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Al–Mg–Mn BASED COMPOSITES FOR TRICYCLE CONNECTING ROD: A REVIEW

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Abstract: Global trend in automobile design of engineering systems encourages cost effective, lighter materials with enhanced strength to weight ratio for easy handling, fuel economy and optimal efficiency in service. However, automobile engines that use carbon steel connecting rods are characterised by low efficiency due to heavy mass. Recent demand for higher engine performance requires connecting rods produced from aluminium alloy based Nano and hybrid composites. This study seeks to review literature on particulate agro wastes as reinforcement in metal matrix composites for possible use in producing tricycle connecting rod. From the extensive literature reviewed, the use of agro wastes nanoparticles as reinforcement for automotive applications is rare. The primary search revealed that Nanoparticles of agro wastes can be produced by ball milling and when characterised could be a suitable reinforcement material for metal matrix composites. Most of the literature reviewed used single reinforcement. The use of dual reinforcement is scanty particularly for local agro wastes. Utilisation of Carbonised and non–carbonised nanoparticles of periwinkle, coconut and palm kernel shells as reinforcement to produce Nano and hybrid composites for production of tricycle connecting rod has not been reported. Furthermore, the base material of waste Al–cans can be recovered through secondary melting and used for the development and characterisation of hybrid agro waste nanoparticle reinforced aluminium alloy composites.
Keywords: Al–Mg–Mn, Mechanical Properties, Nano/hybrid composite, Connecting rod, Review

INTRODUCTION

Composites are made of two or more distinct materials with enhanced properties. The constituent materials, not only differ in chemical composition and form, but are insoluble in each other. Composites possess properties that are more superior to the properties of the individual constituent materials functioning individually (Callister**,** 2007). Hybrid composite consist of a single matrix, enhanced with two or more reinforcements. They provide opportunity to combine different materials ranging from organic to inorganic. Dimensional stability, light weight, high strength along fibre reinforcing direction and thermal stability are among the desirable properties of hybrid composites (Adeosun *et al*., 2014; Valery and Evgeniy, 2013).

Aluminium and its alloys have found wide range of applications in construction, packaging, food and transportation industries due to its excellent corrosion resistance and light weight. Low mechanical properties of aluminium and its alloys have limited their applications as structural materials in the automobile, aerospace and military industries where improved mechanical properties and structural stability are prerequisites. Low mechanical properties of aluminium and its alloys have been addressed overtime by researchers through work hardening, solid solution strengthening, age or precipitation hardening and development of aluminium matrix composites (AMC) using synthetic and or natural fillers. Among metallic alloys, aluminium alloys remain the most considered metallic alloy as a matrix for producing metallic composites. This is due to combined ductility, resistance to corrosion, light weight, good thermal and electrical properties of aluminium alloys (Deng *et al*, 2007; Li *et al*., 2011; Alaneme and Bodurin, 2013; Das *et al*., 2014, Bello *et al*., 2017) which have been revealed earlier in this write–up and their ease of availability. Many studies in literature were aimed at improving the mechanical properties of aluminium and its alloys. Use of expensive synthetic fillers such as silicon carbide, alumina and graphite have increased cost of production and limited applications of AMC in commercial vehicles (Das *et al*., 2008; Goto, 2005; Kok, 2005).

Industrial wastes and organic particles have become attractive alternative reinforcement to synthetic fillers due to their availability, low cost, high specific strength, stiffness, natural renewability and environmental friendliness. Research has shown that the use of those organic particles at micro size level to reinforce aluminium alloys yielded improved mechanical properties (Prasad and Krishna, 2011). An innovation that will yield promising result is the reinforcement of aluminium alloy with nanoparticles obtained from organic wastes such as periwinkle shell (PWS), palm kernel (PKS) and coconut shells (CNS) and the selective combination of two organic nanoparticles to produce hybrid reinforcement for modifying structures of aluminium alloys (Rino *et al*.,2012). This attempt can lead to synergetic interaction of selected nanoparticles within the alloy matrix with higher improvement in mechanical properties than the case when each of the nanoparticles will be used as reinforcement independently.

Varieties of aluminium based alloys and composites have been produced overtime in the quest to develop appropriate materials for varied applications. Aluminium alloys 2014, 2024 were developed and used in the construction of highly stressed parts in aircraft. Aluminium alloys 7075 and 7079 were developed for high static strength in aircraft construction. Aluminium alloy based metal matrix composites such as continuous fibre reinforced boron/aluminium, graphite/aluminium together with discontinuous reinforced metal matrix composites (MMCs) such as silicon–carbide particulate reinforced aluminium, and graphite particulate reinforced aluminium were developed for use in spacecraft to offer maximum resistance to atmospheric factors such as radiation and electromagnetic interference (Suraji, 2001).

COMPOSITES

A composite is a combination of two or more different materials or phases having recognisable interface to form a new structure, whose properties and performance characteristics are different and superior to the properties of the individual constituents taken separately. (Callister**,** 2007) defined hybrid composite as a multi layered material with mixed fibres or particles consisting of two or more reinforcements which differ from one another in a single matrix phase. The constituents are combined in such a way that they keep their individual physical phases and are not soluble in each other i.e. do not form a new chemical compound. This basic fact remains one of the motivating factors for research and development of composite materials overtime. Composites are designed to take advantage of the properties of all the components involved and they exhibit wide range of physical and chemical properties including high stiffness, light weight, dimensional stability, chemical resistance, thermal stability and good strength to weight ratio, which are not evident in monolithic materials. These desirable properties are required in modern engineering designs and applications for improved and efficient performance (Rino *et al.,* 2012). Composites have high specific strength (strength per unit volume) far higher than those of titanium and aluminium. The specific strength of both aluminium and polymer matrix composites are far higher than that of steel and titanium. This makes it possible to develop composite materials possessing the same strength and stiffness as structures made of metals, but whose weight is lighter than structural metals. In most engineering systems, metallic components have been replaced by composites due to the high specific strength of composites.

Composites have found applications in automobile, aerospace and more recently in marine, sports, recreation and defence industries (Das *et al.,* 2014), due to their good damping capacity, satisfactory level of resistance to corrosion, high specific strength, excellent wear resistance, low co–efficient of thermal expansion and high thermal resistance (Kok, 2005; Rino *et al.,*2012; Prasad and Krishna, 2011). Basically, two categories of constituent materials or phases are evident in composites – matrix and reinforcing phase. The primary phase that is continuous in the composite material and is in most cases the one present in a greater quantity is the matrix. It is the base material into which the reinforcement is embedded. The body constituent of the matrix gives the composite its bulk form. The matrix is usually more ductile. It is the outer material that binds together and provides form and protects the reinforcement from environmental and mechanical damage, thus keeping it stiff and undamaged from external forces. The matrix also transfers stress between the reinforcing fibres (Callister**,** 2007). Several metallic materials have been used as matrix for producing metal matrix composites. This ranges from metals for industrial applications such as aluminium, magnesium, copper and their alloys to oxides, nitrides, carbides, hydrates and borides.

The dispersed (reinforcing) phase is the second constituent of the composite. It is embedded in the matrix in a discontinuous form. The secondary phase is usually harder, stronger and stiffer than the matrix. It enhances the mechanical properties of the matrix, bears the load applied to the matrix and offers strength and rigidity to the composite. The reinforcement is a structural constituent which determines the internal structure of the composite.

Reinforcements can either be particulate or fibrous. The dimensions of the reinforcement determine its capability of distributing its properties to the composite. Alumina, carbon, thermoplastics, boron, silicon nitride, silicon carbide and steel are the frequently used synthetic reinforcements for developing composites. Intense researches are presently exploiting the reinforcing potentials of natural fillers such as PKS, CNS, PWS, egg shells, banana peels, bagasse and yam peels for the development of composites suitable for many engineering applications.

Composites are classified based on reinforcing material structure or on the matrix materials. On the bases of reinforcement, composites are classified as, fibre reinforced, particulate reinforced composite, structural composites and Nano composites. Based on matrix materials, composites are grouped into:

- ceramic matrix composites (CMC),
- polymer matrix composites (PMC) and
- metal matrix composites (MMC) (Josmin *et al*., 2012).

The reinforcement could be continuous or discontinuous; it increases stiffness, strength and the temperature resistance capacity of the composite but reduces ductility, fracture toughness and density of the metal matrix composite. Based on shape, reinforcement material may be classified into: fibres, whiskers, flakes and particles or platelets. A fibre is a particle longer than 100 μm with aspect ratio (A–R) greater than 10:1. Fibre reinforced composite is characterised by the length of fibre being much greater than its cross–sectional dimension. However, ratio of length to the cross–sectional dimension (L/D), known as the aspect ratio, can vary considerably. Fibres can either be short or long. Short fibres are discontinuous and have breaks throughout the material. Fibres are responsible for high strength and stiffness ratio to weight of composites. For better strength of the components and maximum load transfer, the fibre should be continuous. A reinforcement having long dimension discourages the growth of incipient cracks normal to the reinforcement that might otherwise lead to failure, particularly in brittle matrices. Whiskers are thin hair like crystals of exceptional mechanical strength used specially as reinforcement for developing structural composite materials. Whiskers of various materials such as carbides, halides, metals, oxides and organic compounds under controlled conditions have been prepared and used as reinforcements for metal matrix composites. Although whisker reinforced metal matrix composites offer higher strength than particle reinforced composites, their production cost is, however higher and often experience breakage and damage during secondary fabrication (Hunt, 1991). A flake is flat plate like material, having no definite shape or orientation. Thin flakes offer attractive features for an effective reinforcement. They have primarily two–dimensional geometry and thus impacts equal strength in all directions in their plane compared to fibres that are unidirectional reinforcements. Flakes when laid parallel can be packed more closely than fibres or spherical particles. Mica flakes are used in electrical and heat insulating applications. Mica flakes is embedded in a glassy matrix to produce composites that can be machined easily and are used in electrical applications. Aluminium flakes are commonly employed in paints and other coatings in which they orient themselves parallel to the surface of the coating and gives them exceptionally good properties. Silver flakes are employed where good conductivity is required. A particle is non–fibrous and generally has no long dimension apart from platelets. In particle reinforced composites the matrix is reinforced by a dispersed phase in form of particles. The merits of particles as reinforcing agent include the following:

- they are the most common and cheapest reinforcements;
- they produce discontinuous reinforcements with isotropic properties;
- composites reinforced with particles could be fabricated into a wide range of product forms using conventional fabrication methods, thereby making them affordable (Odorico, 1990).

Particles dimension are approximately equal in all directions. Particles shape and size play vital roles in reinforcement. The shape of the reinforcing particle may be either spherical, cubic, platelet or any regular or irregular geometry. The arrangement of the particle reinforcement may be random (composites with random orientation of particles) or with a preferred orientation (composites with preferred orientation of particles). In particulate reinforced composites the orientation of the particles is considered for practical purposes to be random.

In general, particles are not very effective in improving fracture resistance. However, particles of rubber like substances in brittle polymer matrices improves fracture resistance by promoting and arresting cracking or cracks in brittle matrices. Previous study shows that angular particles act as stress raisers, rounded or global particles improves impact properties, spherical particles gives better ductility than angular shaped particles (Odorico, 1990). Fine particles strengthen the composites more than coarse particles due to closer inter–particle spacing. Coarse particles are easily incorporated in liquid melts; they are susceptible to both cracking and gravity settling which could results to poor mechanical properties and heavily segregated casting. In particle reinforced composite, as volume fraction increases the composite strength increases due to interaction between particles and dislocation movement within the matrix.

The most commonly used particles for reinforcing aluminium alloy matrix includes, silicon carbide, due to its favourable mechanical properties and density, Al_2O_3 due to its inertness and oxidation resistance. Graphite improves wear properties, B_4C due to neutron capturing properties and the composites are used in nuclear applications. The choice of a particle combination depends on the desired properties. Particles of lead are mixed with copper alloys and steel to improve machinability. Particles place constraints on the plastic deformation of the matrix material due to their inherent hardness relative to the matrix. Uniformly distributed reinforcement of fine particles improves mechanical properties and elevated temperature properties (Kahl and Leupp, 1990; Ray,1995).

REVIEW OF LITERATURE

Al–Cu matrix composites reinforced with Nano sized SiC by combining semi solid stirring with ball milling technology was fabricated. Precursor powders of Sic and Al–Cu alloy powders was fabricated by mixing calculated quantity of Nano–sized SiCp, (Purity 99.9wt.% and approximately 60nm in diameter) with Al–Cu alloy powder (99% pure) with average size of about 10μm using mechanical ball milling with zirconium balls at a speed of 150rpm for 50 hours. The ball to powder weight ratio used was 8:1. An electric resistant furnace was used to melt the Al–Cu alloy at 933K in air and then cooled to a semi–solid condition at 873K. The precursor powder was then introduced into the molten metal and then stirred with a graphite coated rod at a speed of 500rpm, before pouring into a preheated steel die. Both the Al–Cu and the composite were homogenized for 10 hours at 758K to avoid segregation. With the aid of a 200–ton hydraulic press, the materials were extruded at 773K with the extrusion ratio of 16 to a batten shaped samples. The extruded samples were solutionised at 773K for 2 hours and aged at 433K for 18 hours. Extruded samples were machined into dog–bone shaped tensile samples with a gauge cross section of 5.0mm x 2.5mm and gauge length of 30.0mm for tensile test using a servo–hydraulic material testing system (MTS) at a constant strain rate of $3x10^{-4}$ s^{-1} at room temperature. Results of microstructural examinations carried out with Olympus optical microscope, field emission microscope and transmission microscope revealed that the α–Al dendrites of the composites were strongly refined especially in the 3wt.% Nano sized SiCp reinforced composite. Yield strength, ultimate tensile strength and fracture strain of the cast Al–Cu were enhanced from 175MPa, 310MPa and 4% to 220 MPa, 410MPa, and 6.3% respectively. The significant improvement in mechanical properties was attributed to the refinement of the α–Al dendrites, Nano–sized SiCp strengthening and good interface combination between the SiCp and Al–Cu alloy (Feng *et al.*, 2017). The preparation, characterization and mechanical properties evaluation of Al356.1 Aluminium alloy matrix composite reinforced with MgO nanoparticles was carried out. Nano size MgO were synthesized through combustion reaction process in a ceramic crucible containing mixture of magnesium oxide (MgO), nitric acid (HNO_3) and crystal sugar ($C_6H_{12}O_6$) used as fuel with little quantity of double distilled water. The ceramic crucible containing the mixture was placed in a preheated muffle furnace maintained at 850±5°C. As the mixture boils it result into a transparent gel which forms white foam that expand and fill the vessel. This was followed by a reaction initiated at the interior of the mixture and the appearance of a flame in the surface of its foam that continued rapidly throughout the entire volume until a white powder with an extremely porous structure was formed. The composite was produced by adding MgO (0.5, 1.0, 1.5, and 2.0 wt. %) into molten metal in a resistance furnace equipped in a string system at constant rate of 150 RPM for 20 minutes. At 850°c the mixture was cast into sample specimens with steel circular die for mechanical and microstructural analysis. Results of the experimental investigation depicted that the nanocomposite containing 1.5 wt.% MgO Nano powder fabricated at 850°c have homogenous reinforcement of MgO in Al356.1. Both wear properties, tensile and hardness values were equally improved (Girisha and Chittapa, 2013). The mechanical properties of aluminium alloy reinforced with carbon black (CB) using back pressure equal angular pressing (BPECAP) was studied. 2 and 5wt. % nanoparticles of carbon in the form of carbon black (CB) were thoroughly mixed with particles of pure aluminium and then consolidated at 400 by equal channel angular pressing into fully dense bulk composite with the application of back pressure. The results of study showed increase in yield strength from 58–260 Mpa and hardness value from 37.1–96.5 (Goussous *et al.*, 2009). The analysis of Nano –Al_2O_3/2024 Composites prepared by the combination of solid – liquid mixed castings technique and ultrasonic treatment was investigated. The composite was synthesized by applying ultrasonic vibration on the composite melt during solidification process. Microstructural examination of the resulting composites showed reasonable distribution of Al_2O_3 nanoparticles in the aluminium matrix. The subjection of the composite melt to ultra– sonic vibration during solidification was responsible to the refinement of the matrix grain microstructure and the enhanced Nano–sized reinforcement distribution (Hai *et al.*, 2014). The preparation and characterisation of Nano–Al_2O_3/2024 composites by hybrid stir casting technique was carried out. The hybrid casting process consists of the combination of mechanical stir casting and electromagnetic stir casting process. Planetary ball mill rotated at a speed of 80 RPM for 12 hours was used to prepare uniform composite powers of 20μm Mg metal powder and 40nm size Al_2O_3 particles used as reinforcement. The composite was fabricated by heating 900g of Al2024 alloy in a graphite crucible placed in a resistance furnace up to 750°C for complete melting of the alloy. The graphite crucible was then placed in hybrid stir casting set–up and then stirred with the help of both mechanical stirrer as well as electromagnetic stirrer. The stirring of the melt was carried out for 2 minutes in the mushy zone under a temperature range of 620°C to 650°C to create a vortex through which the reinforcement was introduced. Current of up to 25A was used to create an electric field for the electromagnetic stirring. The melt was rotated up to 500rpm with the help of the hybrid stirring. The composite reinforcement particles pre–heated at 1100°C for 20 minutes in an inert atmosphere was injected into the melt with the aid of a stainless–steel injection tube and inert argon gas by the pressure of the inert gas. The mixture was then driven regularly for 10minutes at 400rpm by the mechanical stirrer, moved up and down to ensure uniform dispersion of reinforcement in the melt. The melt solidified under the electromagnetic field produced by 5 Amperes current since the tendency to produce shear stresses in the final product was negligible under such a low magnetic field. Analysis of the composite was carried out through scanning electron microscopy (SEM), EDAX and tensile testing. SEM micrographs revealed distributed nanoparticles in the Al2024 matrix. This was attributed to the combined effect of electromagnetic stirring coupled with mechanical stirring (hybrid stirring) that helped to refine the grain microstructure and hence enhanced the resulting distribution of Nano–particles in the melt. Tensile tests result showed that the ultimate tensile strength and yield strength improved by 43% and 86% (Kapil *et al.*, 2014).

An experimental study of the tribological behaviour of aluminium hybrid nanocomposite with the additions of solid lubricant was carried out (Ravindran *et al.*, 2013). Both the matrix material Al2024 and filler materials (SiC and Gr) were prepared by mechanical milling followed by a blend–press–sinter methodology. The Al2024/5wt% SiC– X wt.% graphite (X = 5 and 10) hybrid Nano composites was synthesised by powder metallurgy (PM) approach. Wear loss evaluation was carried out using pin on disc type apparatus. X – Ray Diffractometer was used to characterize the sintered samples while the observation of worn surfaces and wear debris morphology was carried out with scanning election microscope. The formation of lubricating layer on the surface of sample was used to determine the primary wear mechanism for the hybrid Nano–composites. The result of the experimental study showed that the Nano–composite reinforced with 5wt% SiC and 10wt% Gr showed the highest enhancement in tribological performance. Increasing the reinforcement content led to increase in both hardness and wear resistance of the hybrid Nano–composite.

(Devaraju *et al.*, 2013) studied the influence of adding Gr_p/Al_2O_3p with SiCp on the wear properties of aluminium alloy 6061–T6 hybrid composites via friction stir processing. The hybrid composite was synthesized by incorporating mixture of (SiC + Gr) and (SiC + Al_2O_3) particles of 20μm average size on an aluminium alloy 6061–T6 plate using friction stir processing (FSP). Test results showed that the combined pinning effect of both SiC and Al_2O_3 assisted by the high hardness of Al_2O_3 helped to produce a hybrid composite with enhanced hardness and wear properties. Microstructural analyses revealed uniform dispersion of SiC, Al_2O_3 and Gr in the nugget zone (NZ). The addition of Gr micro particles rather than Al_2O_3 with SiC particles was observed to decrease the micro hardness of the aluminium alloy 6061–T6 surface hybrid composite, but significantly increased the dry sliding wear resistance of the hybrid composite.

The synthesis and characterisation of Al6061–fly ash–SiCp composite was carried out by modified stir casting route. The composite was produced by adding various weight percentages of SiC particulates and a constant weight percentage of fly ash (FA) to the aluminium alloy. In each case the mixture was stirred thoroughly to ensure homogeneous distribution of both reinforcements. Magnesium was added to the melt to improve the wettability of both SiC and FA in the Al6061 matrix. Casting into a permanent mould was carried out at 800°C. After the solidification and cooling, the composites were prepared for micro–structural and mechanical properties investigations. Results of their investigation revealed that hardness and tensile strength were enhanced as the weight percent of SiC increases in the aluminium matrix with constant weight percent of FA. Homogeneous dispersion of FA and SiC was also revealed by the optical and scanning electron micrographs. The addition of FA was also reported to have prevented the dissolution of SiCp and promoted the formation of aluminium carbide (David *et al.*, 2013).

(Venkat *et al.*, 2013) explored the use of fly ash and graphite particles as low–cost reinforcing materials for enhancing the tribological and mechanical properties of AlSi10Mg alloy matrix.

The AlSi10Mg/fly ash/graphite (Al/FA/Gr) hybrid composite was synthesised by stir casting technique. Dry sliding wear characteristics of the developed hybrid composites were studied using pin–on–disc machine by varying load and weight fraction of fly ash. Wear test was carried out at a constant sliding speed of 2m/s and sliding distance of 2400m. Their research findings showed that the hybrid composites exhibited higher hardness and tensile strength compared to both the unreinforced alloy and Al/Gr composites. Both wear rate and coefficient of friction (COF) of the composites was reduced owing to the addition of FA and Gr particles. The load bearing capacity of hard fly ash particles and the formation of lubricating film of graphite between the sliding interfaces were reported to be responsible for the enhancement in the tribological characteristics of the composites. As the applied normal load increased the COF and the wear rate of both unreinforced aluminium alloy and composite decreased. Increase in the FA content resulted in a decrease in both COF and wear rate of the hybrid composites, with the 9wt. % FA and 3wt. % Gr reinforced composite exhibiting the highest wear resistance and lowest COF at all the applied loads. In the mild wear regime of Al alloy and composite, abrasive wear and delamination were dominant. Plate–like wear debris was generated during delamination wear due to subsurface deformation and crack propagation. Adhesive wear with the formation of transfer layers was reported to be the dominant wear mechanism in the severe wear regime.

The effect of alumina (Al_2O_3), fly ash and hybrid reinforcement on the mechanical properties A356 aluminium alloy hybrid composites were studied. A356 ingots were cut and placed inside a cast iron crucible of 4kg capacity and then heated to a temperature of 30°C above the melting point to obtain complete melting. The liquid A356 aluminium alloy was kept at 800°C for approximately 8 minutes while being stirred at 500rpm.

Before the introduction of the reinforcement, the scum at the surface of the liquid was removed and 1wt% of magnesium was injected into the crucible to enhance the wettability between the reinforcement and the matrix. Reinforcement particles (100μm) pre–heated to 400°C was added in the vortex generated during stirring using a turbine stirrer. 0.5% Hexachloro ethane tablet was added for degassing while stirring before pouring the molten mixture into a cast iron mould pre–heated at 300°C. The temperature inside the crucible was raised by 100°C further and held for 30 minutes to minimize porosity and then allowed to cool to room temperature. In each case 3000g of A356 alloy and 4, 8, and 12wt% fly ash, alumina, hybrid reinforcement was utilized respectively to produce A356–fly ash, A356 –alumina and A356–hybrid composites.

Hardness test of the composites was carried out with a Highwood HWMMT–X7 micro hardness tester. Compression test was carried out as per ASTME9 test standard while tensile test was conducted according to ASTME8–95 test standard on 300KN machine capacity with specimen dimensions of 12.50 ± 0.05 and 62.50 ± 0.05–gauge diameter and gauge lengths respectively.

Microstructural results revealed that the produced composites possessed refined grain structure. Hybridisation enhanced the diminutive density of the composites as the percentage reinforcement addition increases. Porosity was found less in both fly ash and hybrid reinforced composites. The A356 – 12wt% Al_2O_3 composite exhibits the maximum hardness. The addition of fly ash, alumina and hybrid reinforcement resulted in increased compressive and tensile strength (Kulkarni *et al.*, 2016).

REMARKS

This review has validated the possibility of the synthesis of nanoparticles of PWS, PKS and CNS through mechanical milling. The study has equally revealed that the matrix material (aluminium alloy) could be recovered through secondary melting of assorted brands of waste aluminium cans. The extent of work carried out overtime to enhance the mechanical properties of aluminium alloy has been reflected. Extensive literature search revealed that aluminium alloy has been reinforced with nanoparticles of SiC (Gaurang *et al.*, 2016), MgO (Girisha and Chittappa, 2013), Al_2O_3 (Hai *et al.*, 2014), carbon black (Goussous *et al.*, 2009).

The combination of more than one filler (hybriding), including SiC/Gr, Al_2O_3/SiC, (Devaraju *et al.*, 2013), FA/SiC (David *et al.*, 2013), FA/Gr, Al_2O_3/ FA (Kulkarni *et al.*, 2016) has also been used to reinforce aluminium alloys to produce composites with enhanced mechanical properties. However, the use of hybrid PWS/CNS, PWS/PKS and CNS/PKS nanoparticles as reinforcement for aluminium alloys have not received attention in literature. Research findings in all the reviewed papers are in good correlation, especially in the experimental results of Ravindran *et al.*,2013., David *et al.*, 2013., Feng *et al.*, 2017., Hai *et al.*, 2014 and Vencat *et al.*, 2013), who reported increase in hardness, strength and wear resistance as reinforcement content increases.

CONCLUSION

Although substantial works have been carried out to improve the properties of aluminium alloys for possible automobile applications, notwithstanding use of periwinkle, coconut and palm kernel shell Nano particles for developing eco–friendly aluminium matrix Nano and hybrid composites is very scarce. This has formed the basis of the ongoing PhD study on sustainable aluminium metal matrix composite for automobile application (Tricycle connecting rod) at Department of Metallurgical and Materials Engineering, University of Lagos, Nigeria. Findings from the investigation will be communicated in another article in Future.

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