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Titanium and Epoxy for Automobile application: A Review

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***Abstract*— The transportation industry is no doubt a fast-growing sector of the economy of most countries. As the world population grows, there is a corresponding increase in the demand for an improved and functional transportation system. However, manufacturers and researchers in the automobile industry face a lot of challenges in order to meet up with the ever-increasing vehicle demand and government regulations. These challenges include the need to develop a motor vehicle that would be safe, economical and functional with low emission. Several strategies towards the development of advanced materials have been adopted to meet up with these challenges such as the replacement of heavy metallic parts with high strength and lightweight composite materials; and the use of nanoparticles as additives in fuel, tyre, lubricants, coatings and paints. Titanium as a material with low density, high rigidity, high corrosion resistance, good thermal stability, high strength, structural stability, and reflectivity together with epoxy resin which among other thermosetting and conventional thermoplastic polymers has improved mechanical, electrical, chemical and thermal properties, as well as low shrinkage, low cost and high compatibility with various reinforcing materials, have played significant roles in this regard. This review, therefore, examines the various applications of titanium and epoxy in the automobile industry. They have successfully been applied in the manufacture of lightweight parts, development of anti-fouling, anti-fogging, self-cleaning, corrosion resistant, flame retardant, hydrophilic and hydrophobic glasses, paints and coatings, efficient brake system and lubricants, improved engine performance, enhanced tyre and anti-microbial automobile interior components. This paper highlights the enormous applications of Titanium and epoxy in automobile.**

***Key Words*- Automobile Industry, Composite material, Epoxy resin, Thermoplastic Polymer**

I. Introduction

As the world population is ever increasing, there is a corresponding increase in the demand for consumer goods. In the area of individual mobility, automobile demand is more frequently depended upon compared to other means of transportation. Therefore is ever increasing concern among researchers towards developing automobile systems that would both meet customer and regulation demands.

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Nanotechnology has become a dominant technology in the field of research and development of automobile system. Nanotechnology is the capability to examine, manipulate and fabricate things in nanometer scale [1].

Nanomaterials are classified into zero-dimensional (0-D), one dimensional (1-D), two dimensional (2-D) and three dimensional (3-D) according to the number of dimensions they have in the nanometer scale [2]. Most developments in the automobile sector are based on replacement of conventional materials with composite materials. Composite is a multi-phase material formed when two component materials combine to form a single component, each retaining its original properties but combine together to give properties different from their individual properties. The composite phases complement the shortcomings of each other. The dispersed phase is known as the reinforcement while the continuous phase which binds and transfers the load to the reinforcement is known as the matrix phase [3].

The introduction of nanomaterial as reinforcement due to quantum effect produces unique properties in matrix material [4]. Based on matrix material, nanocomposites are of three types namely polymer matrix nanocomposite, ceramic matrix nanocomposite and metal matrix nanocomposite [5]. Polymer based composite has attracted the attention of many researchers and industries due to their relative ease of fabrication, multi-functional performance, improved fatigue and damage resistance, low cost, high specific strength and high specific modulus, good noise damping property and high corrosion resistance [6].

Polymers are classified according to into thermoplastics and thermosetting plastics based on their thermal processing behaviour; addition and condensation plastics based on the mechanism of polymerization; and based on the polymer structure into carbon-oxygen, carbon-sulfur and carbon-nitrogen. Thermoplastics can be re-melted after curing while thermosetting polymers have a higher melting point than thermoplastic and cannot be re-melted after curing [7]. Epoxy resin among other thermosetting and conventional thermoplastic polymers has improved mechanical, electrical, chemical and thermal properties as well as low shrinkage, low cost and high compatibility with various reinforcing materials [8]. Epoxy resin has been reinforced with various nanomaterials such nanofibers, nanoclays, carbon nanomaterials and nanoparticles for automobile, aerospace, sports, marine, biomedical, electronic, tooling, painting and coating applications [9].

Although titanium is very expensive, it has still retained is place automobile manufacturing because of increasing concern for safety, weight reduction and functional reasons. It has the best combination of strength to weight ratio and corrosion

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resistance properties more than any known metal in the world. Just like metals such as calcium, cobalt, zirconium, iron, tin, cerium and hafnium, titanium has the capability to crystalize in different crystal structures. At low temperature, a hexagonal closed packed structure known as α titanium is stable while at a high temperature beyond transition temperature, body-centered cubic structure known as β titanium is stable. These properties make titanium a suitable material for epoxy matrix reinforcement adopted for various applications [10].

This review focuses on the automobile applications of titanium and epoxy resin both in their nanometer scale, as composite and separately for various purposes. According to the United Nations, 2008 prediction, the total world vehicle fleet would increase up to 1.5 billion by the year 2030 from 750 million [11]. As the world vehicle feet increases, maintaining efficient fuel economy and reduction of CO_2 emissions among other challenges have become crucial design criteria for researchers and automobile industries towards the development of advanced material to overcome these challenges. Replacement of heavy metal parts with light-weight composite materials ha been identified as a possible means of overcoming these challenges. Sequel to this, automobile parts such as body panels, exterior panels, bumpers, powertrains, chassis, tires, instrument panels, suspension, steering, intake manifolds, fuel cells, brakes, leaf springs, drive shafts, sensors, wheel covers, fascias supports, valve covers, antiglare coatings, glazing, filters, cross-vehicle beams, fuel tanks, and other accessories are now being replaced with polymer nanocomposite materials [12], [13]. It has been estimated that 10–20 % reduction in the weight of the total vehicle improves the fuel economy by 5–10 % [14].

II. Brake Systems and Lubricants

Automobile brake system operates on the principle of conversion of kinetic energy into heat energy. During the braking operation, the brake pad and brake disc are the first parts that bear the heat energy (Figure 1). For effective brake system, the brake pad and brake disc have to certain requirements namely high friction coefficient between the pad and the disc and thermal stability at high temperature.

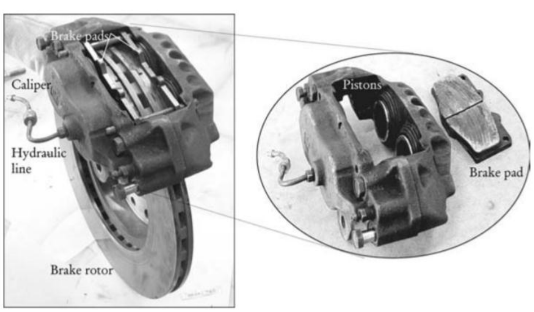

Figure.1 Brake calliper and brake disc arrangement [15].

Automobile brake system operates on the principle of conversion of kinetic energy into heat energy. During the braking operation, the brake pad and brake disc are the first parts that bear the heat energy (Figure 1). For effective brake system, the brake pad and brake disc have to certain requirements namely high friction coefficient between the pad and the disc and thermal stability at high temperature. Conventional brake pads component parts include frictional additives, fillers, binder and reinforcing fibres. Carcinogenic nature of asbestos formally used in the manufacture of brake pad has limited its market acceptance. Potassium titanate particles have been identified as a suitable replacement. On the other hand, a phenolic resin which has been used over the years as a binder material in brake pad decompose at high energy braking condition has low impact strength and also brittle in nature. Modified epoxy resin has been used to overcome this shortcoming in the manufacture of brake pad [15]. Titanium alloys are used in brake for brake sealing washer, brake guiding pins and brake pad carrier plates [10].

Proper lubrication of contact surfaces of moving parts such as in the engine, gearbox, brake, steering etc plays a significant role in the quest to improve emissions, fuel economy and overall performance of the automotive system. Hydrocarbon molecules constitute 90 % portion of lubricants and the remaining 10 % are additives determining their properties [16]. Nanoparticles as additives in lubrication have been investigated. Even at very low content (0.1-2.97 %), nanoparticles play a significant role in the improvement of tribological performance of lubricants. Their mechanisms have been described as a colloidal effect, rolling effect, surface repair and third body [17], [18]. Titanium has a promising application as an additive in nanolubricant technology [19]. Wu et al. [20] observed an increase in the viscosity of API-SF engine oil with TiO_2 as an additive. Shenoy et al. [21], predicted that TiO_2 additive would result in 23 % and 35 % improvement in load capacity of bearing operating with API-SF engine oil and base oil respectively under static condition. In another similar study, Binu et al. [22] reported 40 % improvement in the load carrying capacity of the journal bearing operating with TiO_2 nanoparticles added engine oil compared to engine oil without any addition of nanoparticles. Ye et al. [23] also observed an increase in load carrying capacity as well as a reduction in wear and friction of liquid paraffin using TiO_2 modified with tetrafluorobenzoic acid and synthesized via sol-gel process as an additive. Sabareesh et al [24] achieved 17 % enhancement in the coefficient of performance of compressor operating with mineral oil-based lubricant containing TiO_2 nanoparticles. Redwood viscometer indicated the viscosity of the lubricant increased with an increase in the volume fraction of TiO_2 nanoparticles up to 0.01 %. It was observed that beyond 0.01 % addition of the nanoparticles leads to an increase in the roughness value measured by speckle interferometry. Thus 0.01 % was then observed as the optimal volume fraction for enhancement of coefficient of performance. The overall compressor work was improved by 11 %. Titanium-based composite has also been used as a lubricant additive. Luo et al. [25] reported improvements in the anti-wear, ant-friction, dispersion stability and conversion from sliding friction to rolling friction with TiO_2/AL_2O_3 nanocomposite as an additive in lubricating oil.

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Although mineral oil-based lubricants have widely been used in the automotive system [26], environmental concern, constant depletion of crude oil and non-biodegradability among others have limited their application. Biolubricants have attracted significant attention of researchers as a suitable replacement of mineral oils in lubrication. It has been reported that there are about 350 known oil-producing crops although not all of them have been used for lubrication purposes [27]. Biolubricants from vegetable oil have an inherent competitive advantage over mineral oil-based lubricants such as higher viscosity, higher viscosity index, lower pour point for cold starting, higher flash points, higher fire retardant, better rust and corrosion resistance, reduced emissions, biodegradability, non-toxic nature and better anti-wear behaviour [27]. Titanium has recorded success in the improvement of lubricant properties. Lanthanum-doped TiO_2 nanocomposite modified with oleic acid (OA/La- TiO_2) additive improved the anti-wear behaviour and reduced friction property of rapeseed oil [28]. Zulkifli et al. [29] observed 15 % and 11 % reduction in coefficient of friction and wear scar diameter respectively of palm oil-based lubricant containing TiO_2 nanoparticles. These improvements were observed in an experiment on tribotester under160 kg for 10 minutes at 1200 rpm.

III. Paints and Coating

Many automobile parts require a protective coating to enhance their appearance and durability. The uppermost coat layer ranges between 5 to 50 µm in thickness (Figure 2).

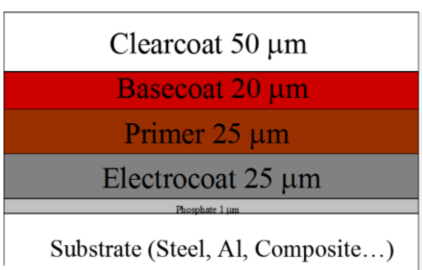

Figure. 2 Schematic diagram of automotive coat layers [30].

This layer protects the inner layers and substrates from the degrading effects of chemical and UV rays. It can also provide scratch and blemish resistances. It has been identified that scratch performance of the exterior body paint is the most important phenomenon that customers are concerned about [30]. Epoxy has been widely used as a protective material for many types of surfaces because of its chemical and corrosion resistance, good adhesion property and excellent thermal and mechanical properties [31]. Many systems have been developed to meet the automobile body parts with high surface performance. Bock et al [32] in research, identified hydroxy-functional epoxy resins as well as other polymers with hydroxyl groups to be a suitable matrix material in the production of transparent coating with improved scratch performance. The polymeric matrix used for this purpose needed nanoparticles such as titanium dioxide nanoparticle sol of size 4 to 60 nm dispersed in the resin via jet dispersion technique. Recently, Lei et al. [33] demonstrated the hydrophobic and transparent coating based on deweltted epoxy structure on a glass substrate. The scratch resistance performance of the coating was appreciable. It was observed that 5 % epoxy concentration displayed the maximum contact angle of approximately 113^o. Also, the surface roughness increased as the concentration of the epoxy coating increased. Furthermore, the coating was observed to reduce the rate of crack propagation. It also observed that the inclusion of nanoparticles such as silicon dioxide and titanium dioxide can improve the strength of the epoxy coating. Mild steel has attracted the attention of many automobiles manufacturers due to some advantages such as low weight, flexibility, malleability into stylish and memorable shapes, ferromagnetic nature which makes it easy to be sorted out for recycling and energy efficient production compared to other metals. Mild steel is used for automobile chassis and body panels. However mild steel is susceptible to corrosion. Izadi et al. [31] identified that epoxy coating on mild steel can significantly improve the corrosion performance. During the study, it was observed that corrosion resistance, active protection, and cathodic disbonding performance of epoxy coating can be improved by hybrid sol-gel modification of the surface of the mild steel and by the addition of green inhibitor loaded Nano containers (GIN). Increasing environmental and health concern have made the used of lead and chromium (VI) based coating in automobile fuel tank unacceptable in the automobile industry. However, Ogata et al. [34] described the improved corrosion resistance, weldability and resistance to gasoline degradation of epoxy coating reinforced with nickel and flake aluminium particulates on lead and chromium (VI) free galvanized steel sheets used in the fabrication of automobile fuel tanks. The metal particulates were added to improve the welding ability of the steel sheets. Hu et al. [35], investigated the potential application of TiO2 waterborne epoxy resin coating in an automobile. Adhesive shear strength test and laboratory photo-catalytic performance test indicated that the coat is capable of decomposing some exhaust pollutants such as NO, HC and CO. Also British Pendulum, sand patch method, and pavement permeability test indicated that TiO_2 waterborne epoxy resin coating can seal fog on asphalt pavement thereby improving skidding resistance of automobile tires on asphalt pavement. The presence of TiO_2 also improves the photo-catalytic performance of epoxy coating [36]. The flame retardant coat has been reported based on a combination of titanium and aluminium flakes dispersed into a binder material [11]. This type of coat can stand a temperature of 400 ^{0}C and as high as 800 ^{0}C when titanium aluminium complex coat is formed as a result of the occurrence of burn off.

The most recent advancement in automobile paints and coatings is the development of polymer matrix based super-hydrophobic Nano coatings [37]. They have exceptional hydrophobic property. Epoxy is utilized for this purpose. It has been observed that the introduction of Nano-fillers such as TiO_2 can result to super-hydrophobic Nano coatings with unique combined properties such as anti-corrosion, anti-bacterial, anti-icing, anti-fogging, self-cleaning and anti-fouling properties [38]. TiO_2 nanoparticles addition not only

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protects the paint, but it also reflects UV rays from automobile coating [30].

IV. Engine Component

In a tribology study [39], it was observed that about 41 % of total energy consumed are due to energy losses that take place in an automobile engine. Out of this percentage, friction loss constitutes about 66 % caused by piston rings (19 %) and piston skirt (25 %) sliding against the cylinder wall and engine bearing (Figure 3).

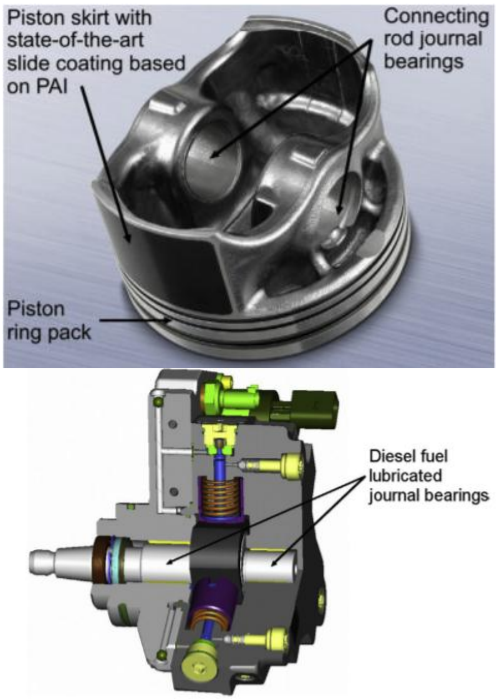

Fig. 3 From left to right, diesel engine piston and fuel injection pump showing where slide coating can be applied [39]

Therefore for improved fuel economy and reduction of emission, friction and wear in the automobile engine must be reduced as low as possible. Reduction of mechanical losses would then lead to appreciable improvement in the fuel economy as well as a reduction in the greenhouse emissions. Automobile manufacturers now utilize polymeric slide coating in the automobile engine compartment in order to reduce friction and to increase wear resistance. Modern polymeric slide coating is comprised of three components namely a binder, solid lubricant and a solvent. Epoxy resin especially novolac resin and polyimide resin are the most favourable binder due to their high-temperature performance required in an automobile application, easy process ability and chemical stability. The mechanical properties, as well as high temperature performance according to the aforementioned researchers, can be improved with fibre reinforcement. However, the use of nanoparticles such as TiO_2 was observed to exhibit superior properties compared to fibre fillers or micro-particles.

Commercial pure titanium and titanium alloy such as commercial pure titanium grade 1and grade 2, Ti-6Al-4Sn-4Zr-1Nb-1Mo-0.2S, Ti-4.5Fe-6.8Mo-1.5Al, Ti-46-8Al-1Cr0-2Si, Ti-6Al-4V, etc. have been adopted in automobile production of engine components and accessories such as connecting rod, valves, valve springs, valve spring seats, valve cups, camshaft, bucket tappets, piston pins, turbocharger rotors, exhaust valves and mufflers and crankshaft because of their high temperature performance and corrosion resistance [10], [40].

Heat transfer problem has great influence in the performance of automobile engine. Radiator which comprises of tubes channels acts heat exchanger between its content and the surrounding. Most radiators utilize two fluids (air and the coolant) the coolant conducts heat from the engine and then transfers it to the air causing the coolant to leave the radiator at a lower temperature and then back into its storage tank. As the coolant travels through the tubes, part of the heat is also being conducted away by the fin. So thermal conductivity is essential for the effective performance of the coolants. Conventionally, substances such as water, ethylene glycol and mineral oil have been used as a coolant in automobile radiator for the removal of excess heat generated. The performance of these fluids is below optimal requirement. This has attracted the attention of researchers towards the development of an efficient cooling system. The dispersion of micro-particles into radiator coolant was introduced to facilitate thermal conductivity of coolants. Although considerable success can be achieved using this approach, they can lead to blockage of fluid channels. This challenge has completely been solved through nanotechnology. It was observed that the introduction of nanoparticles into coolants improve their thermal conductivity to a great extent. This phenomenon is known as Nano fluid technology. Nano fluids are had competitive advantages over conventional fuel namely higher thermal conductivities than that fuels in the macroscopic scale, high stability and minimal damage such as wall abrasion in case of pressure drop common with millimetre or micrometre particles suspensions. Among other metallic nanoparticles, titanium nanoparticle has attracted the attention of researchers due to some its excellent properties such as toxic free nature, high availability due to its high industrial production and stability without stabilizer [41].

The problems encountered towards the development of Nano fluid have been the use of proper Nano fluid preparation techniques to avoid biphasic solid-liquid system and agglomeration of nanoparticles. However, the surfactant has been used in the treatment of nanoparticles to combat agglomeration. Titanium dioxide nanoparticles have been used by many researchers for this purpose although it has been proved that aluminium oxide has better performance than titanium oxide. The used of Nano fluid leads to a reduction in the size of automobile radiator and subsequently leads to an improvement in fuel economy and weight reduction [42]-[44]. Saleh et al. [45] demonstrated the thermal conductivity and viscosity of titanium dioxide nanoparticles suspended in distilled water. It was observed that the thermal conductivity and relative viscosity of the Nano fluid increased significantly with an increase in the volume fraction of titanium dioxide nanoparticles. Thermal conductivity also increased with temperature. However, the temperature did not have influence

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over the relative viscosity of the Nano fluid. He et al. [41] observed an increase in convective heat transfer and thermal conduction with increasing concentration titanium dioxide nanoparticles in aqueous TiO_2 based Nano fluid. Many researchers have supported the improved thermal conductivity and viscosity of titanium dioxide nanoparticles Nano fluid [46]-[49], [29].

V. Light-Weight Parts

Achieving light-weight is key to achieving fuel economy. The appreciable effort has been directed towards replacement of conventional material with light-weight parts in automotive industries. Titanium and epoxy resin have played a significant role in this regard. Sardou et al. [50] reported light-weight composite coil springs using epoxy resin reinforced with E glass fibre. Extended fatigue life was achieved through a unique positioning of the reinforcing fibre. It was observed that weight reduction of about 75 % can be obtained with the application of composite coil spring.

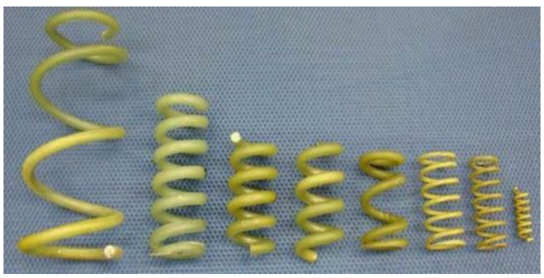

Fig. 4 Epoxy/E-glass fibre composite coil spring.

Sharma et al. [51] observed that the inclusion of titanium dioxide nanoparticles in the reinforcement of steel alloy used in an automobile can lead to weight reduction of the component. For lightweight application, titanium alloys are used for valves, steering knuckles, wheel hubs, wheel brackets, suspension springs and links [10], [40]. The disc brake rotor is one of the automobile parts that has received the attention of light-weight campaign. Pearlitic matrix grey cast iron due to its high thermal conductivity, good damping property, easy fabrication, friction and wear performance and low price has widely been used in making disc brake rotor for efficient braking system [52]. However, for weight reduction, light-weight materials have considered as a suitable replacement for grey cast iron. Aluminium alloy due to its low weight and stiffness compared to grey cast iron has considered for this purpose [53]. However, in terms of specific strength, resistance to corrosion, toughness, tribological properties and load carrying capacity, Duraiselvam et al. [54] in their study reported that titanium alloy is preferred to aluminium alloy for disc brake rotor. In their study laser processed Ti-6Al-4V indicated 760 HV hardness improvement compared to 350 HV of unprocessed alloy making it a suitable material for brake disc rotor. Blau et al. [55] also reported a reduction in weight up to 37 % as well as resistance to road-salt corrosion of titanium alloy and titanium composite based disc brake rotor. Titanium composite showed better wear property compared to titanium alloy for the truck motor. However, the wear rate in all the titanium-based brake disc rotors were higher than that obtainable with cast iron. The authors then suggested the inclusion of hard particles to improve wear performance. The high rate of wear of titanium alloy was further stressed by Ananth and Ramesh [56]. Thus, they investigated the coating of aluminium alloy with TiAlN and AlCrN improved with molybdenum disulphide. Significant reduction in coefficient of friction was obtained with both coatings. However, AlCrN coating gave the best improvement in tribological properties. Furthermore, many researchers have reported enhancement of wear performance of metal surfaces with epoxy based coating [57]-[60].

VI. Light-Weight Parts

Fossil fuels are not only being depleted, but they also contribute to global warming, unsustainable and also non-renewable. Hence the need for alternate sources of energy. Biofuel has attracted a lot of attention as a green energy source which will go a long way in the reduction of CO_2 emissions. The used of biofuel in transportation has been an attractive research topic. It has been observed that the transportation sector accounts for about 23 % of the total CO_2 emissions. Also a 70 % reduction in CO_2 emissions by the year 2060 the use of biofuel in an automobile. Thus in India for example, crops such as sugarcane, rice and have been proposed. All these facts have accelerated sweet sorghum, as well as perennial plants such as neem, mahua, karanja and jatropha, have been used for the production of bio-ethanol and bio-diesel production. These biofuels are not without some challenges. There has been identified poor blending of biofuel with petrol fuel. Also, biofuels have high oxygen content and the presence of heteroatoms like nitrogen and sulphur make their properties different from conventional fuels. Combined deoxygenation techniques such as hydro-deoxygenation, decarboxylation and de-carbonylation reduce biofuel oxygen content. Although plant-based biofuels have achieved a recommendable result, they lead to the reduction available edible feedstock. Thus, there is a corresponding increase in the prices of edible feedstock. It was estimated that about 90 % of biofuel currently in use are based on edible feedstock. Therefore, the attention of researchers ha been shifted to non-edible feedstock based biofuel. The success of this depends on the quality of lipid extraction from these non-edible feedstock. Microalgae, a photosynthetic micro-organism has widely been studied for this purpose. This is where nanotechnology comes into play. TiO_2 nanoparticles have used the production of biofuel as a catalyst during deoxygenation, in the removal of heteroatoms as well as in the enhancement of lipid extraction [61]-[64].

Proper combustion of fuel in an automobile is key to improving engine performance and reduction of harmful emissions. It has been observed that the addition of metal oxide nanoparticles such as TiO_2 nanoparticles into biofuel can reduce specific fuel consumption, improves brake thermal efficiency, reduces hydrocarbon emission, shortens ignition delay due to increased chemical reactivity thereby reducing carbon monoxide emission, reduces oxides of nitrogen by acting as oxygen donating catalyst, reduces smoke produced at different brake power, increases cylinder pressure as result of

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increased surface area and also increases heat release rate [65], [51]. In modern vehicles, fuel cells are used as either as a primary or back-up power supply. The development of efficient bipolar plate, an essential part of polymer electrolyte membrane fuel cell is a key bottleneck in developing efficient fuel cells. Metals conventionally form oxide thereby increasing the rate of corrosion. Conductive epoxy composite such as graphite/epoxy composite has been developed to overcome this challenge [66]. As the source of energy for an automobile is being shifted away from petroleum products, the microbial fuel cell has attracted the attention of researchers as an alternative source of energy. Titanium has a promising application in the development of modified electrode of the microbial fuel cell for power generation. Ying et al. [67], reported enhancement of current generation in a microbial fuel cell with stainless steel mesh modified with thin film TiO_2 prepared by the electrochemical process used as the anode. The maximum current density of the modified mesh was 69.5 ± 1.2 A/m^2 while 2431 ± 224µg port/cm^2 density of protein (12 times higher than unmodified stainless steel mesh) was observed on the mesh. This was attributed to the biocompatibility of TiO_2. Graphene/TiO_2 nanocomposite fabricated by the microwave-assisted solvothermal process was used as the anode in a microbial fuel cell to improve its performance [68]. Both bio and electro-catalytic performance of anode of E-coli microbial fuel were observed with polyaniline reinforced titanium dioxide composite. The catalytic performance of the anode was dependent on the percentage of polyaniline. However, the best performance was obtained with 30 wt. % polyaniline [69].

VII. Glass

Automobile windows, headlights and mirrors have glass components. Quite often, water droplets, dirt, oil and other particles which cling onto the glass as well as the presence of cracks or scratches cause light either from the sun or other vehicles falling on them to scatter, thereby creating glare. Glare can lead to accidents. Therefore glasses used for automobile headlights, windows and mirrors require some special features such as antifogging, anti-reflecting, self-cleaning, UV shielding, transparent, scratch resistant, impact strength and water repellant properties. Epoxy based coating, as well as titanium dioxide nanoparticles,, have been utilized by various researchers to improve the above-mentioned properties of glasses used in automobile windows, headlights and mirrors. The antifogging property effect of TiO_2 nanoparticles on glass surfaces is based on capillary action. They make such surfaces superhydrophilic in nature with contact angle that is less than 5^o. Hence there is increased water absorption and spreading of water droplets which in turn reduces the scattering of light [70]-[76]. The epoxy coating improves the strength of a glass surface by filling flaws on glass surfaces. As a result of this, there is reduced the crack length and this is also capable of producing healing stresses [71]. Fig. 5 shows conventional and modernized antiglare rear view mirror.

Figure. 5 (a) Conventional automobile mirror. (b) Antiglare mirror [11].

Self-cleaning is an interesting natural phenomenon. It is found in rice plant, lotus plant, fish scales, butterfly wings, canna leaf, rose plant petal, gecko foot, cicada, cactus plant etc. [77]-[79]. Development of artificial self-cleaning materials constitute an interesting research field in material science for various applications, for example, cost of regular maintenance of various surfaces can significantly be reduced with self-cleaning materials. The surface of self-cleaning materials are either hydrophilic or hydrophobic. In hydrophobic surfaces, water droplets spread evenly to form a firm. Contaminants are washed away in the cause of spreading while in hydrophobic surfaces, the contaminants are trapped by the water droplets which rolls off their surface due to their high water repellant property [79]. Wettability of material surfaces are determined by their contact angles. Surface with a contact angle less than 90^o is hydrophilic while hydrophobic surface has a contact angle greater than 90^o. On the other hand, superhydrophilic surface has a contact angle less than 10^o while super hydrophobic surface has a contact angle greater than 150^o [80]. Self-cleaning technology finds so many applications in automobile windows, mirrors, paints etc. Titanium dioxide has been studied for this purpose. Banerjee et al. [79] in their review demonstrated photocatalytic self-cleaning ability of titanium dioxide based surface coating. Upon illumination with surface energy greater than the band gap energy of titanium dioxide, the contact angle is significantly reduced and there is excitation of an electron from the valence band to the conduction band. The excited electrons can react with atmospheric oxygen to produce superoxide radicals while the positive electron-hole at the valence band can also absorb atmospheric oxygen to generate hydroperoxyl radicals. These radicals when they come in contact with pollutants can transform them into carbon dioxide and water, thereby cleaning the surface. However, the photocatalytic self-cleaning property of titanium dioxide is not without some limitations. It was noted that the excited electron can recombine with the positive electron-hole and this reduces the self-cleaning ability. Also, TiO_2 has large band gap which limits it to absorption of only UV portion of the spectrum which is just a small portion of the overall spectrum. Several techniques were identified that could improve the photocatalytic activity of titanium dioxide based coating namely roughening of the

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surface, metal doping, non-metal doping, dye sensitization, hybrid metal-non-metal doping and formation of hetero-structures with other semiconductors like SiO_2. Furthermore, the aforementioned authors reported that the general consensus has not been reached on the photocatalytic self-cleaning principle of TiO_2. However, the improvement of the photocatalytic activity via the above-mentioned techniques were attributed to narrowing of TiO_2 band gap, the formation of confined energy level in the band gap and oxygen vacancies defects.

In another study, Kim et al [81] reported 8 nm titanium dioxide nanotube structure exhibiting both super-hydrophobic and superoleophobic properties prepared by electrochemical etching and hydrothermal synthesis technique. The contact angle of both water and oil wettability was approximately 174^o. When the surface of TiO_2 nanotube was coated with perfluorosilane, the contact angle was further increased to 178^o. In contrast, it was observed that with the as-prepared TiO_2 nanotube displayed superhydrophilic properties. Wettability of TiO_2 nanotube is not stable. For example, hydrophobic surface treated TiO_2 nanotube upon irradiation with UV-A and UV-C became hydrophilic [82]. Hydrophilicity of TiO_2 nanotube can be controlled by varying the diameter of the nanotube, heat treatment, chemical modification and anodization [82][83][84][85]

VIII. Tyre

Tyres are an essential component of the automobile. They are essential for transmission of motion and braking, lessen the impact from the road, bearing vehicle weight and for maintaining and changing direction. Tyre performance to a great extent influences fuel economy. Tyres are chiefly made of rubber mixture with several reinforcing elements such as steel threads, reinforcing fillers, polyester etc. Properties essential for effective performance of automobile tyres include low rolling friction with a firm grip, reduced abrasion wear, resistance to tear and tear propagation, reduced vibration and shock absorption. Fillers amount to about 30 % of rubber mixture used in tyre making. The presence of the fillers improves the durability and properties of tyres. The performance of tyres depends on the interactions between the rubber and the reinforcing fillers. Nano fillers due to their surface properties have been used to improve the properties of tyres. Fillers commonly used include silica material, soot and carbon black [11], [86]. Figure 6 below shows the structure of the tyre. The use of metal oxides such as titanium dioxide nanoparticles as solid filler give tyres some unique properties such as UV blocking, antifouling, antimicrobial and improved tensile strength and modulus. Titanium dioxide nanoparticles are also used as pigment on tyre wall and also in combination with silane in the modification of fillers to improve their interaction with the rubber mixture [87]. Addition of nanoparticles of titanium dioxide as filler in tyre making can reduce dynamic hysteresis loss. It has been reported that a 10 % reduction in dynamic hysteresis loss can give 2 % decline in fuel consumption [88].

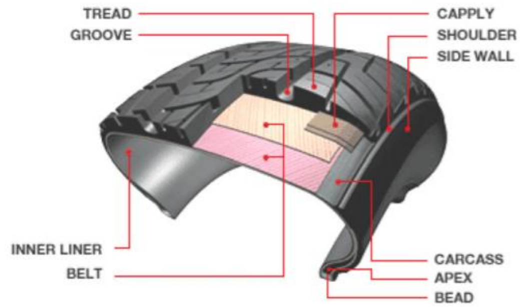

Figure. 6 Structure of tyre [86].

IX. Automobile Interior

There is a need for the interior part of a vehicle where we come mostly in contact with to be kept as healthy as possible. However, they are commonly infested with microbial and bacterial activities. The automobile interior accessories such as the seat, dashboard, door padding, foot carpet etc. are now incorporated with particles that induce the antimicrobial and antibacterial effect. Some oxidizing agents, radical formers and compounds of chitosan and ammonium have been used to this end but their usage is limited due to their toxic nature. Nanoparticles of silver due their high biocompatibility and resistance to sterilizing agents have been used in the automobile interior. Their operation is based on biocidal process. Microorganisms are killed when their negatively charged cell membrane react with the positively charged biocide. However, silver nanoparticles also have some shortcomings. They are easily oxidized to lose their antibacterial effect, difficulty to be dispersed in the polymer matrix thereby forming agglomerates and delayed antibacterial activity whereas bacterial multiply very fast. Titanium nanomaterials such as titanium dioxide nanotubes and nanoparticles are widely applied in bioengineering such as in automobile interior components as well as in biomedical field owing to their strong oxidizing ability, chemical stability, non-toxic nature and antibacterial property. They are activated when there is an absorption of light. The excited charge carriers released in the process react with oxygen to form hyperoxide radicals. The oxidizing of these radicals kill the microorganisms by attacking their cell membrane [11], [89]. Haider et al. [90], reported antibacterial activity of thin film coating (1mg/cm^2) of titanium dioxide nanoparticles upon irradiation with sunlight. The coating showed 100 % efficiency in the killing of Pseudomonas aeruginosa and staphylococcus aurous types of bacterial and degraded potassium permanganate pollutant. The optical activity of the TiO_2 nanoparticles was dependent on the calcination temperature adopted after sol-gel preparation process. The lower the calcination temperature, the higher the band gap of the TiO_2 nanoparticles.

X. Conclusion

Titanium and epoxy have had a significant contribution to the technological advancement of the automobile industry. It finds application in the development of safe, functional and durable automobile system with low emissions, low

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maintenance cost and improved fuel economy. This review has outlined some of the successful applications of titanium and epoxy in the automotive industry. They include (a) Epoxy coating for the improvement of the tribological properties of automobile brake and titanium as lubricant additive; (b) Titanium nanoparticles for enhanced flame retardant and self-cleaning (through superoleophobic, super-hydrophobic, superhydrophilic, anti-fouling and anti-fogging phenomena) paints and coating; (c) Epoxy coating and titanium particle based coating in the reduction of friction and wear of two surfaces rubbing against each other for efficient performance of the engine (d) Titanium alloy for high strength and light-weight parts; (e) Titanium particles based Nano fluid as automobile fuel; (f) Self-cleaning and anti-glare glasses; (g) Improved tyre performance; and (h) Anti-microbial interior components.

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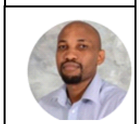

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