

MRS_002: Sustainable Materials from Wastes for Engineering Applications

^{1,*}Sefiu Adekunle Bello; ¹Abdul Ganiyu Funsho Alabi; ¹Sunday Wilson Balogun; ¹Mohammed Kayode Adebayo; ¹Suleiman Danjuma Daudu; ¹Aisha Mayowa Akintola; ¹Karimat Aderoju Saba

¹Department of Materials Science and Engineering, Kwara State University, Malete, Kwara State, Nigeria

Corresponding Author: sefiu.bello@kwasu.edu.ng

Abstract

Nonedible components of agricultural production have been reported to have harmful impacts on the environment. This spurs research on value-added products from agricultural waste, resulting in the emergence of new materials with enhanced properties compared to traditional materials produced from synthetic materials. In Nigeria, many studies have been successfully completed, ending up in journal article publications. However, the transformation of such materials into a business scale to create wealth and boost the economic growth of the country has been a problem due to a lack of funds and the implementation of policies to encourage local consumption of locally produced materials, especially in automotive and other engineering industries. Indigenous technologies for local productions of vehicle parts like automobile bumper fascia, bumper beam and vehicle bonnet have been developed and remain only as patents and journal article publications. Government policy is needed to foster commercialisation for local consumption of such materials by vehicle manufacturing industries in Nigeria. This presentation has been made to showcase various emerging technologies on local productions of artefacts in Nigeria with the hope of calling the government's attention to the development for possible support for commercialisation.

Keywords: Emerging, Materials, Government, Policy, Economics impact

Introduction

Transportation is unavoidable to human. The most common and cheapest means of transportation is by land through use of automobiles. Nearly all vehicles used in Nigeria are imported. Generally, importation faces scarce foreign reserves, causing difficulty in currency conversion. A huge amount of money is spent annually. According to National Bureau of Statistics, vehicle's importation increased by 72.4% in 2017 (Okafor, 2018). With this, as at third quarter of the same year; Nigerian's vehicle per person is 0.06 (Nairametrics, 2017). This implies that Nigeria automobile market is broad and untapped. The annual expenditure on importation can be domiciled in this country if automobile parts and other items used in this country are manufactured locally.

Bonnet or hood (in USA or Canada) is one out of 250 components that work together as a system for providing means of transport. It is designed to cover and protect automobiles' engine. Based on its functional and production requirements, it is expected to have good mechanical properties, thermal stability and wear resistance. Bumper is a front or rear part of automobiles, designed and shaped to be impact absorbing and protecting automobiles from damage in a low impact collision. It has three components which are bumper fascia, bumper beam, and energy absorber. Bumper beam serves as the shock absorbing component of a vehicle. It is installed at the front and rear of vehicle with the aids of bracket. It is a crash box via impact absorption in the axial direction (Davoodi *et al.*, 2011). Energy absorber reduces the impact energy by an elastic deflection at the transverse fixing point and the fascia is the cover to other bumper components. It provides the aesthetics and resists aerodynamic drag.

Initially, bonnet and bumper were produced from heavy steels because of the steel's high energy absorption. This provides safety of the vehicle and its passengers in an accidental collision with obstacles. On the other hand, high weight of the vehicle contributes to its heaviness and causes high impact on pedestrians in a vehicle-pedestrian infraction at low speed. This inflicts injuries on many pedestrians globally and in a severe case, it leads to death. Increasing pedestrian fatalities and disabilities resulting from road accidents daily is ranked as a major health problem globally. In 2004, road traffic problems were estimated to be ninth leading cause of death. It is projected to double by the year 2030. Thus, according to (Fredriksson, 2011), it is equivalent to fifth leading death cause. In 2011, estimates demonstrated that pedestrian problems were 12% of all road traffic problems in United State of America (USA), 15% in western Europe, 33% in Japan and more than 55% in Africa countries. The high rate observed in Africa is attributed to underdeveloped state of road infrastructure and high exposure of pedestrians to roads especially those engage in hawking for their livelihood along highways.

Upon the identified vehicle problems due to vehicle collisions with pedestrians, many studies were performed using finite element modelling approach by different authors globally. According to many reports in literature, essence of such research is to identify which vehicle components that first touches the pedestrian in any vehicle infractions with road walkers. Bumper, bonnet and windscreen were reported to be the components that tough the pedestrian in any collisions. It has

been reported that on collision, bumper impacts on pedestrians off lift the pedestrian from the ground and cause knocking of their heads on the vehicle bonnet or below the wind screen. To address this problem, legislations were made globally including European Union and Asian Pacific legislations such European New Car Assessment Programmes (NCAP) (Fredriksson *et al.*, 2010; Davoodi *et al.*, 2011; Carroll *et al.*, 2014) and ECE/324 Regulation No 42 (Balamurugan, 2009; Carroll *et al.*, 2014). NCAP dictates considerations of pedestrian safety to the design of bumper and bonnet which entails uses of lightweight materials for the vehicle components. These legislations were considered by researchers in Nigeria especially in the department of Materials Science and Engineering, Kwara State University, Malete in developing materials for automobile applications. Developments of emerging technologies on local fabrication of automobile components in Kwara State university focuses on the university's agenda on community development towards addressing local problems. It is in line with the Federal Government's initiatives on economic diversification and transforming Nigeria into a global automotive manufacturing hub which is embarked on, by the National Automotive Design and Development Council (NADDC). Therefore, this article aims to showcase state of arts of automobile materials in Nigeria with goals of calling government's attention to the locally developed materials for possible support to transform proofs of concept from research findings to vehicle size scaled artefacts for commercialization to boost economy of the country.

Developed Materials for Automobile Applications

Materials developed for automobile applications in Nigeria includes alloy, metallic and polymeric nanocomposites. These materials were sourced from locally available materials including scraps and agricultural wastes.

Alloy

Alloy is a mixture of elements in which a principal element is a metal. Principal element (metal) is otherwise called matrix or solvent and has the highest proportions among other elements. Examples of alloy are steel; cast iron that contain iron and carbon; duralumin that has aluminium, copper, magnesium and manganese; solder that harbours lead and tin and brass that contains copper and zinc. Aluminium alloys have been used extensively in the automobile components because of their lightweight in addition to their excellent mechanical properties. Heat treatable Al 6061 is used in making vehicle frames and panels. Al-Si-Mg (A356) is used in making engine block and transmission cases because of its excellent mechanical and wear resistant properties and Al-Si-Cu (A319) is used in making suspension parts. Properties of the alloy reflects its microstructure which contains both solid solution and intermetallic. Solid solution is a homogeneous structure that contains both solvent and solute. It has crystal structure which can be FCC, BCC, HCP, etc. It can also be substitutional or interstitial solid solution. It has moderate strength and ductility, and it is responsible for strength and ductility of the alloy. Intermetallic is a compound. It is hard and less ductile. Its presence as an alternate structure in the alloy improves the strength of the alloy but impairs its ductility and toughness. Moreover, recent emerging high entropy alloy (HEA) technology gives births to numerous metallic materials that have optimum combination of high strength and ductility. This is achievable by high entropy hypothesis that eliminates or limit

formation of intermetallic in the development of the HEA. A new approach to alloy development establishes a mixture of at least five principal elements of equal or nearly equal proportions producing a large change in entropy favouring formation of solid solution enhancing both strength and ductility, hence the name; high entropy alloys (HEAs) otherwise called multicomponent alloys. The high change in entropy after mixing all principal elements making up the multicomponent alloy limits/prevents precipitation of intermetallic (Li *et al.*, 2013) through overcoming enthalpies of formation of the intermetallic compound and promotes formation of solid solution while the melt of the metal mixture solidifies. This forms a basis for excellent combination of properties like strength, ductility, impact energy, hardness, wear, refractory and corrosion resistance properties by the HEAs. This concept was first reported in a published paper in 2004 by Professor Yeh, J. W. of National Tsing Hua University, describing production of crystalline multicomponent alloys through development of metallic alloys having at least five principal elements of nearly equal concentration or proportions (Yeh *et al.*, 2004; MacDonald *et al.*, 2017) with proportion of each element in the alloy mixture ranges from 5% and above but must be less than 50% (Li *et al.*, 2018).

Composites

Composite is defined as a material developed from a combination of two or more micro or macro-constituents that differ in form and chemical composition. The properties and structural performances of composites are much superior in some manner to the properties of the individual constituents, acting independently (Valery and Evgeny, 2001). Mathematically, the composite has a matrix and a reinforcement. The matrix acts as a binder that connects reinforcement together. The matrix can be a metal (alloy), polymer and ceramic. The reinforcement or filler is the load bearing capacity of the composites. It is present in a smaller proportion than the matrix. The reinforcement can be fibrous or particulate. Fibres are cylindrical materials having a long length but very small diameter. Its diameter determines whether it is a coarse fibre or nano fibre. The fibre can be continuous or random. Continuous fibre has a length that runs throughout the material while the random or short fibres appear in length smaller than the length of the whole material. Particulate reinforcement can be coarse, fine, ultrafine and nanoparticles. Particle has only one dimension which is a diameter. When the diameter is greater than 400 μm , it is described as coarse particles. When it is less than 400 μm , it is called a fine particle which can be fine, ultrafine or nanoparticles.

Despite the excellent mechanical properties of composites in addition to their lightweight, applications of composites have been limited due to cost. The high cost of composites can be from high expenses of the matrix and those of the synthetic fibres. Moreover, to make the composites affordable, efforts have been made to source reinforcement from agricultural wastes, which they are nonedible components of agricultural productions. Large amounts of agricultural wastes generated from agricultural productions constitute nuisances in the environments. This is because many people don't realise their values, they are left untapped, become rotting and serve as sources of ailment/epidemics in the society rather than being a source of income.

Selected agricultural wastes

Coconut shells (CSs) are natural composites, that possesses a protective chamber for coconut and its juice. A coconut fruit contains three layers which are endocarp and mesocarp as shown in Figure 1. The endosperm is the edible component of the fruit. It is described as albuminous testa which is white and fleshy. It harbours the coconut juice. The endocarp is the inner layer. It is a hard lignocellulosic composite which is called a coconut shell and the mesocarp is the ductile fibre-spongy husk called coconut coir (Sarki *et al.*, 2011). They are agricultural wastes obtained from home and coconut processing industries after the edible parts have been removed. Report has shown that CSs and spongy coir contain carbonaceous materials such as cellulose, lignin and pentosans, which are potential materials for reinforcement (Sarki *et al.*, 2011; Agunsoye *et al.*, 2014). Globally many researchers are now focusing on agricultural wastes such as coconut shell, palm kernel shell, banana peel, cashew shell, walnut shell, ground nut shells and *Delonix Regia* seed to replace highly expensive conventional glass and carbon fillers for polymer and metal matrix composite productions (Hassan *et al.*, 2013; Agunsoye *et al.*, 2014; Bello *et al.*, 2015c; Hassan and Aigbodion, 2015). The agricultural wastes or natural fillers have advantages of low cost and sustainability in developing ecofriendly composites for engineering applications.

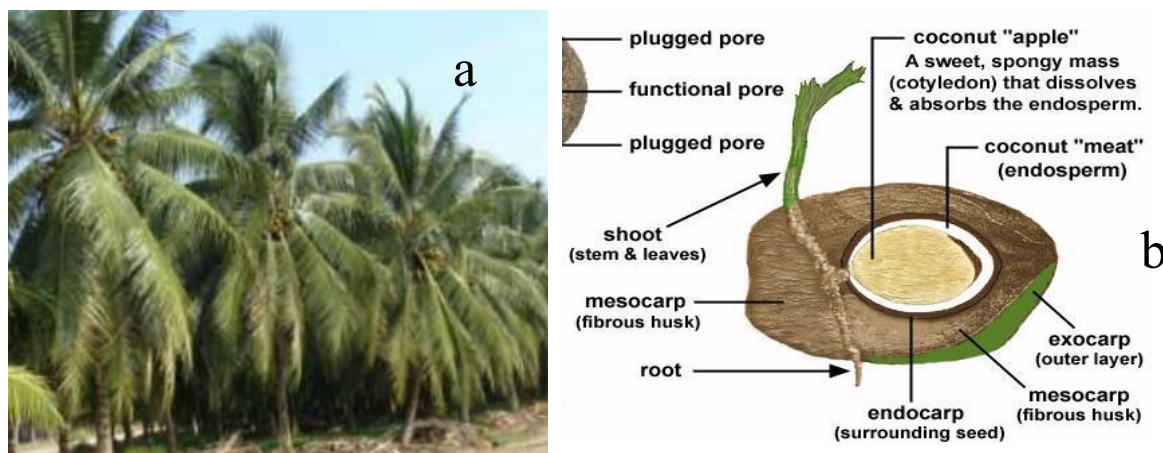


Figure 1: Computer model showing (a) coconut tree and (b) coconut fruit



Figure 2: Images of (a) flamboyant tree (b) eggshells and polyethylene wastes

Delonix regia is also called pride of Barbados or flamboyant tree (Figure 2a). It is a flowering tree in tropical and subtropical climates. In the beginning of rain season, it bears bountiful and showy flowers which produce a characteristic captivating scent. The tree has antioxidants and phytochemicals like flavanol, anthocyanins, and phenolic acids as bioactive secondary metabolites which help in treating different ailments (Modi *et al.*, 2016; Bello, 2022). Moreover, the producing flowering parts called pistils provide the ovaries (green colour) and when matured, they turn to brownish pods called flamboyant fruits. These fruits are produced two times in a year. They are not edible and contain hard seeds. Being hard, both pods and seeds are potential sources of reinforcement for composite productions. Besides the identified benefits of the flamboyant tree, its issue is that its nonedible pods contribute to the solid wastes when dry. Pods and seeds fall from the tree and litter the environment.

Eggshells (Figure 2b) are structural chambers for embryonic chicks. They protect chicks and provide exchange of gas for the chicks. They are container for eggs and give egg protection against contamination and mechanical damage. Eggshells contain 95 % calcium carbonate in form of calcite and 5 % organic matters including protein, polysaccharides, and collagens. Eggshells are major source of calcium for bone strengthening. In addition, impact of date seeds, eggshells and flamboyant pods include environmental dirtiness, odour, flies, and disease outbreak that make cities and human settlements no inclusive, unsafe, no resilient and unsustainable. These are against the European Union Sustainable Development Goal (UN SDG) 11. Recycling of the wastes for emerging useful nanocomposites will enable wealth creation from wastes and help solving global threat from wastes that have negative impacts on our environment.

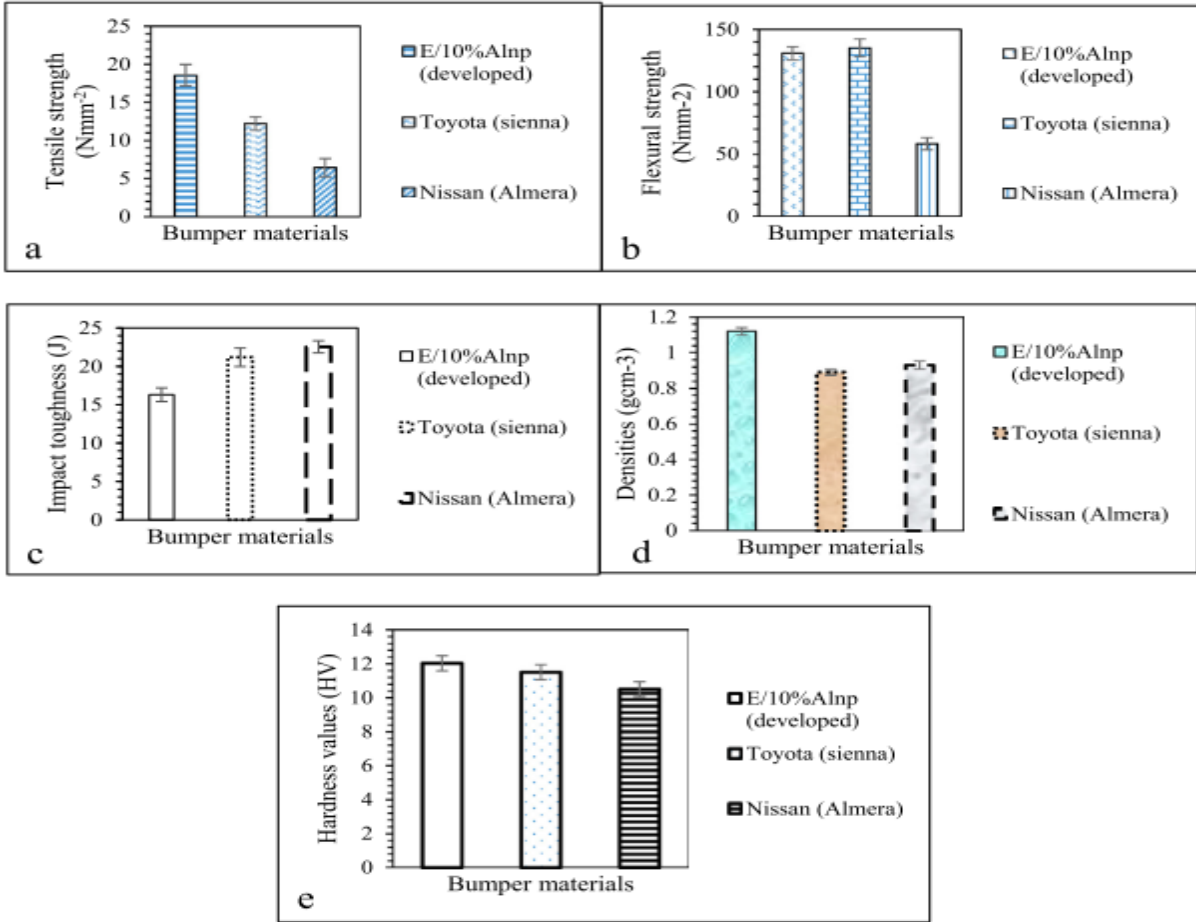


Figure 3: Benchmarking properties of aluminium nanoparticle reinforced epoxy bumper fascia with those of existing materials selected from NISSAN and TOYOTA vehicles (adapted from (Bello *et al.*, 2020))

Aluminium nanoparticle reinforced epoxy bumper fascia

This bumper beam was produced from aluminium nanoparticle and epoxy. Aluminium particles were produced from aluminium rods which were produced from aluminium cans. Rods were turned into tiny brittle fibres through wet milling using Colchester/triumph lathe machine, model 2000. The fibres were converted into nanoparticles through optimized milling using 87002 LIMOGES planetary ball mill (model: 28A20-92). About 0.1% carbonised coconut shell was added to the aluminium fibres which acted as seed during milling. Size of the aluminium nanoparticles was determined using TEM. The detail was published in the article (Bello *et al.*, 2017; Bello *et al.*, 2018). 59 nm aluminium nanoparticles (Alnp) were added to glycidyl ether of bisphenol A and 1,3-diethanamine benzene hardener. The mixture was stirred and degassed using vacuum oven before pouring into the mould. Mechanical analyses were performed on different grades of composite produced to determine their technical properties as reported in (Bello *et al.*, 2020). Mechanical properties of these materials compared with those of existing bumper fascia is presented in Figure 3.

Hybrid particle reinforced epoxy for vehicle dashboard applications

Similarly, uncarbonised coconut shell nanoparticles were produced. The coconut shells were broken into pieces using the Broyeur Clero hammer crusher. Broken fragments were turned into powders using a disk mill. Powders were classified using sieve set arranged in descending order of aperture sizes. Powders collected in the pan below the sieve of the finest aperture were further milled using a SNH 510....680 tumbler ball mill, model A 50....43 at 10 charge ratios and balls of different sizes (5-60 mm diameter), The drum rotated at 192 rpm. Particles were examined using TEM to confirm its nanoparticle and determine its sizes as reported in the articles (Bello *et al.*, 2015a; Bello *et al.*, 2015b). The synthesised uncarbonised coconut shell nanoparticles and aluminium nanoparticles were used as hybrid reinforcement in glycidyl ether of bisphenol A and 1,3-diethanamine benzene hardener to produce nanocomposites with different proportions of the hybrid nanoparticles to know the proportion of the hybrid particle mixture that gives the optimum properties.

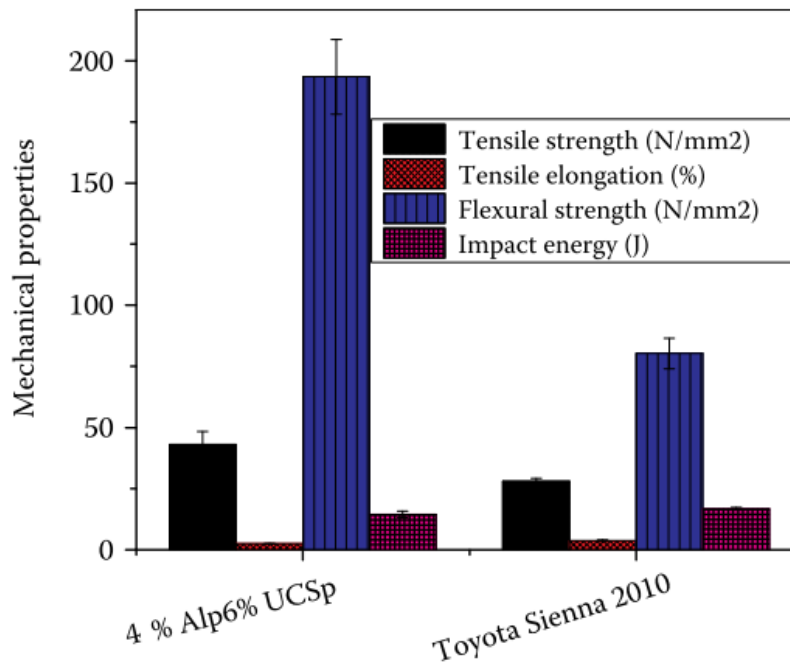


Figure 4: Comparison of mechanical properties of the uncarbonised coconut shell-aluminium hybrid particle reinforced epoxy with those of the existing material for dashboard applications

Results of the mechanical properties carried on the hybrid nanocomposites shows that the epoxy nanocomposite at 4wt% of aluminium and 6wy% uncarbonised coconut shell particle has the highest tensile strength of 43.20 Nmm⁻². Therefore, it is selected as the candidate material for the vehicle dashboard. Its other mechanical properties as reported in the article are flexural strength of 193.43 Nmm⁻²; impact energy of 14.52 J; hardness of 1.06 HV and density of 12.03 gcm⁻³. These properties were benchmarked with properties of the TOYOTA SIENNA 2010 dashboard cover (Figure 1). It is observed that the properties of the developed hybrid nanocomposite are superior to those of the existing materials.

Nanosilica reinforced $\text{Al}_{0.44}\text{Si}_{0.32}\text{Ni}_{0.09}\text{Fe}_{0.05}\text{V}_{0.05}$ high entropy alloy (HEA) for vehicle bonnet applications

High entropy alloy ($\text{Al}_{0.44}\text{Si}_{0.32}\text{Ni}_{0.09}\text{Fe}_{0.05}\text{V}_{0.05}$) was developed from aluminium scraps, ferrosilicon, and nickel alloy. To improve the properties, nanosilica was incorporated into the developed HEA and mechanical properties of the developed materials were examined. To probe the suitability of the developed HEA for the vehicle bonnet applications, standard samples were prepared and cut from bonnets of LEXUS LX570 (2018 model), TOYOTA HILUX (2017 model), and TOYOTA CAMRY (2018 model). The cut samples were tested under the same conditions with those of the developed HEAs. Properties of the developed HEAs were benchmarked with those of the materials of the selected vehicle bonnets. Comparison of the properties is presented in Figure 5. Details of the study are published in the article (Bello *et al.*, 2025a).

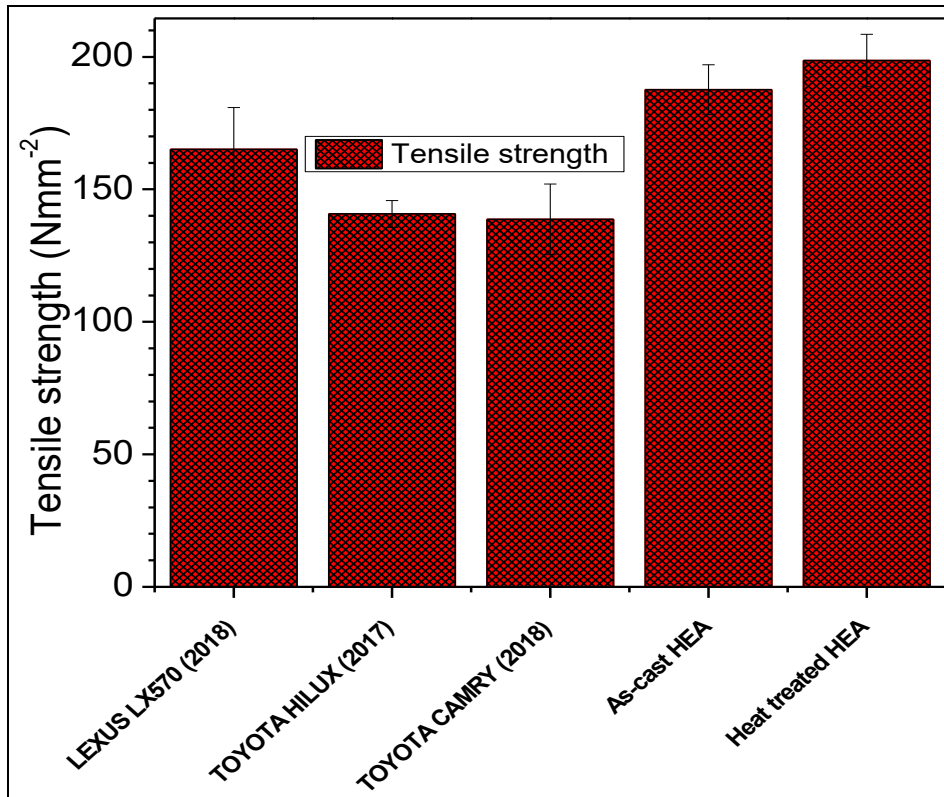


Figure 5a: Tensile strength of the developed high entropy alloys compared with those of existing bonnet materials

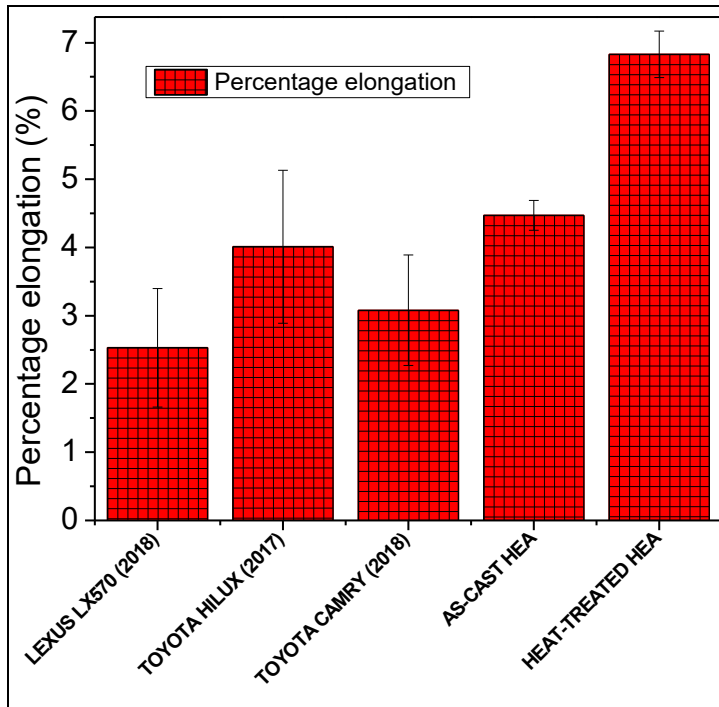


Figure 5b: Tensile percentage elongation of the developed high entropy alloys compared with those of existing bonnet materials

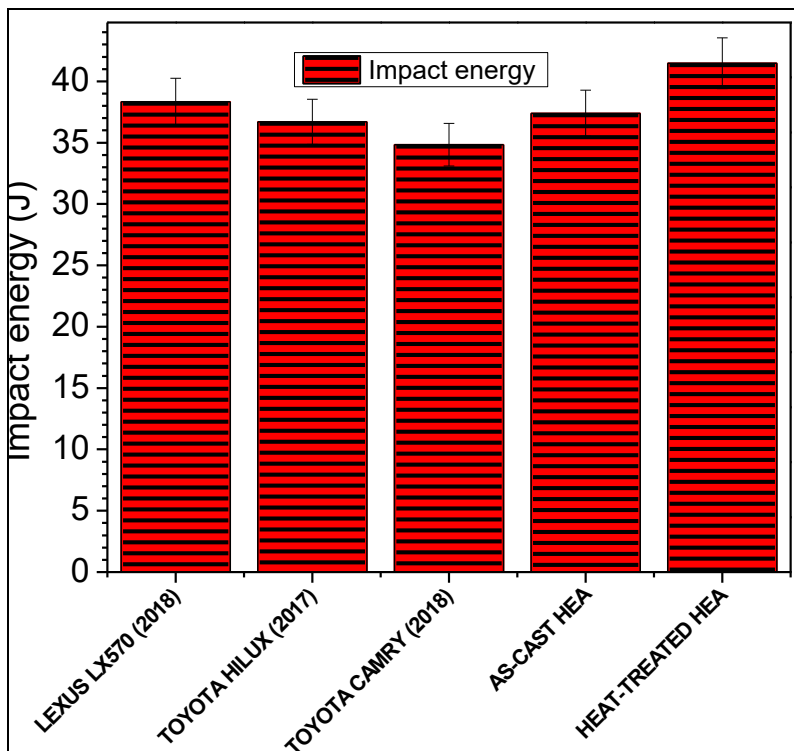


Figure 5c: Impact energy of the developed high entropy alloys compared with those of existing bonnet materials

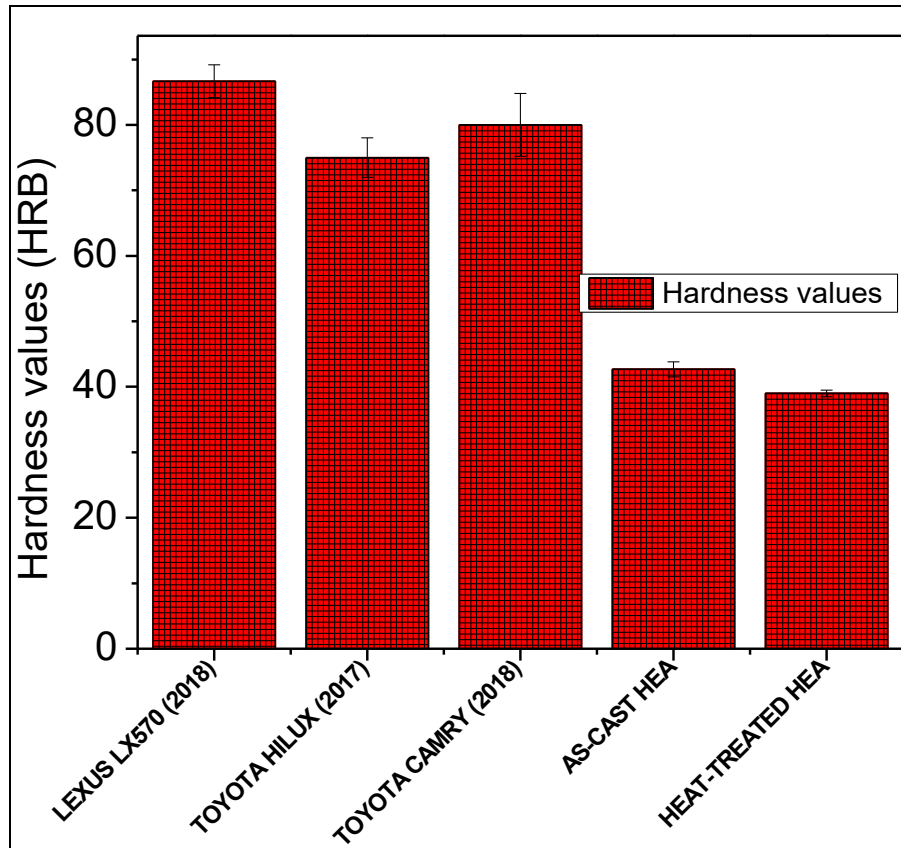


Figure 5d: Hardness values of the developed high entropy alloys compared with those of existing bonnet materials

It is observed from comparison that the tensile strengths of the developed HEAs are greater than each of the bonnet materials. Similar observation is made with the percentage elongation of the HEAs. However, impact energy of the LEXUS LX 570 is greater than that of the as-cast HEA while that of the heat-treated HEA is the greatest. Since properties of the heat treated HEA are superior to those of the bonnet materials, it implies that the heat-treated HEA is the suitable for candidate for fabricating bonnets of LX 570, HILUX and CAMRY but the as-cast HEA can only be used for both HILUX and CAMRY bonnets as reported in the article (Bello *et al.*, 2025a).

Eggshell nanoparticle reinforced low-density polyethylene bumper fascia and dashboard

To address problems of polyethylene wastes (Figure 2b), eggshell and flamboyant pods, they were recycled for green production of new materials targeting applications in the automobile components. Eggshells and flamboyant pods were converted into nanoparticles using comminution process. Polyethylene containing eggshells as only reinforcement while varying proportion of additions was developed. Also, flamboyant seed nanoparticle reinforced polyethylene was produced and hybrid particles containing both eggshell and flamboyant seed nanoparticles were used as reinforcement in both recycled and new polyethylene to develop hybrid polyethylene-based nanocomposites. All materials developed were examined to determine their mechanical properties which were benchmarked with standards to ascertain their applications in

engineering components. Results obtained on eggshell nanoparticle reinforced polyethylene affirm their suitability for the automobile bumper fascia as presented in Table 1.

Table 1: Properties of the bumper fascia materials

Bumper fascia materials	Tensile Strength (Nmm ⁻²)	Flexural Strength (Nmm ⁻²)	Impact energy (J)
HONDA ACCORD 2002	15.076	1.861	40.3
TOYOTA SIENNA 2005	13.394	5.561	40.99
LEXUS RX 300	18.224	2.115	41.12333
12wt%Eggshell/VLDPE	13.80	25.385	23.195
10wt%Eggshell/RLDPE	10.64	21.964	21.690
TOYOTA SIENNA 2010	12.23	135.16	21.18
NISSAN ALMERA 2010	6.44	58.3	25.54
Azdel Plus C401-B01 40 % Chopped-Fibre-Mat/ polypropylene bumper fascia			18.01

Maximum tensile strength of 13.8 Nmm⁻² was obtained for the eggshell nanoparticle reinforced virgin/new low-density polyethylene at 12wt% of eggshell nanoparticle additions. Tensile and other mechanical properties of this material were benchmarked with those of the existing materials for bumper fascia as the details were published in the article (Bello *et al.*, 2025b). Comparison indicates that its properties fall within the range of materials' properties for the bumper fascia. The same observation is made with the eggshell nanoparticle reinforced recycled low-density polyethylene though its properties are inferior to those of the new polyethylene-based composites. It can also be used to fabricate bumper fascia for the NISSAN Almera. Its tensile strength is much greater than that of the NISSAN Almera bumper fascia and its impact energy is very close to that of the NISSAN Almera. Details of research on eggshell particle reinforced recycled low-density polyethylene were communicated in the article (Bello *et al.*, 2023).

Moreover, findings on flamboyant pod-eggshell particle reinforced low-density polyethylene declare that at 4wt%-flamboyant pod-6wt%-eggshell hybrid nanoparticle additions, both recycled low-density polyethylene (RLDPE) and new/virgin low-density polyethylene (VLDPE) have maximum tensile strength of 19.26±3.21 and 28.39±1.42 Nmm⁻², respectively comparing with

other developed nanocomposites. Details were published in the article (Bello *et al.*, 2024). According to the report in the article, RLDPE-based hybrid nanocomposite records a tensile modulus of $1069.26 \pm 38.13 \text{ Nmm}^{-2}$ while that of the VLDPE-based hybrid nanocomposite is $1137.42 \pm 85 \text{ Nmm}^{-2}$. Properties of both RLDPE and VLDPE-based nanocomposites compared with TOYOTA SIENNA XLE dashboard cover (2010-2013 model) are presented in Figure 6. It is noted in Figure 6a that the tensile strength of VLDPE based hybrid particle nanocomposite is slightly greater than that of the material for the lower layer of the dashboard cover. Both hybrid materials have superior tensile strength to that of the dashboard upper layer. Similarly tensile moduli (Figure 6b) of the hybrid nanocomposites are comparable with that of the material for lower layer of the dashboard cover and much greater than that of the material for the upper layer. Flexural strength and modulus (Figure 6c-d) of the lower layer are much greater than both of the developed hybrid nanocomposites as reported in the article (Bello *et al.*, 2024) from which the data for plotting the graph were drawn.

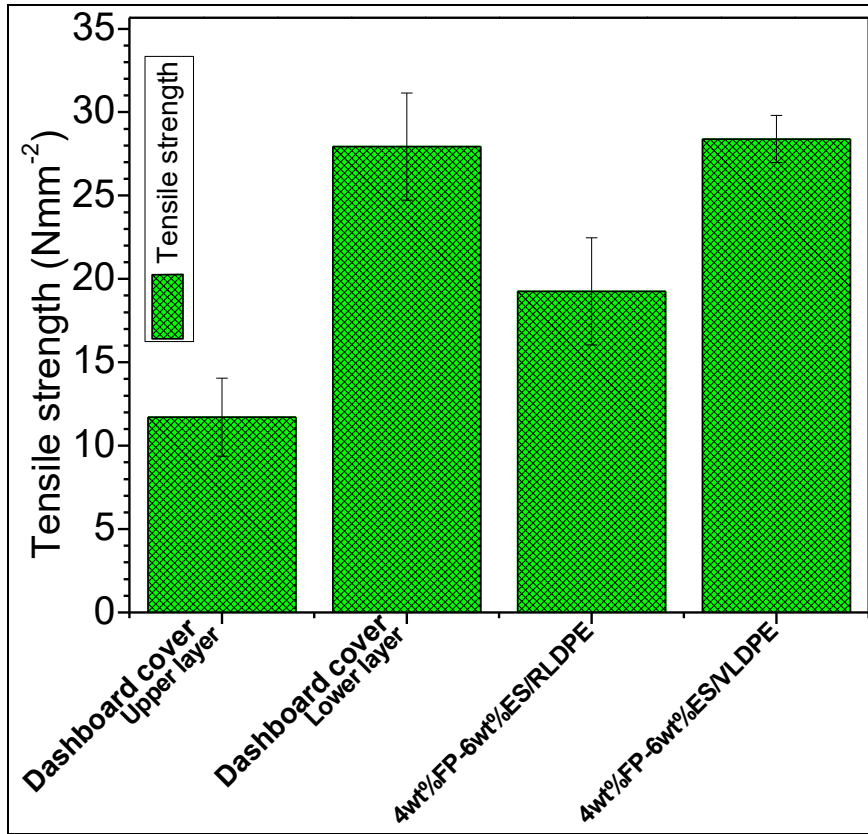


Figure 6a: Tensile strength of hybrid particle reinforced low-density polyethylene benchmarked with tensile strength of the XLE TOYOTA Sienna dashboard cover

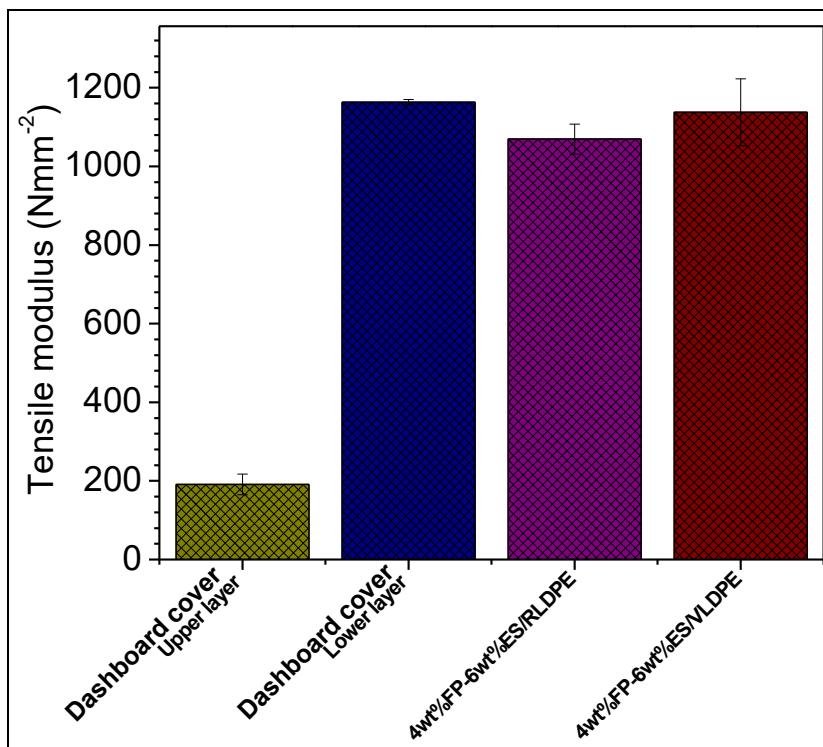


Figure 7b: Tensile modulus of hybrid particle reinforced low-density polyethylene benchmarked with tensile strength of the XLE TOYOTA Sienna dashboard cover

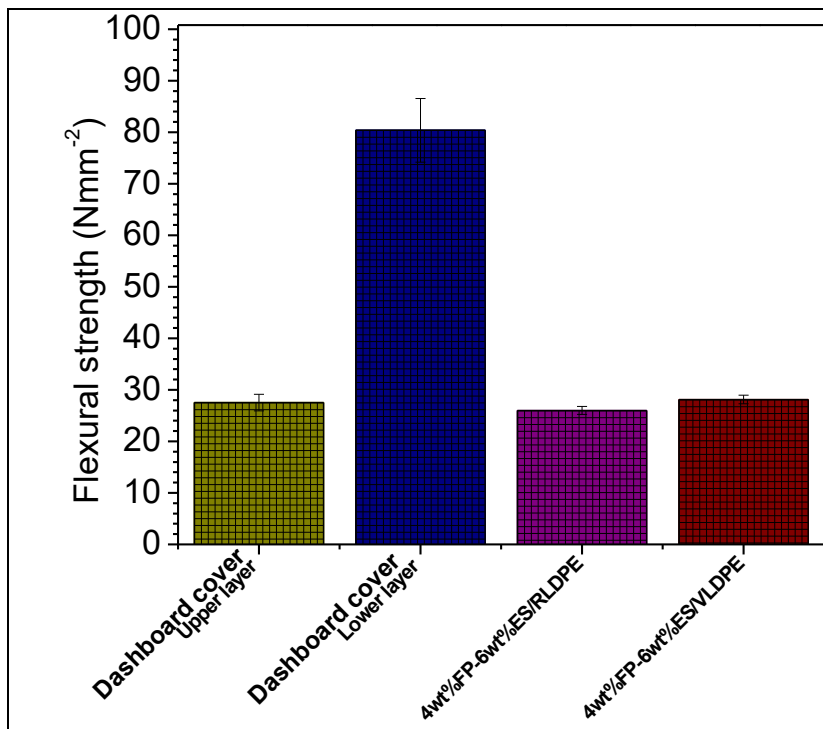


Figure 8c: Flexural strength of hybrid particle reinforced low-density polyethylene benchmarked with tensile strength of the XLE TOYOTA Sienna dashboard cover

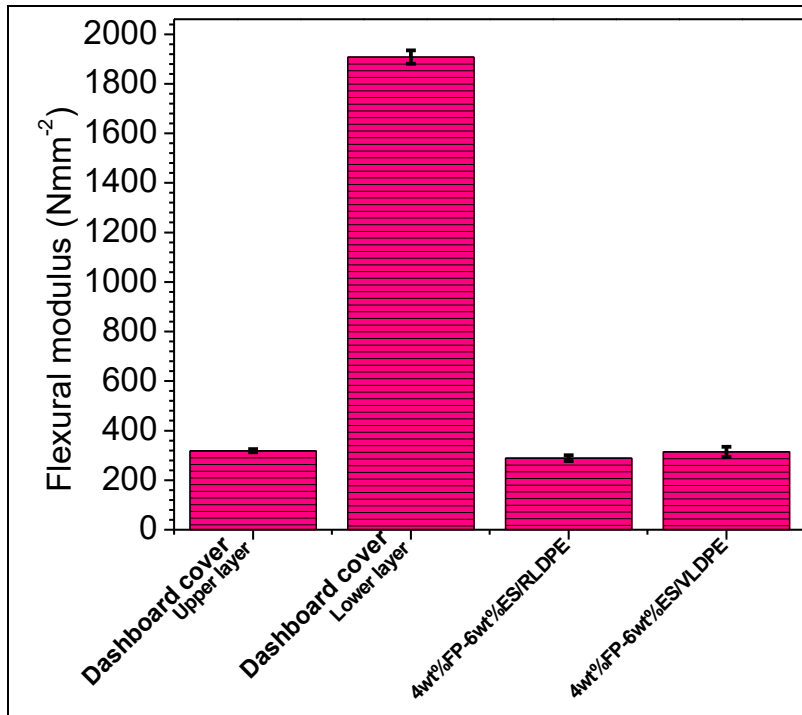


Figure 9d: Flexural modulus of hybrid particle reinforced low-density polyethylene benchmarked with tensile strength of the XLE TOYOTA Sienna dashboard cover

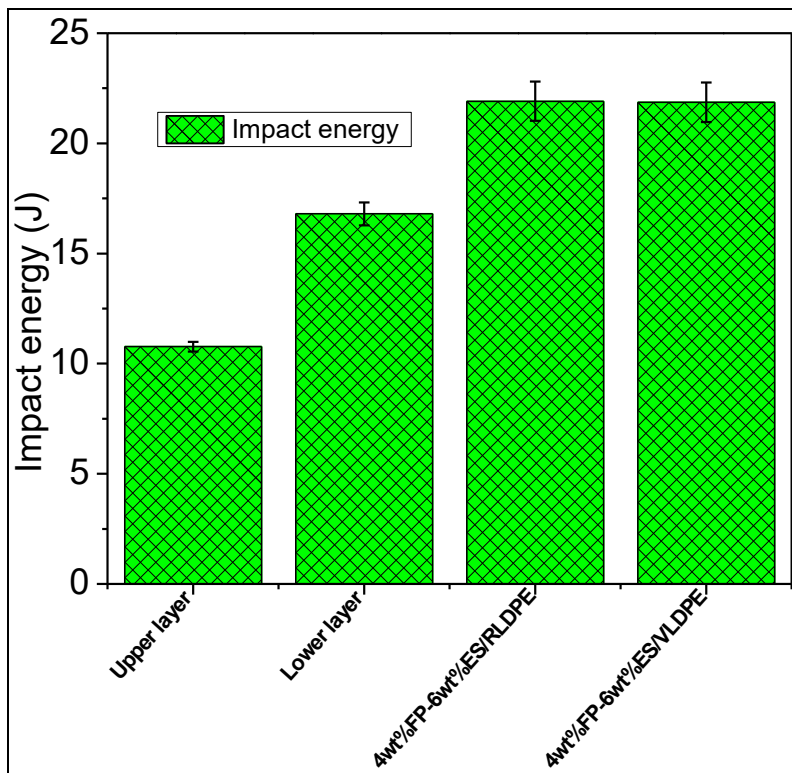


Figure 10e: Impact energy of hybrid particle reinforced low-density polyethylene benchmarked with tensile strength of the XLE TOYOTA Sienna dashboard cover

Since the dashboard is designed to absorb vibration of the vehicle due to road conditions, impact energy serves as a prerequisite for selecting the material for fabricating the dashboard cover. Greater impact energy of both RLDPE and VLDPE based nanocomposite makes them suitable for the application. However, smaller tensile strength of the 4wt%-FP-6wt%-EP/RLDPE than that of the material for lower layer of the dashboard may be its setback as reported in (Bello *et al.*, 2024). Moreover, suitability of the 4wt%-FP-6wt%-EP/VLDPE is ascertained because of its favourable tensile strength, tensile modulus and impact energy.

Conclusions

In this article, different materials locally developed for fabricating automobile components like bumper fascia, dashboard cover, and bonnets have been presented. Proof of concepts from continuous research on this field have confirmed potentials of the developed materials for the targeted applications. These have been communicated globally through article publications in high-ranking international journal outlets and summary of such proof of concepts have formed the focus of this presentation. In addition, this study is not only limited to the materials development but also local technology for prototyping the vehicle component like bumper fascia has been developed. Implication of this is that Nigeria as a nation has many locally developed materials that meet the global standards for driving automobile manufacturing exercises in the country. Moreover, Federal Government's intervention is needed on automobile policy and implementation for mandating all vehicle manufacturing companies whose vehicles are used in Nigeria like TOYOTA, HONDA, NISSAN, FORDS, TATA, INNOSON, etc for local production of vehicle parts and assembly using locally developed materials.

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NATIONAL SECRETARIAT: 3rd Floor, 15B Awolowo Road, Ikoyi, Lagos

☎: 08036812724, 09033130321, 08033417773

www.metminmat.org
mat_met_min@yahoo.com
3m.national@gmail.com

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9th May 2025

Sefiu Adekunle Bello

Department of Materials Science and Engineering
Kwara State University
Malete, Kwara State.

**Acceptance of Abstract for Oral Presentation at the Nigerian Institution of
Metallurgical, Mining and Materials Engineers (NIMMME)
International Conference (Tagged *Kogi* '25)**

Dear Sefiu Adekunle Bello,

We are pleased to inform you that your abstract titled ***Sustainable Materials from Waste for Engineering Applications*** has been **Accepted** for oral presentation at the upcoming Nigerian Institution of Metallurgical, Mining and Materials Engineers (NIMMME) International Conference (Tagged *Kogi* '25), which is scheduled to take place in Lokoja, Kogi State, from 22-25 June 2025.

Kindly submit the full-length paper on or before 23rd May 2025.

Should you need any clarification on your submission, kindly contact the undersigned via email at conference@nimmme.org.ng

Best regards,

Dr Olayode Adesola OLASUPO MNSE, FNIMMME
conference@nimmme.org.ng
+234-803-372-7450