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RESEARCH ARTICLE

REVIEW OF LOW-COST AND LIGHT-WEIGHT NOVEL NANOCOMPOSITE MATERIALS FOR APPLICATIONS IN SPORT CAR COMPONENTS

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ABSTRACT

Chassis and other body parts of sports cars must be rigid, strong but made of light-weight materials. Chassis in modern sports cars are designed with Computer Aided Design (CAD) Technology which aids in the creation, modification, analysis, or optimization of a design to obtain highly specialized curvatures capable of running stress simulations. Frameworks of the modern sports cars utilize monocoque structural skin which is a structural system in which loads are supported by the external skin. Use of stainless steel in constructing car frameworks makes the vehicle heavier and hence search for light-weight but strong and corrosion- resistant materials are desirable for constructing frameworks or chassis of sports cars. Use of aluminium alloys in place of stainless began to reduce weight and magnesium alloys were found to be even better in terms of weight reduction. One such material is the new steel made of Fe-Al-Ni which is much cheaper than other light-weight materials such as titanium alloys used in constructing airplane bodies and comparable in price to conventional steel. As opposed to metal alloys, other viable alternatives are carbon fibers and polymer-mineral nanocomposites. Then came the carbon fiber era where very strong carbon fibers are used in many parts of automobiles. Inorganic particle-polymer composites present the latest developments where nanoparticles of inorganic materials. In this review, we discuss clay-polymer nanocomposites which we developed using montmorillonite clay and poly (vinyl alcohol) polymer. These novels, low-cost and light-weight yet very strong materials can replace stainless steel in constructing body parts of sports cars.

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INTRODUCTION

Stainless Steel Sports car, or sports car, is a small, usually two-seater, Two-door automobile designed for spirited performance and nimble handling which include quick response, easy maneuverability, high acceleration for high-speed driving (Sports car". Merriam-Webster.com, 2017; "Sports car". Collins Dictionary, 2017). In order to achieve these requirements lightness is a mandatory requirement. Stainless steel used in making frames of car chassis contributes significantly to the overall weight of the motor vehicle. Stainless steel has several important properties making it to be the ideal choice of material for automotive applications. These properties include high strength, weldability, corrosion-resistance, and polishability to give good effect in enhancing the outward appearance, unique mechanical properties such as deformability under stress enabling absorption of a large part of the energy produced in a collision so as to give passenger safety and so on. AISI Type 304 Stainless Steel has Rockwell B Hardness of 70, Vickers Hardness of 129, Ultimate Tensile Strength of 505 MPa, Yield Tensile Strength of 215 MPa, Elongation at Break of 70%, Modulus of Elasticity in the range from 193 GPa to 200 GPa, Poisson's Ratio of 0.29, Charpy Impact of 325 J and Shear Modulus 86 GPa (3-6), which are all favorable mechanical properties making stainless steel to be the best material for constructing motor vehicle chassis and body parts. Electrical properties of this steel include electrical

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resistivity of 7.2 x 10^{-5} ohm cm at 20℃ and magnetic permeability of 1.008. Thermal properties which are also important for its use as car parts include coefficient of linear thermal expansion (CTE) of 17.3 µm m^{-1} $°C^{-1}$ at 20℃, 17.8µm $m^{-1}°C^{-1}$ at 250℃ and 18.7 µm $m^{-1}°C^{-1}$ at 500℃, specific heat capacity of 0.5 J $g^{-1}°C^{-1}$, thermal conductivity of 16.2 W m^{-1} K^{-1} and normal melting point in the range of1400 °C – 1455°C (3-6). The composition of AISI Type304 Stainless Steel in weight percentage is as follows: Cmax. 0.08%, Cr 18 – 20%, Fe 66 – 74%, Mn max. 2%, Ni 8- 10.5%, P max .0.045%, S max. 0.03% and Si max 1% (http://www.aerospacemetals.com/contact-aerospace-metals.html). By definition, steel that contains minimum of 11% of chromium is considered stainless because Chromium makes steel stainless by completely covering the entire surface by a homogeneous thin layer of Chromium Oxide which prevents penetration of Oxygen and thereby preventing corrosion.

Aluminium Alloys

Aluminium is only second to stainless steel in use as Automobile components. Use of Aluminium in building automobiles is increasing because Aluminium offers fastest, safest, most environmentally friendly and cost-effective way to increase performance, boost fuel economy and reduce emissions while maintaining or improving safety and durability (http://www.worldaluminium.org). As a rule of thumb, 10% weight reduction in automobiles gives 5.5% fuel economy (Cole and Sherman, 1995). As such, global energy consumption can be reduced drastically by opting for lighter cars as revealed by Julian Allwood of the University of Cambridge (Knight, 2011). Aluminium used in place of steel in cars leads to 8.2% less energy consumption in favor of Aluminium during the entire vehicle life cycle, as well as 10.3% lower CO_2 emissions (http://www.worldaluminium.org, 2012; Musfirah and Jaharah, 2012). It is fascinating to note that from mass-market vehicles like FORD-150 to luxury cars like Audi, Mercedes Benz and Land Rover, the building material of choice is now turning to Aluminum because of its strength and environmental benefits. At the end of the life of the vehicle, on average 90% of Aluminium can be recycled. Use of Aluminium in motor vehicles enables absorbing twice the crash energy than that of mild steel. Aluminium is material for use in powertrain and wheel applications and continues to gain market share in hoods, trunks, doors and bumpers and complete vehicle structures. However, the tensile strength of pure Aluminium is about 90 MPa that is about 5.6 times less than that of steel. In order to increase tensile strength Aluminium is alloyed with other metals and Aluminium alloys have tensile strength in the range from 70 to 700 MPa in comparison to the ultimate tensile strength of 505 MPa of stainless steel. As such, some Aluminium alloys are stronger than stainless steel. Aluminium is alloyed with Manganese, Silicon, Copper and Magnesium to obtain alloys such as AlMn, AlMg, AlMgMn, AlMgSi, AlZnMg, and AlZnMgCu to have improved mechanical properties (http://www.worldaluminium.org). In order to increase the strength thicker Aluminium parts are used but they are still lighter than thinner stainless steel used in car manufacturing. Another important property of Aluminium is that it does not become brittle at low temperatures like steel does. In fact, strength of Aluminium increases as the temperature is decreased. Additionally, Aluminium is much more flexible than steel and hence Aluminium can flex under load and bounce back from force of impacts. Aluminium is much more malleable than steel and hence the former can be extruded either hot or cold into any desired shape. It is an excellent heat and electricalconductor, good reflector of light and heat and has an excellent corrosion resistance due to the presence of 4 nm thick layer of homogenous Aluminium Oxide layer on the entire Aluminium surface (http://www.world aluminium.org). One of the problems with Aluminium and its alloys is their fatigue strength; the highest stress that a material can withstand for a given number of cycles without breaking, which does not have a well-defined limit for Aluminum as does by steel. As such, the strength of Aluminium and its alloys keeps on decreasing with number of cycles. Therefore, when Aluminium is used an ultimate life-time should be indicated.

Magnesium Alloys

The densities of Iron, Aluminium and Magnesium

Are 7.86, 2.70 and 1.74 g cm^{-3}, respectively, at 20°C, and hence magnesium is the lightest among the three. As such, magnesium is 1.5 times less dense than Aluminium and 4.5 times less dense than Iron and hence Magnesium is the Lightest of structural metals. There are reports to show that Magnesium alloy parts have been used in racing cars since 1920s but extensive use of Magnesium began in 1936 when Volkswagen used 22 kg of Magnesium in its Beetle model (Friedrich and Schumann, 2001). Now that VW Polo, Passat and Golf, Porsche 911 and928, Daimler Benz, Renault 18 Turbo, Chrysler Jeep and light truck vehicles, Ford light trucks use Magnesium alloys. Magnesium alloys are used not only in vehicles with internal combustion engines but in those powered by fuel cells and hybrids. Magnesium is alloyed with Silicon, Calcium, rare earths and Strontium etc. These alloys have good castability and physical properties at room temperature but the creep resistance deceases at elevated temperatures. Decrease in creep resistance of Al-Mg alloys is due to the formation of Mg17Al12 alloy at elevated temperatures. In order to suppress the formation of Mg17Al12 alloy various other metal additives are used which include Ca, Sr and rare earths. Mg-Al when alloyed with rare earths, Silicon and Tin form high melting point alloys whereas when alloyed with Calcium and Neodymium improves strength (Zhu*et al*., 2012). AE44 alloy which has the chemical composition of91.55% Mg, 3.98% Al, 0.35% Mn, 0.20% Zn and 3.95% rare earths Ce and La by mass is the best performing alloy developed in terms of cost and castability (Musfirah and Jaharah, 2012; Zhu *et al*., 2012; Kiełbus, 2007). Magnesium alloys are used in engine and transmission (drive train) parts such as gear box, intake manifold, crankcase, cylinder head cover, oil pump housing, oil sump, transfer case, support (AZ91D), cover (AZ91D), engine block, front cover and engine cradle. They are used in interior parts such as steering wheel cores, seat components, rear seat, instrument panel, steering column components, break and clutch pedal brackets, air bag retainers, door inner (AM50), and in chassis components such as road wheels, suspension arms, engine cradle, rear support, tailgate (AM50), and in body components such as cast components in inner bolt lid section, cast door inner, cast A/B pillars, and in sheet components and extruded components (Musfirah and Jaharah, 2012).

Composite Materials

Apart from metal alloys there are other composite materials; both natural and synthetic which have impressive mechanical properties. A composite, by definition, is a material that is formed by two or more materials to give synergistic and improved properties.Most of natural materials are composites which include wood, stones, bones and so on. 60-70% of wood formed from thread-like hollow elongated organic cellulose polymer of which about of which ~ 30-40% is crystalline fibers which are insoluble in water, and the rest is amorphous and soluble in water. Although Cellulose Fibers are flexible they possess high strength. The primary load- bearing components in plants and trees are these hollow fibers of cellulose. These fibers het themselves self- reinforced when the plants and trees are alive to enable them to bear more loads. In our bodies, all the connective tissues are made of structurally complex fibers of the protein called collagen formed primarily from Glycine, Praline and Hydroxoproline amino acids. There are hydrogen bonding between H bonded to polar atoms such as O and N with other O and N atoms in the monomer units of the polymer. Collagen polymer alone has a low melting point depending on animal from which it is obtained; for example melting points of human (type IV collagen), pig and cow, fish and plants are 46℃, 37℃ and less than 20℃, respectively. Glass transition temperature and degradation temperature of collagen are 135℃ and 433℃, respectively. The majority of the natural bone is made of bone matrix which is composed primarily of inorganic needle-like Hydroxyapatite [formula unit $Ca_{10}(PO_4)_6(OH)_2$] nanoparticles of 60 nm in length and 1-2 nm in width, distributed and assembled in ananotechnological architecture within the Organic Polymer, Collagen, to give four levels of hierarchical structure to provide outstanding mechanical performance at minimal requisite mass as shown in Figure 1 below (https://www.doitpoms.ac.uk/tlplib/bones/bone_mechanical.php).

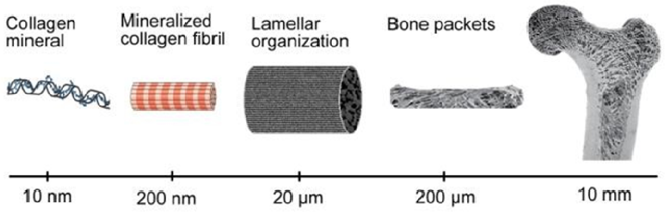

Figure 1. Four levels of hierarchical structure of natural bone

The Young's modulus of dry collagen, bone mineral (Hydroxyapatite), cortical bone in the longitudinal direction and the cortical bone in the transverse direction are 6, 80, 11-21 and 5-13 GPa, respectively, while the tensile and compressive strengths vary in the ranges of 60-70 MPa and 70-280 MPa in the longitudinal direction and ~50 both in the transverse direction. It has been reported that the typical stress-strain curves for compact bone, tested in tension or compression in the wet condition, are approximately a straight line. Bone generally has a maximum total elongation of only 0.5-3%, and, therefore, bone is classified as a brittle rather than a ductile solid. Although bone is classified as a brittle material it has excellent toughness. The fracture energy of the bone is 1.5 kJm^{-2} and is comparable to that of steel at low temperatures and of wood when measured parallel to the grain (15). Tooth is a special type of bone which consists of a flexible core and the hard enamel surface. The compressive strength of tooth varies through the thickness where the outer enamel is the strongest with ultimate compressive strength as high as 700 MPa (16). The most remarkable features of woods and bones are that they have strong and stiff fibers are embedded in a low density matrix to result in a strong, stiff and lightweight composite. In the early development of aero-planes wood was used as the primary structural material. As such, natural composites such as woods and bones can be considered as the predecessors of the man-made synthetic composites. In the nineteen thirties, aero-plane manufacturers shifted to Aluminium alloys instead of wood to make structural components of aero-planes. In order to achieve further improvements in more weight optimized performance and fuel-efficient design they opted to continuous glass fibers which were very strong, durable, creaseless, non-flammable and insensitive to weathering. Better processability was obtained by coating glass fibres with various resins.

Figure 2. The first carbon fiber body shell is in McLaren F1 (1996) Photo: By Viggen - Own work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=9804965

Figure 3. All body panels of BMW i3 made of carbon fiber reinforced plastics (18). SOURCE: BMW i3: Cheap, mass-produced carbon fiber cars finally come of age, By Bill Howard on July 30, 2013 at 1:40 pm. https://www.extremetech.com/extreme/162582-bmw-i3-will-bmws-new-ev-finally-be-the-breakthrough-for-carbon-fiber-cars

Although glass fibres are strong they are not stiff enough to be used in high-speed aircrafts. In 1952, the oyal Aircraft Establishment, Farnborough, U.K., developed high-strength carbon fibers and in 1958, Union Carbide, USA, developed high- modulus continuous carbon fibers. In 1959, Government Industrial Research Institute of Osaka, Japan, developed high-strength graphite fibers. Carbon fibers have several advantages such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermalexpansion. High strength carbon fibers produced from Polyacrylonitrile (PAN) which is carbonized at 1500-2000℃ is the material with highest tensile strength of 5,650 MPa and is 11 times higher than that of stainless steel. Graphitized Carbon Fiber heated at (2500-3000) ˚C has the modulus of elasticity of531 GPa. The carbon fiber T400 produced by Toray, Japan, has a tensile strength of 4,000 MPa. Toho Rayon developed a carbon fibers with tensile strength up to 6,000MPa. Carbon fibers developed by Toray, Celanese and Akzo are used in aerospace application from secondary to primary parts in in McDonnell Douglas, Boeing and Airbus planes. Composites such as carbon fiber reinforced plastics (CFRP), kevlar fiber reinforced plastics (KFRP), and glass fiber reinforced plastics (GFRP) are used extensively in high-end racing cars. Omnidirectional carbon fiber weaves in them are used in the "safety cell" monologue chassis assembly of high-performance race-cars (http://www.motorauthority.com/news/1087167_red-bulls-how-to-make-an-f1-car-series-explains-carbon- fiber-use-video; Howard, 2013). Figure 2 shows McLaren F1 (1996) which contains the first carbon fiber body shell. BMW i3 could be a breakthrough for carbon fiber production as well as for electric drive. This four-passenger electric car can go 100 miles on a charge or accelerate to 60 mph in less than 7 seconds but weighs only 1224 kg. As shown in Figure 3, all body panels in these cars are made of CFRP and they costs less than US$ 50,000. Not only passenger cars but also 592-hp McLaren MP4-12C supercar capable of running at 200 mph and Lamborghinis use CFRP in their bodies. According to Daniel Schafter, head of production of Concept BMW I, the use of CFRP in BMWi3, there is a weight reduction of 250-300 kg that can compensate the weight of the battery (Howard, 2013).

Polymer Nanocomposites

Polymer nanocomposites are a new class of composite Materials in which nano-sized (size range between 1 nm and 100 nm at least in one dimension) particles, nanoclays, nanotubes, nanofibers etc. are in mixed with polymers. Properties of nanocomposites depend not only on those of their individual components but also properties of acquired by the composite material which are not found in individual components. The lattermay depend on the morphology of the nanocomposites and interfacial characteristics of the assembled components in the nanocomposites. There are basically two distinct types of Nanocomposites intercalated nanocomposites and exfoliated nanocomposites. In an intercalated nanocomposite the layers of the polymer and the other material alternate. One such example is the clay-polymer nanocomposites where polymer molecules are present within the interlayer spaces of clay sheets. Alternatively, in exfoliated nanocomposites, the filler particles are embedded within the polymer matrices. An exfoliated clay sheets dispersed in the pockets of polymer structures belong to exfoliated nanocomposites. We have prepared a large number of such clay-polymer nanocomposites some of which are intercalated ones and others are exfoliated ones. We used montmorillonite clay (MMT) and monomers of electronically conducting polymers (ECP) such as pyrrole, aniline and ethylenedioxythiophene were polymerized within the interlayer spaces of MMT clay particles to result in MMT-ECP nanocomposites. Here the interlayer cations of MMT (usually Na^+) were exchanged for oxidizing cations such as Ce(IV), Fe(III), Co(III), Ag^+, Hg^{2+}, Pd^{2+}etc. and monomers were introduced into the interlayer spaces of MMT containing one of these cations. Monomers are then oxidatively polymerized by the oxidizing cations and the respective polymers [polypyrrole (PPY), polyaniline (PANI) or polyethylenedioxythiophene (PEDOT) are formed while the cations are reduced to their lower valency state cation or metal atoms.

As such, we prepared MMT/PPY/Ce(III), MMT/PANI/Ce(III), MMT/PEDOT/Ce(III), MMT/PANI/Ag(0), MMT/PPY/Ag(0), MMT/PEDOT/Ag(0), MMT/PPY/Fe(II), MMT/PANI/Fe(II), MMT/PEDOT/Fe(II), MMT/PPY/Hg(0), MMT/PANI/Hg(0), MMT/PEDOT/Hg(0), MMT/PPY/Co(II), MMT/PANI/Co(II), MMT/PEDOT/Co(II), MMT/PPY/Pd(0), MMT/PANI/Pd(0), MMT/PEDOT/Pd(0) nanocomposites of which most of the nanocomposites are of intercalated type while MMT/PEDOT/Co(II) formed exfoliated nanocomposites. However, even in intercalated nanocomposites, polymer segments have come out of the interlayers and wrapped round MMT sheets. All these nanocomposites are electronically conducting and most of them have excellent catalytic activities for oxygen reduction half-reaction comparable to that of very expensive C-Pt catalysts currently used in fuel cells. These fuel cells can be used to power motor vehicles (GaminiRajapakse *et al*., 2010; Wijeratne *et al*., 2011; Krishantha *et al*., 2006; Rajapakse *et al*., 2006; Krishantha *et al*.,2006; Krishantha *et al*., 2006; Ranaweera *et al*., 2007; Rajapakse *et al*., 2008; Saundararaja *et al*., 2009; Rajapaksae *et al*., 2010; ChathurangaSenarathna *et al*., 2014; Rajapakse *et al*., 2015; Senarathna*et al*., 2016).Nanocomposites promise new applications in many fields such as mechanically-reinforced lightweight components, non-linear optics, battery cathodes, nanowires, sensors and other systems; all of which find applications in motor cars. Most of the exfoliated nanocomposites are prepared by dispersing the filler particles in the polymer matrix. Both thermoset polymers such as polyamide (nylon), polyphenylene sulfide (PPS), polyetheretherketone (PEEK), poly(ethylene terephthalate) (PET), polycarbonate and thermosets such as bisphenol A, bisphenol F, Novolac, aliphatic, glycidylamine epoxy resins can be used to disperse nanomaterials within the polymers to prepare exfoliated nanocomposites.

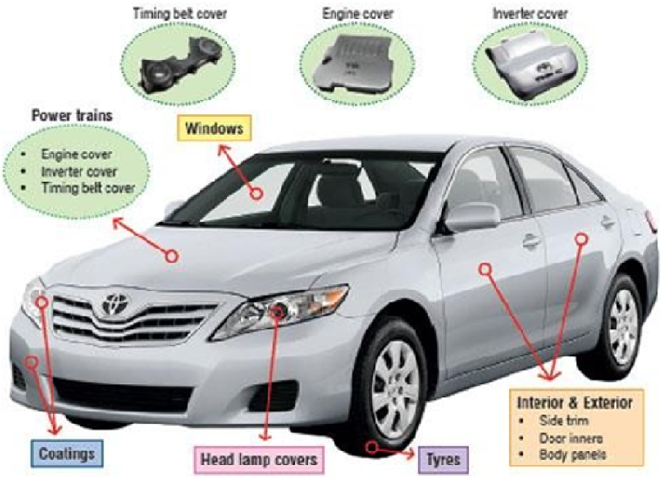

Figure 4. An illustration of the use of nanocomposites in automobile components. Source: Polymer nanocomposites drive opportunities in the automotive sector. Nanowerk Spotlight, http://www.nanowerk.com/spotlight/spotid=23934.php

Applications of nanotechnology in automotive industry spans horizons of versatility in power train, light-weight construction, energy conversion, pollution sensing and reduction, interior cooling, wear reduction, driving dynamics, surveillance control, up to recycle potential and much more. Additionally, use of nanomaterials in motor vehicles contribute to CO_2-free engines, safe driving, quiet cars, self-healing body and windscreens, up to a mood- depending choice of color and a self-forming car body. In 1991, Toyota Motor Co. used nylon 6-clay nanocomposites in timing belt covers and engine covers in their Toyota Camry cars (Presting and König, 2003).Weight of motor vehicles is primarily due to engine and transmission system and the use of light- weight materials will undoubtedly reduce the weight, increase the performance and fuel efficiency. In this regards, replacement of stainless steel by carbon nanotubes which has shown to reduce weight by 100 times. Furthermore, use of Aluminium alloys in chassis also made a huge weight loss of the motor vehicles. Young's modulus in the layer direction is 50 to 400 times higher than that of a typical polymer (Carter *et al.*, 1950). Clay minerals in polymers reduce the coefficient of thermal expansion helping to prevent dimensional changes during moulding. The plates of exfoliated clay minerals in clay-polymer nanocomposites highly rest the matrix deformation by resisting to deformations in two directions thus giving significantly improved dimensional stability of materials. Clay minerals also contribute to improved resistance to degradation of polymers, gives better flame retardance.In addition to clay-nylon-6 nanocomposites used in making timing belts and engine covers, clay-polypropylene nanocomposites have been used in Step-assist, doors, center-bridge, sail panel, seat backs, and box-rail protectors. Clay-thermoset polymers with glass fibers are used in rear floor, clay-natural rubber nanocomposites in tires, treads,Inner liners and internal compounds (Galimberti *et al.*, 2013). The electric car Chevy Volt produced by General Motors (GM) uses 45.4 kg of thermoplastics including composites in the hood and doors, plus unreinforced polymeric materials in the rearDeck lid, roof and fenders particularly continuous glass fiber reinforced sandwich composite for lightweight horizontal body panels. Tesla sport car uses carbon fiber/epoxy composite as power-to-weight ratio tanks and sink. The British automaker use Lotus uses aluminum chassis along with a composite roof and stressed composite body panels in its sport model Evora (Coelho *et al.*, 2012).

Nanocomposites We Developed

We developed several composite materials of Thermoplastic polymers of montmorillonite clay (Saundrarajah *et al.*, 2010) and hydroxyapatite nanoparticles (Wijesinghe *et al.*, 2016; Wijesinghe *et al.*, 2017).

Montmorillonite-Poly (vinyl alcohol) (MMT-PVA) Nanocomposites

As an example, we give below preparation, Characterization and mechanical properties of montmorillonite-poly (vinyl alcohol) (MMT-PVA) nanocomposites. MMT-PVA nanocomposites were prepared by a solution-intercalation film-casting method as detailed in reference 40 (Soundararajah *et al.*, 2008). MMT suspensions were prepared by suspending sodium montmorillonite at concentrations of MMT 2.5 wt. % in distilled water. The suspensions were stirred for 1 h at room temperature. Low- viscosity, fully hydrolyzed (98.0-98.8%) atactic PVA was added to the stirring suspensions so that the total solid concentration (TSC) is 5 wt. %. The mixtures were then heated at 90˚C to dissolve PVA and stirred for further 30 min. Films were casted in an oven at 40℃. Various compositions with different clay contents (2, 4, 6, 8, 10 wt. %) were prepared with constant polymer content. The samples were analyzed by X-ray diffractometry (Seimens D-5000, Cu Kα λ = 0.1540562 nm). Table 1 gives the interlayer spaces (d) of MMT in different samples which were calculated from XRD data of the samples. The d spacing of 15.43 Å in neat MMT is due to the presence of hydrated Na^+ ions within the interlayer to counter balance the negative charge of the clay sheets. When these ions are fully dehydrated d spacing reduces to 9.96 Å. Introduction of large polymer molecules results in the expansion of d- spacing and when it is highly expanded clay sheets delaminate and get dispersed in the polymer matrix forming exfoliated nanocomposites. Those with d- spacing > 20 Å can be considered as exfoliated nanocomposites. At low clay loading, the interactions between polymer functional groups (-OH in PVA) and those of polar groups of MMT result in exfoliation of the clay sheets since there are relatively more polymer is present to delaminate a given amount of polymer. This process happens due to the intercalation of polymer and subsequent expansion of the interlayer spaces. When the clay content is increased for a fixed amount of polymer the intercalation of polymer and subsequent expansion of the clay layers are insufficient to delaminate the clay sheets and hence intercalated clay-polymer nanocomposites are formed. The d-spacing depends on the amounts of polymer and clay and it decreases as the amount of clay is increased in a fixed amount of the polymer as reveled by the data given in Table 1 for MMT- PVA case.

Table 1. The interlayer spaces (d) at 25℃ of MMT in different samples extracted from XRD data

MMT-PVAnanocomposite	Clay content%	d-spacing/Å
MMT	100	15.43
MMT-PVA2	2	28.48
MMT-PVA4	4	29.22
MMT-PVA6	6	28.10
MMT-PVA8	8	27.93
MMT-PVA10	10	27.75

Table 2. Mechanical properties of montmorillonite and montmorillonite-poly (vinyl alcohol) nanocomposites

Nanocomposite	Tensile strength/ MPa	Young's modulus/GPa	Two legtrouser tearing energy/kN m-1
PVA	23	0.25	18
MMT-PVA2	29	0.36	23
MMT-PVA4	38	0.59	43
MMT-PVA6	36	0.40	29
MMT-PVA8	37	0.42	20
MMT-PVA10	34	0.44	30

There are considerable improvements in mechanical properties of MMT-PVA nanocomposites when compared to those of neat clay and neat polymer. Tensile strength of PVA is 23 MPa. Table 2 collects the mechanical properties of neat PVA and MMT-PVA films prepared in this study. Addition of MMT to PVA results in the increase of mechanical properties, in general, but the compositions that gave exfoliated MMT-PVA nanocomposites show greater improvements than those of intercalated nanocomposites. The exfoliated MMT-PVA nanocomposites formed at 4 wt.% clay loading in PVA results in 1.65, 2.36 and 2.39 times enhancements in tensile strength, Young's modulus and two leg trouser tearing energy, respectively from those of neat PVA. These results are encouraging although absolute values are still low for high-strength applications.However, measurements were done by casting films and there is no proper weaving of molecules in thin films. These mechanical properties can be greatly enhanced by making fibers from these nanocomposites. For example, the tensile strengths of neat polymer fibers are in 1-3 GPA (Wijesinghe *et al*., 2017) compared to 23 MPa in their films. As such, the tensile strength is enhanced by two orders of magnitude when the polymers are woven into fibers. Similarly, the moduli vary from 40-120 GPA again showing a huge increase due to weaving (Wijesinghe *et al*., 2017). As such, high-strength fibers of materials suitable for light-weight applications inAutomobiles can be prepared from clay-polymer nanocomposites.

Hydroxyapatite Nanoparticles Dispersed in Poly(methyl methacrylate) (HA-PMMA) Nanocomposite

This nanocomposites was prepared by first preparing stearic acid (SA) attached hydroxyapatite (HA) hydrophobic composite material. The latter was prepared as follows. 100 mL of 0.30 M ammonium dihydrogen orthophosphate was added drop-wise to the100.0 mL of 0.50 M calcium sucrate solution while stirring, to maintain the Ca: P mole ratio at 1.67. The mixture was then stirred for 24 h. The precipitated HA products were collected by centrifuging and washed from50.0 mL aliquots of distilled water, for 3 times, to remove impurities. Then, washed HA products were further washed with 50.0 mL aliquots of absolute ethanol, for 3 times, to remove water. The final products were dispersed in 100 mL of absolute ethanol. 0.20 g of stearic acid was added to HA dispersant while stirring and heated at 60°C, for 20 min. HA/stearic composite was collected by centrifuging and the precipitate was washed with absolute ethanol for 3 times and allowed to dry under ambient conditions. This HA-SA composite material was used to prepare HA-PMMA nanocomposites and the procedure adapted is as follows. First, 20.0 mL of freshly distilled MMA monomer was added to a 50.0 mL beaker. Then0.20 g of benzoyl peroxide and 0.20 g of HA/stearic acid nanocomposite were added to above monomer solution while stirring. The mixture was heated at 80 °C for 15 minutes and allowed to cool at room temperature. Finally, cooled mixture was poured into the plastic template and allowed to complete the polymerization process. Another, PMMA matrix was prepared without adding HA/stearic acid nanocomposite.

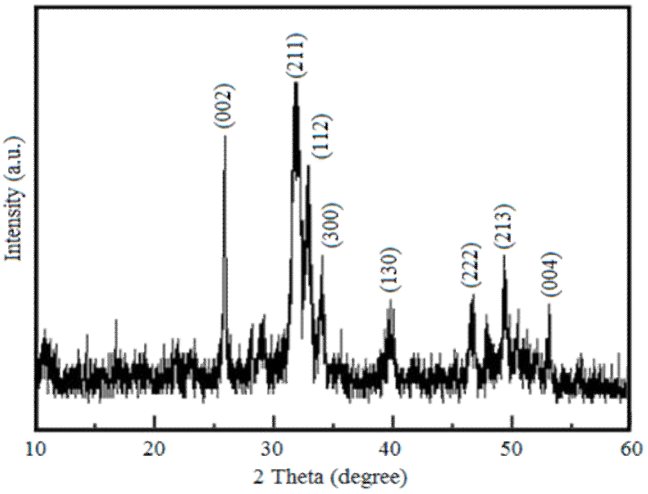

Figure 5. XRD pattern of the synthesized hydroxyapatite/stearic acid composite

The XRD pattern of HA/SA given in Figure 5 contain peaks at 2-theta values of 25.78, 31.74, 32.88,39.68, 46.62, 49.43, and 53.02 which reveal the presence of hydroxyapatite (JCPDS card No.72-1243). According to the Debye-Scherer formula, the crystallite size of HA is estimated to be 28 nm. FT-IR bands of stearic acid are centered at 1710 cm^{-1},2920 cm^{-1} and 2843 cm^{-1}, which are attributed to the stretching vibrations of C-O, C-H and C-C bonds, respectively (Spectrum is not given). These bands are found in the FT-IR spectrum of the HA/SA as well. Bands of the HA/SA nanocomposites, centered at 542 cm^{-1} ,600 cm^{-1} and 1066 cm^{-1} reveal the presence of HA. The new bands have been appeared at around 1990 cm^{-1} which may be due to dissociated carboxylic groups. These would have occurred due to the formation of chelate bonds between carbonyls group and Ca^{2+} in HA. There is no stretching bond of C-O at 1710 cm^{-1} in FTIR spectrum of HA/SA composite. This may be due to the absorption of SA to the surface of HA nanoparticles through the Electrostatic forces. Details of the dominant FT-IR bands of HA/SA nanocomposites are tabulated in Table 3. FT-IR results confirm that the SA has been coated on the HA nanoparticles.

Table 3. Dominant IR bands of hydroxyapatite/stearic acidComposite material where stearic acid molecules are adsorbed on hydroxyapatite particles through their COOH groups

IR band/ (cm^{-1})	Responsible vibration
542,600	υ4 of PO_4^{3-}
900-1200	υ1 & υ3 of PO_4^{3-}
2920	C-H bond vibrations of stearic acid
2843	C-C bond vibrations of stearic acid

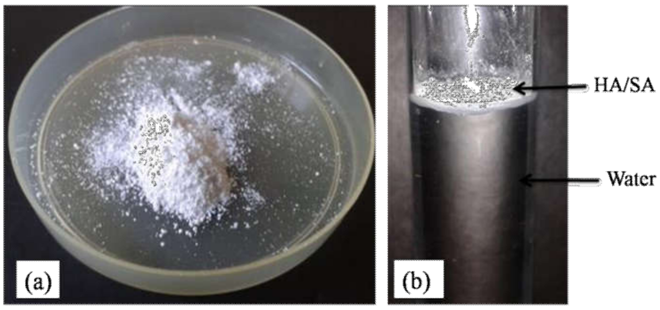

Figure 6. Photographs showing (a) hydroxyapatite/stearic acid compositepowderand (b) hydroxyapatite/stearicacid composite powder particles floated on to water surface when stirred in water

Figure 6 shows photographs of (a)HA-SA composite powder and(b) HA-SA composite powder particlesfloated ontowater surface when stirredin water. This isa clear demonstration of the hydrophobicity of the HA-SA particles sinceotherwise these particles are expected to be sank to the bottom of the test tube or dispersed in the solution as does by hydroxyapatite nanoparticles inthe absenceofstearicacidsincehydroxyapatite nanoparticles have high density in the range 2.7-3.1gcm^{-3} (Rootere and Craig, 1974). Since HA-SA nanoparticles are hydrophobic they disperse very well in methylmethacrylate hydrophobic monomer. Photographs of adispersion of HA-SA in MMA on the day of preparation of the dispersion and after 15 days are shown in Figure 7. These photographs give evidence to excellent stability of HA-SA nanoparticles in MMA. When this dispersion is allowed to polymerize by adding a polymerization initiator benzoyl peroxide MMA polymerizes to form PMMA in which HA-SA nanoparticles are dispersed within the polymer matrix to result in HA-PMMA nanocomposites which eventually solidifies to give pieces of the shape of the container/mould. PMMA is the material used in aircraft windows.

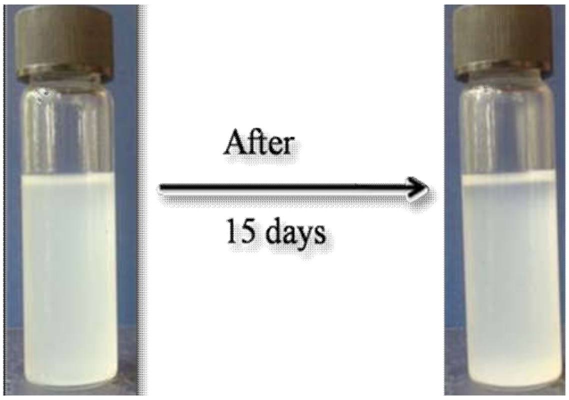

Figure 7. Photographs of a dispersion of HA-SA in MMA on the day of preparation of the dispersion and after 15 days

Table 4. Specific modulus of candidate materials

Material	Young's modulus/ GPa	Mass density/ g cm^{-3}	Specific modulus/ 106 m^2 s^{-2}
Steel	200	7.9	25
Aluminum	69	2.7	26
Carbon fiber reinforced plastic	181	1.6	113
Polymers woven into fibers made from nanocomposite	(40-120) *	(1- 2)*	(40- 60)*

*Anticipated values

PMMA has many advantages over glass because PMMA allows for the design of complex shapes, requires few metal supports that can block the field of vision, prevents optical distortions, and makes the final product substantially lighter. HA-PMMA nanocomposites are also highly optically transparent and have all the important characteristics of PMMA given above. Additionally, HA-PMMA nanocomposites have much improved mechanical properties than those of the neat polymer. As such, they are better light-weight substitutes for glass and even body parts of sport cars.It would be of particular interest to compare the physical properties in terms of specific values such as specific modulus which can be calculated by dividing the Young's modulus by the density of the material.An interesting comparison of specific properties of engineering materials is given in the Laboratory Module 5 EGR 250 – Materials Science and Engineering Section 1 of the School of Engineering GrandValley State University (Peirson, 2005). Table 4 gives the specific modulus of the candidate materials used to construct automobile body parts. Interestingly, the specific moduli of carbon fiberReinforced plastic is 4.5 times higher than those of steel and Aluminium while Polymer-Inorganic nanoparticle fibers have 1.6-2.4 times higher specific moduli than those of steel and Aluminium. As such, as per light-weight and more efficient applications are concerned low-cost polymer nanocomposites and carbon fibers stand out to be better than traditionally used steel and Aluminium.

Conclusion

In this review, we discussed materials that are used in manufacturing motor vehicles with particular emphasis on sport cars. Here, we considered the weight reduction of sport cars as of primary importance and hence starting from Stainless Steel that is originally used we discussed its replacement by lighter materials. In doing so, Aluminium alloys were the first to be used. Magnesium alloys were found to be even lighter. Then came the use of Carbon fibers, Clay-polymer nanocomposites and Inorganic nanoparticle- polymer nanocomposites. We reviewed all of them giving necessary data whenever necessary. Finally, we discussed two examples of the latest materials that we have developed giving synthesis procedures, characterization of materials and the feasibility of using them in manufacturing sport cars. We further discussed clay-electronically conducting polymer nanocomposites that we have developed. These materials are excellent catalysts for the oxygen reduction half-reaction of fuel cells. Since they are of very low-cost compared to traditional C-Pt catalysts sport cars powered by fuel cells can be realized in the near future.

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