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ORIGINAL ARTICLE

Novel epoxy-carbonized coconut shell nanoparticles composites for car bumper application

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Abstract

The structure and mechanical properties of carbonized coconut shell nanoparticles (CSnp) reinforced epoxy composite have been evaluated to establish the possibility of using the composite as a new material for automobile car bumper application. Epoxy resin of the type LY556 was blended together with CSnp at 5–25 wt%. Scanning electron microscopy (SEM), mechanical test, and thermogravimetric analysis (TGA) were examined. SEM morphology reveals adhesion between CSnp and polymer matrix at low wt%CSnp while at higher weight percent of CSnp agglomeration of CSnp was observed. The addition of CSnp at 25 wt% produced the optimal hardness values of 26.35 VHN, tensile stress of 338.75 MPa, and flexural strength of 156 MPa, while at 10 wt% CSnp produced optimal impact energy value of 5.71 J. The developed epoxy composite when compared with two existing Toyota models showed improved impact energy at break of 10.5% over Big Daddy Model and 37.45% over Carina model under the same testing conditions.

Keywords Coconut shell · Mechanical properties · Microstructure · Car bumper and thermal properties

1 Introduction

Polymer composite materials have been a part of the automotive industry for several decades. Because of their favorable properties (e.g., high specific tensile and compressive strength, controllable electrical conductivity, low coefficient of thermal expansion, good fatigue resistance, and suitability for the production of complex shape materials), reinforced composites are very widely used [1–3]. In the present scenario, they have become the alternatives of conventional structural materials such as steel, wood, or metals in many applications [4].

Glass-fiber-reinforced polymers dominate composite materials used in automotive application [5]. However, the major limitation of using these synthesis fibers is due to their high cost, which resulted to overall increase in the cost of the components. Effort is being made by researchers all over world to look for alternatives materials that are less cost and ecofriendly. Akindapo et al. [6] studied the comparative assessment of mechanical behavior of groundnut shell and rice husks as reinforcement in epoxy matrix. The results obtained show that the groundnut shell-reinforced epoxy composites have superior mechanical properties. Kumar et al. [7] review the effect of coconut shell powder on the mechanical properties of coconut fiber-reinforced epoxy composites. In this paper, coconut shell powder (filler) at different contents (4 *v*/*v*%, 8 *v*/*v*%, 12 *v*/*v*%, 16 *v*/*v*%) and various proportions (8 *v*/*v*%, 12 *v*/*v*%, 16 *v*/*v*%, and 20 *v*/*v*%) of coconut fiber (reinforcement) had been used to prepare the epoxy composites. The results show that the mechanical properties decreased as volume fraction of coconut shell powder increases.

Easwara et al. [8] investigated treated and untreated sisal polyester composites. The composites were produced using sisal fiber percentage of 10, 15, 20, 25, and 30%. ASTM D256 standard was used for the impact test. The results obtained show that the untreated sisal polyester composite has peak impact strength of 3.581 N-m at its 30%. Treated sisal polyester composite has peak impact strength of 1.962 N-m at its 30%.

Ravikantha et al. [9] reported on the development of tribological property of epoxy glass composites filled with coconut shell powder (CSP). The CSP were reinforced in epoxy resin to prepare organic fiber-reinforced composites of different compositions. Dry sliding wear and abrasive trials were

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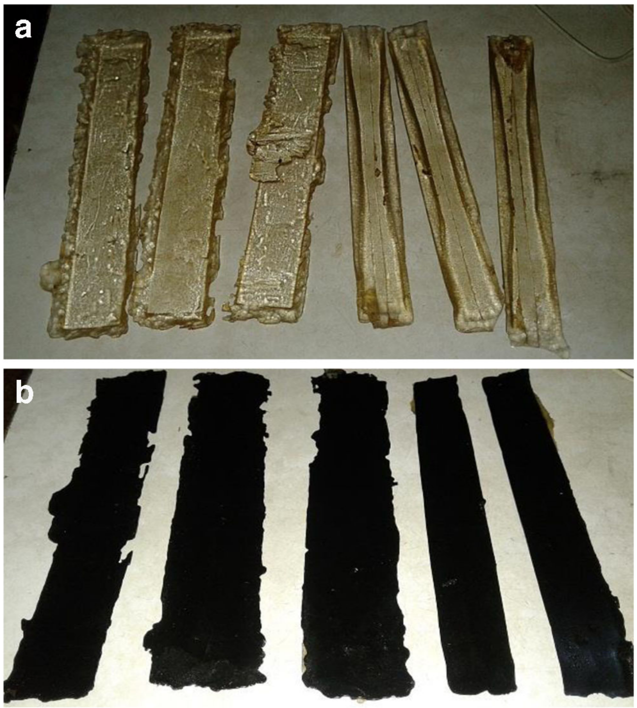


Fig. 1 **a** Control samples. **b** Reinforced samples

conducted using a standard pin-on-disc test set up following a well-planned experimental schedule based on Taguchi's orthogonal arrays. Taguchi's technique helps in saving time and resources for large number of experimental trials and predicts the wear response of epoxy composites within the experimental domain. The findings of the experiments indicate that the wear rate is greatly influenced by various control factors. Analysis of variance (ANOVA) is performed on the measured data and signal-to-noise (S/N) ratios. An optimal parameter combination is determined which leads to minimization of the wear rate. The results showed that inclusion of the CSP in epoxy resin improved the wear resistance of the composites greatly.

Manjunatha et al. [10] investigated composites developed using coconut shell particles as fillers in epoxy resin. The effect of particle size and filler volume fraction on mechanical properties was evaluated experimentally. Specimen's preparation and testing was carried out as per ASTM standards. The results of the investigation showed that the tensile, flexural, and impact properties are found to decrease with the increase in the filler particle size and filler volume fraction. Coconut shell particle-filled epoxy composites indicated hardness, greater than that of neat epoxy. The observations from fractographic investigation carried out to determine the mode of fracture under different types of loading are also reported.

Somashekhar et al. [11] studied the mechanical properties of coconut shell powder and tamarind shell powder reinforced with epoxy composites. The composites were made by mixing coconut shell powder, tamarind shell powder, and epoxy resin at definite ratios and they are tested for mechanical properties. From the results, it has been found that tamarind shell powder with coconut shell powder increases the tensile properties by around 50%. The best result and increase in mechanical

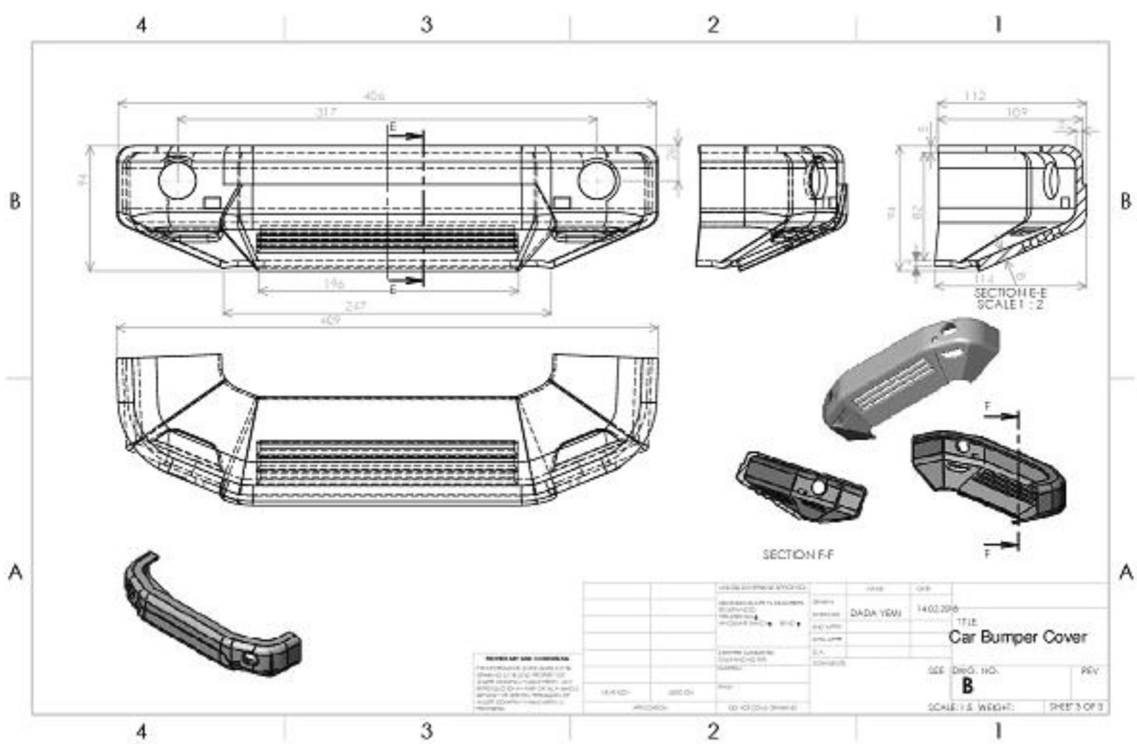


Fig. 2 **a** Engineering design of car bumper prototype. **b** Showing the core and the wooden mold. **c** Showing the wooden mold with cavity

Fig. 2 continued.

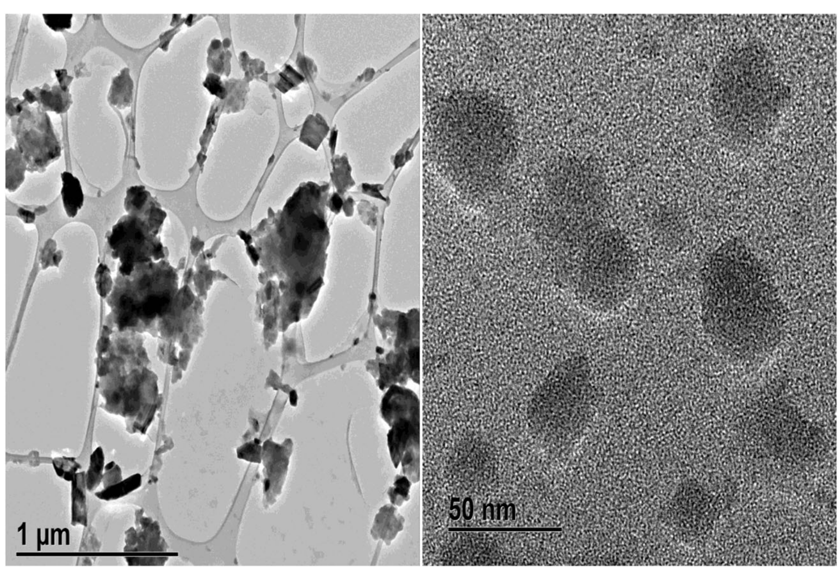
properties are obtained when the composition of the material is 50% of coconut shell powder and 5% of tamarind shell powder along with 45% of epoxy resin.

Agunsoye et al. [12] investigated the mechanical, morphological, and thermal stability of the recycled waste polypropylene composite reinforced with treated and untreated coconut shell particulate. The results obtained show that with 10% coconut shell particulates addition, the impact energy of the developed composites and thermal stability of the treated coconut shell-reinforced composite started decreasing.

Sapuan and M. Harimi [13] reported on the tensile and flexural properties of composites made from coconut shell filler particles and epoxy resin. The tensile and flexural tests of composites based on coconut shell filler particles at three different filler contents, viz. 5, 10, and 15%, were carried out using universal tensile testing machine according to ASTM D 3039/D 3039 M-95a and ASTM D790-90, respectively, and their results were presented. Experimental results showed that tensile and flexural properties of the composites increased with the increase of the filler particle content. The composite materials demonstrate somewhat linear behavior and sharp fracture for tensile and slight non-linear behavior and sharp fracture for flexural testing. The relation between stress and percentage of filler for tensile and flexural tests were found to be linear with correlation factors of 0.9929 and 0.9973, respectively. Concerning the relation between the modulus and percentage of filler for tensile and flexural tests, it was found to be a quadratic relation with the same correlation factor approximated to 1. The same behavior was observed for the strain versus percentage of filler for tensile and flexural tests, with the same correlation factor.

Durowaye et al. [14] investigated the mechanical behavior of coconut shell and palm fruit particulate polyester composites to develop an engineering material for industrial application. The highest hardness value for coconut shell particulate polyester composite was 208 BHN while that of palm fruit particulate polyester composite was 182.30 BHN. Mishra et al. [15] investigated the mechanical behaviors and water absorption capacity of coconut shell dust (CSP), fly ash-reinforced epoxy hybrid composites. The Vickers hardness test gave the values of 15.884, 16.098, and 16.88 VHN for

Fig. 3 TEM image of the coconut shell nanoparticles



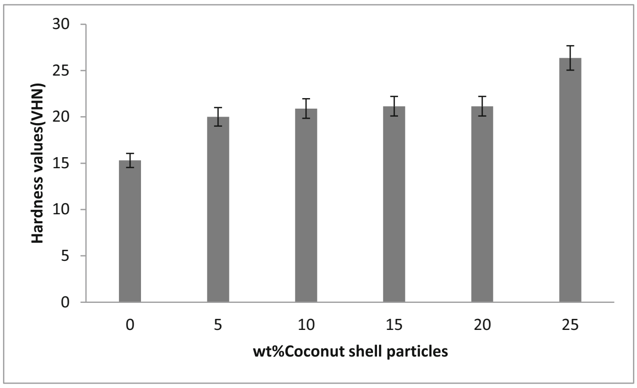


Fig. 4 Hardness against %weight of coconut shell addition

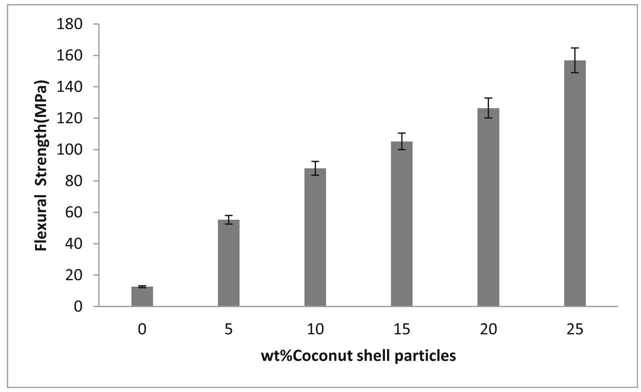


Fig. 6 Flexural strength at peak versus %weight of coconut shell addition

10, 15, and 20% CSP reinforcement, respectively. From the foregoing work, it has been observed the effect of coconut shell particles composites for car bumper application has not been given attention. Hence, this present work attempt to exploit the use of carbonized nanoparticles coconut shell for the reinforcement of epoxy composite for possible use for the production of automobile car bumper.

2 Materials and method

2.1 Materials

The epoxy resin and hardener used for this study were obtained from Ojota market in Lagos, Nigeria, while the coconut shell was sourced from a farm in Badagry in Lagos State, Nigeria.

2.2 Method

2.2.1 Preparation of carbonized coconut shell nanoparticles

The coconut shell was crushed into smaller sizes using a wooden mortar, pulverized with grinding machine, and sorted with sieve of 150 μm size. The sieved particle is put into a rectangular crucible of dimension (80 × 100 × 150) mm and placed inside an electrical furnace. The temperature of the furnace was raised to 1050 °C and held for 4 h to achieve homogeneity. The carbonized particle of coconut shell was milled using jam ball mill for 90 h to achieve nanosize particle. Particle size and morphology of the produced nanoparticles were examined by TEM (Jeol, JSM2010) using a 200-keV electron beam on the sample mounted on a carbon-coated copper grid.

2.2.2 Composite preparation

The epoxy resin was weight and poured into a dry steel bowl; 5 wt% of nanoparticles carbonized coconut shell was added to the epoxy resin and stirred for 2 min to obtain homogenization of the mixture. Hardener was added to the mixture and stir for 2 min until homogenization phase was obtained. The mixture was poured into a wooden mold of different cavities containing different dimension for various test analysis and was allow to cure at room temperature (28 °C). This process was repeated for 10, 15, 20, and 25 wt% addition of nanoparticles, respectively.

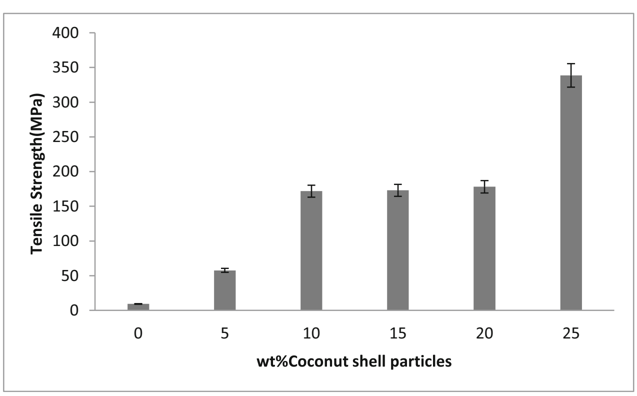


Fig. 5 Tensile stress at break against %weight of coconut shell addition

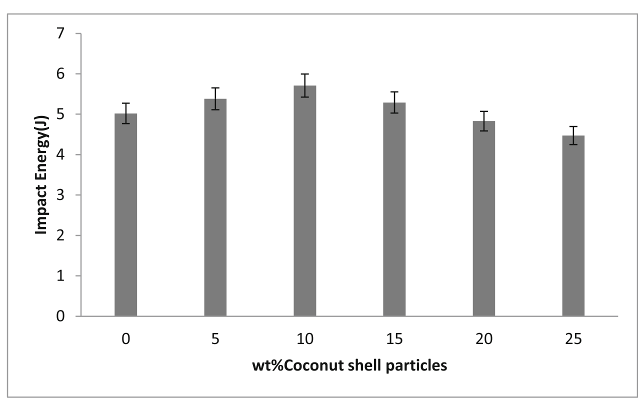


Fig. 7 Impact against wt% addition of coconut shell addition

2.2.3 Characterization of the composites

Epoxy composite coupons with dimension of 80 × 10 × 6 mm were used (see Fig. 1). An Instron tensile machine, model 3369; system ID: 3369s3457 was used to stretch the samples using a uniaxial tensile load at a cross head speed of 0.008 ($8X10^{-3}$) ms^{-1} equivalent to strain rate of 0.0001 ($1X10^{-4}$) s^{-1} until fracture occurred.

Flexural examination was carried out on coupons with dimension 120 × 10 × 6 mm using three-point bending method in accordance with ASTM D 790-03. Each sample was positioned horizontally on two pivots at a distance of 60 mm apart and loaded perpendicularly at the center using Instron 3369 tensile machine until the samples fracture.

Seteram TG-DSC 11, manufactured in France, interfaced with a SETSOFT 2000 software was used in this work and the test was carried out in University of Johannesburg, South Africa. The TGA was run in the vertical mode in order to create uniform heat distribution in the specimen and the reference. The specimen, which was 5 mm in diameter and 1 mm in thickness, weighed approximately 60 mg, and was placed in one of the pans; the other pan was pure graphite used as a

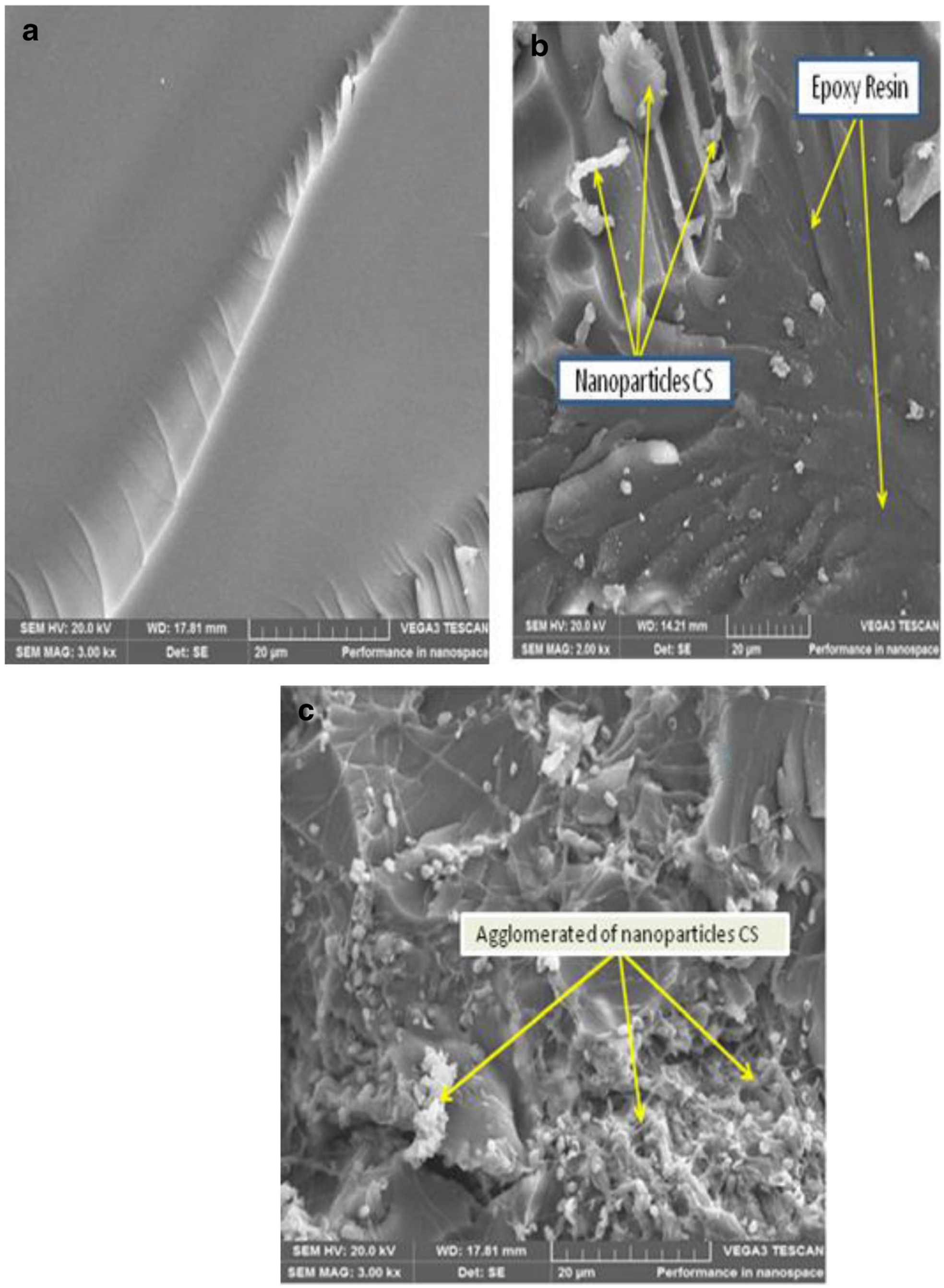


Fig. 8 **a** SEM of epoxy resin, **b** SEM of 5 wt% nanoparticles carbonized coconut shell composite, **c** SEM of 25 wt% nanoparticles carbonized coconut shell

reference. The samples were loaded in the TGA at room temperature, and each scan was conducted over a temperature range. A heating rate of 10 °C/min was used in all scans. Dry nitrogen was introduced and passed through the calorimeter cell to minimize oxidation. The positions of the peak temperatures on the TGA thermograms were determined by direct measurement from the graph.

2.2.4 Car bumper prototype production

The prototype was scaled down to a laboratory size (1:8 of the actual size of the Toyota highlander bumper) (see Fig. 2). The pattern was constructed with a wood, showing all the necessary cavities as indicated in the original bumper. The mold was design in two patterns (top and bottom) with a gating system which aid the flow of the resin into the intrinsic cavities of the mold. Grease was used as the mold release agent and it was smeared directly on the cavities of the mold using a brush. Of epoxy resin, 670 g was poured into a dry steel bowl and 5 wt% of carbonized coconut shell nanoparticles was added to the epoxy resin and was stirred manually for 2 to 3 min to attain a harmonize mixture. Of hardener, 270 g was added to the epoxy resin. The mixture was stirred vigorously using a steel rod for 2 min to attain homogenous mixture. The homogenized mixture was carefully poured into the mold cavity at a temperature of 28 °C and was allowed to solidify. After 24 h, the cast was carefully removed from the mold with the help of chisel.

3 Results and discussion

The TEM image is shown in Fig. 3. From Fig. 3, it was observed that the coconut shell nanoparticles were observed to be solid in nature, but irregular in size. The average particles size obtained are within the ranges of 50 nm.

Hardness values for the composite indicate that the 25% weight of coconut shell additions shows the highest values which is due to increase in CSnp addition reaction which dominates the cross-linking process leading to the formation of a stronger material which exhibits better hardness. (see Fig. 4).

From Fig. 5, it is clearly seen that the tensile stress at break increase drastically as the coconut shell addition increase from 5 to 25 wt%. In general, the maximum tensile stress of 338.75 MPa was recorded at 25 wt% of coconut shell addition. It might be attributed to better dispersion of coconut shell in the matrix and interfacial bonding. Similar observation was observed in Davoodi et al. [16] for car bumper application.

From Fig. 6, it was observed that as the %weight of coconut shell addition increases the flexural strength increaesd (see Fig. 6). At 25% weight of coconut shell addition has the highest flexural strength. This could be attributed to the high degree of cross-linking which imparts high bending strength to the new composite and resist the force at bend.

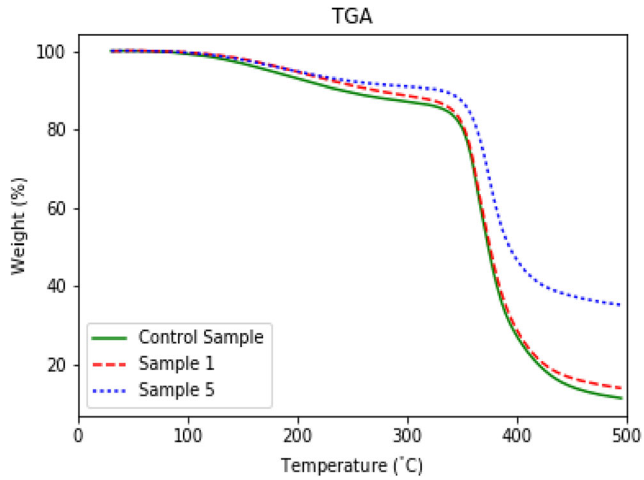


Fig. 9 Thermogravimetric analyses (TGA) curves of the polymer composite

The result of the Charpy impact test is represented graphically in Fig. 7. From Fig. 7, it was observed 10% weight coconut shell addition has the highest impact energy. Beyond the 10 wt% CSnp, the impact energy decreased. However, the impact energy values obtained in the work are within recommended standard for bumper application [17].

SEM micrographs of the fractured surfaces of coconut shell nanoparticles-reinforced epoxy composite are shown in Fig. 8. In Fig. 8b, there was some dispersion of CSnp in the polymer composite at 5 wt%, while CSnp agglomeration was observed at 25 wt% (Fig. 8c). This observation was a further indication of the improved tensile, flexural strength values that were achieved under mechanical testing of the coconut shell nanoparticles-reinforced composite.

Thermogravimetric analyses were performed on the composites to compare their thermal stability. The control sample is thermally stable up to about 130 °C. Above this temperature, a first degradation step was observed until ≈ 280 °C, resulting in a weight loss of 16% (see Fig. 9). In the temperature range between 281 and 320 °C, no obvious weight loss was observed. Above the main degradation stage, all the

Fig. 10 **a** Front view of the prototype; **b** back view of the prototype

volatile materials are driven off from the sample resulting to residual ash content of about 5%. The main degradation occurred at 321 until 498 °C.

The composites are thermally stable up to about 130 °C. Above this temperature, a first degradation was observed ≈ 280 °C resulting in a weight loss of 15 and 14%, respectively. Between 281 and 320 °C, no obvious weight loss was observed. The last degradation stage occurred at 320 to 498 °C, all the volatile materials are driven off from the samples resulting to residual ash content of about 7 and 36%.

The developed epoxy composite when compared with two existing Toyota models showed improved impact energy at break of 10.5% over Big Daddy Model and 37.45% over Carina model under the same testing conditions (Fig. 10).

4 Conclusions

From the results and discussion above, the following conclusions are drawn:

1. The addition of nanoparticles size carbonized coconut shell at 25% weight produced the optimal hardness value (26.35 VHN), tensile stress at break (338.75 MPa), and flexural strength (156.9 MPa) and at 10% weight produced optimal impact energy (5.71 J).
2. The developed epoxy composite when compared with two existing Toyota models showed improved impact energy at break of 10.5% over Toyota Big Daddy Model and 37.45% over Toyota Carina model under the same testing conditions
3. The work has established that nano-sized carbonized coconut shell particles can be used production of automobile bumper.

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