the nano- Al_2O_3 filler level was enhanced from 2 % to 4 %. Though, a little higher deflection was recorded at 6% filler content (L3). This suggests that although the composite gains increased stiffness with increased filler content, 6% is at the brittleness range and can deflect manly before failure.

- L1 (2% filler): The measured maximum deflection is 7.08mm which implies that the composition of the lamina provides moderate strength with adequate flexibility.
- L2 (4% filler): Lower deflection of 6.435 mm hints at the fact that compression stiffness of the composite increases with the amount of filler content.
- L3 (6% filler): The increase of deflection to 6.808 mm at 6% filler content may be attributed to the fact that the composite has become more stiff and bends easily before breaking.

It is quite in agreement with the prior research work done on the influence of nanoparticles in fiber reinforced composites. When incorporated in limited quantities, nanoparticles have great potential to enhance the mechanical characteristics of composites through the packed matrix fiber interface and the infiltration of voids. But when there is too much filler load, it reveals poor dispersion and high void volume hence decreasing the mechanical performance. In the present investigation, the nano-Al_2O_3 filler was determined to be at its most efficient at 2wt.% because the flexural strength began to reduce thereafter.

Table 6. Flexural properties of sample with 2% nano- Al_2O_3 by wt.

Specimen	**1**	**2**	**3**	**Average**
Max force (kN)	1.37	1.261	1.384	1.338
Max flexural strength (MPa)	15.658	14.414	15.819	15.297
Max deflection (mm)	7.628	6.35	7.263	7.08

Table 7. Flexural properties of sample with 4% nano- Al_2O_3 by wt.

Specimen	**1**	**2**	**3**	**Average**
Max force (kN)	1.32	1.393	1.295	1.336
Max flexural strength (MPa)	15.086	15.915	14.798	15.266
Max deflection (mm)	6.109	6.359	6.837	6.435

Table 8. Flexural properties of sample with 6% nano- Al_2O_3 by wt.

Specimen	**1**	**2**	**3**	**Average**
Max force (kN)	1.198	1.272	1.275	1.248
Max flexural strength (MPa)	13.694	14.537	14.568	14.266
Max deflection (mm)	6.845	7.147	6.433	6.808

Table 9. Comparison of the Flexural properties at different compositions of the specimens.

Flexural property	**2% Al_2O_3**	**4% Al_2O_3**	**6% Al_2O_3**
Max Flexural strength (MPa)	15.297	15.266	14.266

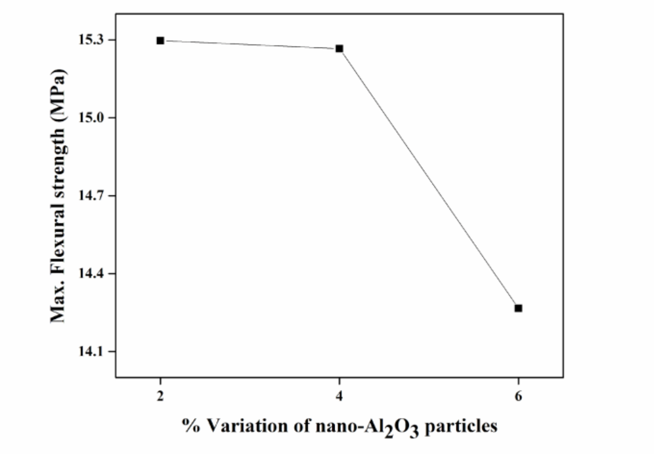

Fig 7. Variation of Flexural strength against nano Al_2O_3 fillers by wt%.

3.4 Impact test analysis

This was done with a view to measuring the energy absorption capacity, impact strength, and resistance of the hybrid cotton-glass fiber reinforced polymer composites containing 2%, 4%, and 6% wt of nano-Al_2O_3 as fillers which were described as L1, L2, and L3 respectively. The notch toughness test was performed on the Charpy impact testing machine following the ASTM tests, and the test results are the averages of three specimens for each composition.The extent of section was determined by the energy that the composite specimens were able to absorb before fracturing. The findings are summarized in the Tables 10 through 12 and represent the change of impact strength in dependencies of varying concentrations of nano-Al_2O_3 filler.

- L1 (2% nano-Al_2O_3): The composite had an average impact strength of 494.529 kJ/m² and an impact resistance of 3428.57 J/m.
- L2 (4% nano-Al_2O_3): The impact strength raised up to 522.697 kJ/m², with a consequent impact resistance of 4094.285 J/m.
- L3 (6% nano-Al_2O_3): A maximum impact strength of 697.31 kJ/m² and impact resistance of 4718 J/m was gotten for 6% filler composite.

Energy dissipation during impact rises when the nano-Al_2O_3 filler material was added and the content was raised. These energy absorption values were evaluated by determining the work done during the impact test.

- L1 (2% filler): The energy absorbed by this composite was 24 J.
- L2 (4% filler): The energy absorbed was further raised to 28.66 J.
- L3 (6% filler): The highest Work done on the composite was obtained when the filler concentration was 6%, and equaled 30. 667 J.

The findings of the impact test reveal the positive correlation between the nano-Al _{2} O _{3} filler amount and impact strength as well as impact resistance. This indicates that the nano-fillers have a significant influence on the improvement of the mechanical properties, specifically the fracture strength and energy of the hybrid composites.

- L1 (2% filler): The observed impact strength of the present composite with 2% of nano-Al_2O_3 content was comparatively low when compared to higher filler content composites. This suggests that although the nano-fillers enhance the general composite properties, 2% filler content offers a middle of the road reinforcement in terms of the energy absorption capability and impact loading of the composite.
- L2 (4% filler): As observed when the filler content was raised to 4%, impact strength and energy absorption were again raised, leading to the assertion that the nano-Al_2O_3 particles contributed to enhanced reinforcement in the form of a better distribution of impact energy over the composite material. The filler possibly improves the interfacial adhesion between the fiber and the matrix and makes the composite stronger to resist the impact forces.
- L3 (6% filler): When the impact strength and the energy absorption are concerned the best results have been seen for the composite containing 6% nano-Al_2O_3. These improvements in toughness may due to the facts that the density of nano-particles is higher than that of micro particles, this may serve as crack arrestor hence delaying crack extension during impact. However, going by the fact that the impact strength has been boosted beyond doubt, the material may be made even more brittle especially at this high filler loading and could fail catastrophically under very extreme loading.

The energy dissipation per wall thickness also escalated corresponding to a higher concentration of nano-Al_2O_3 filler. The composite with 6 %Filler was the most resistant hence can withstand more impact forces than the other composites. This increase in resistance is desirable most often in situations when the material is exposed to dynamic or pulsating loads.

- L1 (2% filler): The peak impact force for this composition was the least among the three, meaning that although the composite can dissipate some energy, its ability to withstand high impact load is small.
- L2 (4% filler): The composite has become tougher at 4% filler content that is evident in the enhanced resistance recorded above.
- L3 (6% filler): The presented researcher demonstrated that the 6 % filler composite had the maximum impact strength and therefore it can be recommended for use in situations where a structure needs to be tough and resistant to shock loads.

The improvement of the impact strength with increase in nano-Al_2O_3 filler content is also supported by early work on the nanoparticle reinforced composites. Nano-fillers increase the energy management capability of the material through the interfacial adhesion between fiber and matrix and decrease the size of the micro-crack initiation site. The presence of the nano-Al_2O_3 particles may well promote the development of a more uniform and homogeneous composite structure capable of withstanding impact forces more effectively. The sharp rise in the dose of filler particles might also lead to the enhancement of brittleness as a result of which the overall ductility of the composite is affected.

Table 10. Impact properties of sample with 2% nano- Al_2O_3 by wt.

Specimen	1	2	3	Average
Depth under notch (mm)	6	7.8	7	6.933
Cross sectional area (mm^2)	42	54.6	49	48.53
Work done (J)	16	32	24	24

Table 11. Impact properties of sample with 4% nano- Al_2O_3 by wt.

Specimen	1	2	3	Average
Depth under notch (mm)	8.5	8	7	7.833
Cross sectional area (mm^2)	59.5	56	49	54.833
Work done (J)	30	26	30	28.66

Table 12. Impact properties of sample with 6% nano- Al_2O_3 by wt.

Specimen	**1**	**2**	**3**	**Average**
Depth under notch (mm)	7	7	6.3	6.766
Cross sectional area (mm^2)	45.5	45.5	40.95	43.98
Work done (J)	30	32	30	30.667

Table 13. Comparison of impact properties at different compositions of the specimens

Impact property	**2% Al_2O_3**	**4% Al_2O_3**	**6% Al_2O_3**
Impact strength(kJ/m^2)	494.529	522.697	697.31
Impact resistance(J/m)	3428.57	4094.285	4718

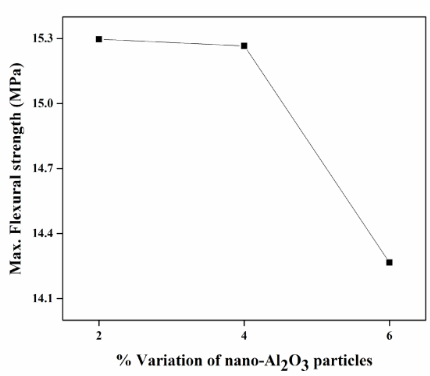

Fig 8. Variation of Impact strength against nano-Al_2O_3 fillers by wt%.

3.5 Density and void fractions analysis

The density and void fraction analyses were performed to studying the effects of different nano-Al_2O_3 filler loading (2 wt%, 4 wt%, and 6 wt%) on the density and void percent in the hybrid cotton-glass fiber reinforced polymer (FRP) composites. The theoretical and experimental densities of the composites were computed and the void fractions obtained as the difference between theoretical and experimental density of the composites.
The theoretical and experimental densities for the three kinds of composites are listed in Table 14. The theoretical density was estimated by employing a rule of mixtures, while the experimental density was determined by weighing the specimens and then calculating the volume.

- L1 (2% nano-Al_2O_3): The theoretical density according to the mixture percentage came up to 2.52 g/cm^3, whereas the experimentally calculated density was 2.45 g/cm^3. The calculated void fraction came to be 2.77%.
- L2 (4% nano-Al_2O_3): The theoretical density became 2.37g/cm^3 and as I have said before, the experimental density was found to be 2.19 g/cm^3. Consequently, the void fraction rose to a value of 7.59%.
- L3 (6% nano-Al_2O_3): The calculated theoretical density was 2.68 g/cm^3 and the calculated experimental density was 2.53 g/cm^3 with a calculated void fraction of 5.59%.

Void fractions are surprisingly expressed as the proportion of the composite volume occupied by air or other gases that get trapped in the composite during the fabrication process. Void content is significant because it is actually the load-bearing constituent in composites and influences mechanical characteristics and durability. It can easily be judged from the figures that the addition in the composites through the fillers of nano-Al_2O_3 led to raise the void fraction to higher rate, where in the L2 possessing 4% of filler has utmost void fraction of 7.59%.

- L1 (2% filler): The lowest void fraction of 2.77% proved that the composite structure has less air gaps or cavity in it.
- L2 (4% filler): The void fraction increased sharply to 7. 59% because this composition was found to have a higher level of voids, we think the possible reason could be due to improper dispersion of the fillers or the higher viscosity of the matrix that causes problems associated with degassing during the fabrication of the composites.
- L3 (6% filler): The porosity went down slightly to 5.59%, this means that even though the filler content has gone up, manufacturing most likely permitted better packing and hence a lower porosity.

Density analysis reveals that both the theoretical and experimental densities rose with the incorporation of nano-Al_2O_3 fillers and that the experimental vents are always lower than the theoretical values due to the existence of voids.

- L1 (2% filler): The small difference in the relative densities is an evidence of good filler dispersion and relatively little void content in this composite as compared with the theoretical density. The small value of void fraction (2.77%) indicates that this manufacturing process for this particular composite yielded low potential of air entrapment and thus a high degree of compactness.
- L2 (4% filler): With the reduced experimental density to theoretical density ratio and high void fraction of 7.59%, the produced composite can be considered porous. This could be due to poor dispersion of the nano-Al_2O_3 particles so that they are only partially dispersed and are closely packed, so that during fabrication of the composites, the resin cannot flow through it readily and getting trapped in the structure with the air. The decrease of the experimental density is also due to the increment of the void content that detracts from the strength of the composite by decreasing the overall density.
- L3 (6% filler): As the theoretical and experimental densities improved with higher filler content the void fraction was relatively high but stable (5.59%). This indicates that, although the nano-fillers are capable of enhancing the density of the composite, they at the same time complicate the degassing process hence including more air within the structure. However, the slightly lower figure than L2 shows that there is some enhancement of the production process or the distribution of the matrix materials.

The mechanical properties in most cases are inversely proportional to the void fraction since the voids act as stress concentrators which cause failure when externally loaded. Hence in this study, the increase in void fraction from 2.77 % (L1) to 7.59 % (L2) , 5.59 %(L3) may affect the tensile and flexural properties for the composites with higher filler content.

- L1 (2% filler): Low void fraction was used to explain the enhancement of tensile and flexural strength of this composition since porosity hinders the load bearing capacity of fibers and matrix.
- L2 (4% filler): The raise in void fraction reduced the tensile and flexural strength of the composite, consistent with findings from previous studies. Nevertheless, voids make the density lower, cause the dangers of crack formation to rise, and decrease the load-carrying ability of the composite.
- L3 (6% filler): This may be due to the reduction of the void fraction compared to L2 although overall high void fraction led to brittle behaviour of the composites. However, the net change in density failed to offset the detrimental impact of porosity all together.

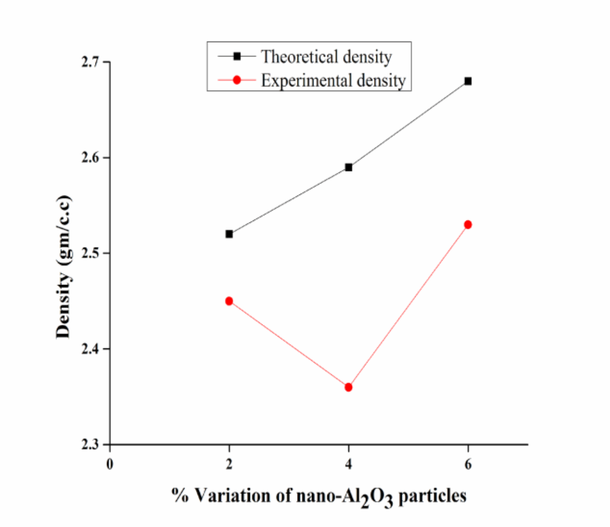

Fig. 9. Variation of Density against nano-Al_2O_3 fillers by wt%.

Table 14. Theoretical and Experimental Density of different specimens.

% Nano-Al_2O_3filler	**Theoretical density in (g/cm^3)**	**Experimental density in (g/cm^3)**	**Void fractions in (%)**
2%	2.52	2.45	2.77
4%	2.37	2.19	7.59
6%	2.68	2.53	5.59

4 Conclusions

- Among all the prepared cotton-glass FRP composites with 2% nano-Al_2O_3 filler, the highest tensile strength of 102.2 MPa, the highest flexural strength of 15.297 MPa and the highest impact strength of 494.529 kJ/m² were obtained from the hybrid composite.
- When loading increased the filler content up to 4% nano-Al_2O_3, the properties had lower properties and these decreased results were showing tensile strength 99.174 MPa, flexural strength slightly reduced to 15.266 MPa and lastly impact strength enhanced to 522.697 kJ/m². At 6% nano-Al_2O_3, tensile strength was again found to be decreased to 93.7 MPa, flexural strength was 14.266 MPa and the maximum impact strength was 697.31 kJ/m².
- With regard to the density and void fraction measurement result, the composite containing 2% nano-Al_2O_3 has an experimental density of about 2.45 g/cm³ and a void fraction of approximately 2.77%. At 4% nano-Al_2O_3, the experimental density reduces to 2.19g/cm³, and the void fraction rises to 7.59%, the maximum recorded. In the 6% nano-Al_2O_3 composite, the experimental density of the composite is less than that of the epoxy matrix i.e., 2.53 g/cm³ with void fraction of 5.59%.

Results from this work suggest that impact strength can be improved as nano-Al_2O_3 filler loading increases provided that the formation of voids does not result in brittleness and a degradation of tensile and flexural strength. It is therefore concluded that, when attempting to optimize for both strength and toughness, the material should be produced with 2% of nano-Al_2O_3. Further, increased production efficiency is required for formulations with increased filler content for improved clearances and better mechanical properties.

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