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Review

Potential applications of nanotechnology in transportation: A review

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ABSTRACT

Nanotechnology is the building of structurers at nanoscale at the order 10^{-9} m. A significant development in the field of transportation will put an imprint in the development of our society. Therefore industries are now heavily investing in researches and developments in order to develop safety, environment friendliness, comfort and outstanding transportation systems. In this paper we will discuss the recent applications of nanotechnology in transportation field which include nanofilters, anti-glare coatings, carbon black in tyres, GMR sensors, fuel additives, dirt protection, nanocatalysts etc. Some interesting nanotechnological applications like nanosteel, low friction aggregate components, switchable materials, glare free wiper free glasses, environmental multisensors, situation adapted driving mode are in the room of research which will become realistic in very future.

Contents

1. Introduction

When the size of a material is reduced to nanometer range chemical, physical and biological properties of the material changes which are entirely different from the properties of their individual atoms, molecules or bulk materials (Tomar, 2012). The reasons for these changes are large surface area to volume ratio, spatial confinement, large surface energy, and reduced imperfection. Higher hardness, super elasticity at high temperature,

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improved breaking strength and increased facture toughness are the important mechanical properties that are considerably improved. They are mainly due to the decreased grain size and at this size deformation cannot occurs. This results in prolonged durability of machines, effective lubrication systems, lightweight materials etc. (Matthias et al., 2008).

At nanoscale, the surface area to volume ratio increases and therefore more atoms are exposed to the surface thereby making surface properties more dominant than the properties of the bulk material. As a result chemical reactivity and unique material attributes are introduced. These enhanced properties help in resistance against oxidation, mechanical abrasions, corrosions and high temperature (Kantamneni et al., 2013). Nanoparticles are very small enough which make them smaller than the wavelength of the visible light therefore no reflection occur from these particles. Dispersion effect which makes longer wavelength to be deflected less than the shorter wavelength by nanoparticles cause color effect. Controlling the size of the nanoparticles helps to achieve desired wavelength region for intended applications like windshield, light reflection and scattering, clear glasses etc. (Tomar, 2012; Kantamneni et al., 2013).

When particles are reduced to nanometer range, their energy levels become discrete, that is, they get quantized. Charge carriers are able to move freely in bulk materials, but when its size is reduced, scattering at the boundaries will occur. As a result electronic properties of the particles are affected (Matthias et al., 2008). By reducing the size of the particles, ferromagnetism disappears and transfers to super paramagnetism due to the huge surface energy.

1.1. Necessities in transportation

Individual mobility is the basic need of people and an important prerequisite of modern society. The United Nations estimates that the world wide vehicle fleet will double from 750 million today to approximately 1.5 billion by 2030 (Matthias et al., 2008). Questions concerning passenger safety, intelligent traffic guidance systems, pollutant reduction and effective recycling at the end of the value added chain to save scarce resources are becoming more urgent.

Nanotechnology contributes crucially to necessary developments and the production of innovative materials and processes in the automotive, aerospace and water transportation sectors. For instance, modern tyres achieved their high mileage, durability and grip through nanoscale soot particles and silica. Materials with nanoparticles or layers at the nanoscales have beneficial effects on inner and outer surfaces, on the body or on the engine and drive. Let us see important applications of nanotechnology in the transportation sectors one by one.

2. Applications of nanotechnology in automobiles

Most of the researches and developments based on nanotechnology are in automobile sector as we depend on it more frequently compared to air or water transportation. Nanotechnology is applied to body parts, emissions, chassis and tyres, automobile interiors, electrics and electronics, engines and drive trains. The important parts of automobiles those are shaped by nanotechnology is depicted in Fig. 1.

2.1. Body parts

Body parts applications include paint coatings, light weight parts, self-cleaning and scratch resistant nanopolymers.

2.1.1. Paint coatings

Every body parts is painted with one or another color and by different methods. Paintings are mainly done for decorative and protective purpose. Usual paintings in automobiles have three coats- primer, basecoat and clear coat. However, in most cases it vary from four to six layers to impart various properties to it. Corrosion protection, aesthetic characteristics, cost and environmental requirements, ease of mass production, appearance and durability are the crucial performance factors driving the automotive coating technologies. Modern automotive coating processes mainly consist of five steps which include pretreatment, electrodeposition, a sealer, a primer and finally the topcoats. Pretreatment cleans and removes excess metals and forms an adequate surface for enabling bonding of corrosion protective layers. The corrosion protection layer is then deposited by electrodeposition method. Sealer is to prevent water leaks and minimization of vibrational noise and chipping. The most common sealer is Poly Vinyl Chloride (PVC). The main objective of a primer is to promote adhesion between

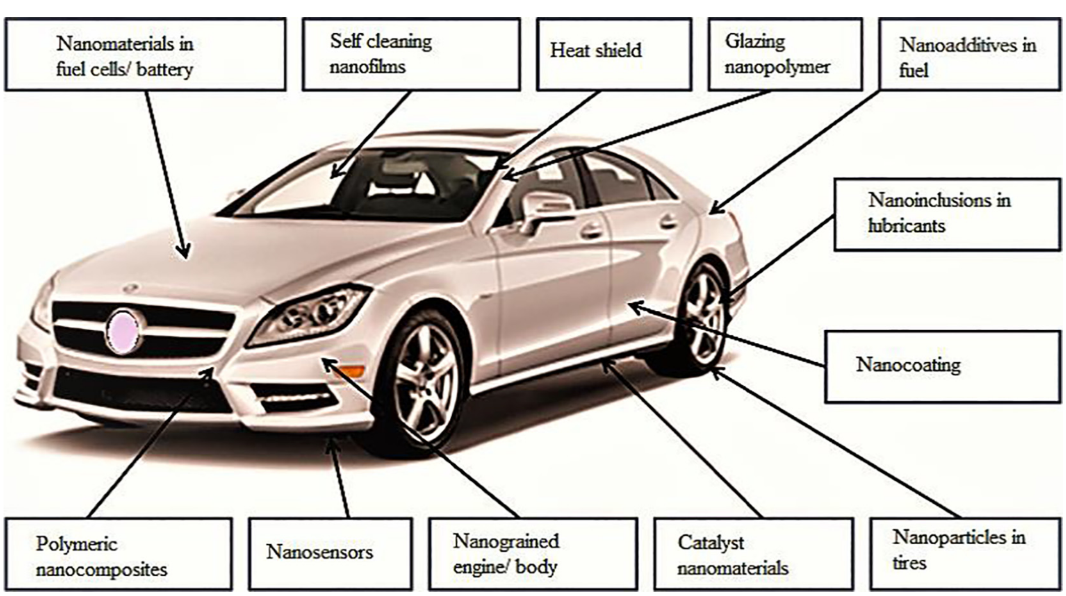


Fig. 1. Various parts of automobile in which nanotechnology is applied (Not representing the actual vehicle) (Asmatulu, 2013).

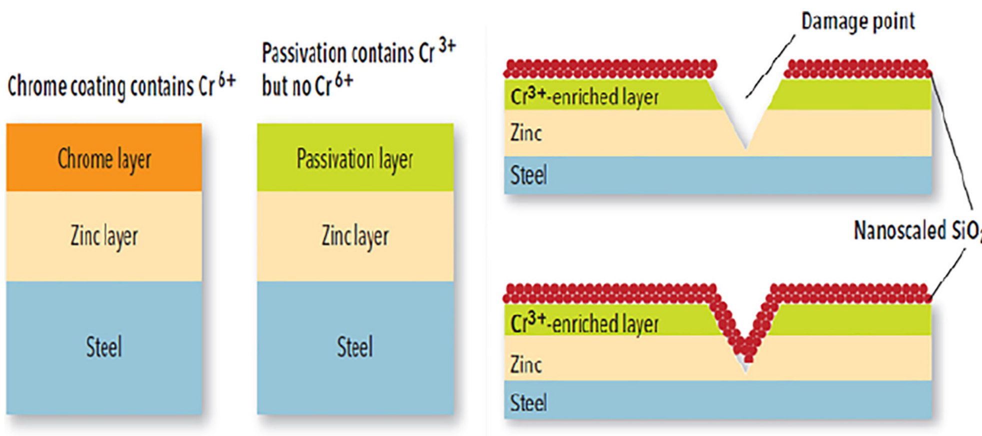


Fig. 2. (a) Conventional anticorrosion coating (b) Nanoparticle added anticorrosion coating (Mohseni et al., 2012).

the basecoat and the surface and impart anti- chipping properties (Akafuah et al., 2016). The primer acts as a protector and leveler which makes easier for the basecoat to apply. Its function is to protect the body from ultra-violet (UV) rays, corrosion, bumps, and stone chips. Basecoat is the one we referred as the paint and its gives the visual properties and color effects. Clear coat is the transparent and glossy coating that has interface with the environment. It can be either waterborne or solvent and is chemically stable (Seubert et al., 2008).

The key problems associated with the conventional paints are low paint transfer efficiency, low flame retardant property, less surface finish and adhesive to dust particles and water. Most of these disadvantages can be overcome with the incorporation of various nanoparticles (nps) into these paints. Early, Cr(IV) coatings were used in paints for high anticorrosion performance due to their high self-healing property in corrosive environment, unfortunately, they are highly toxic in nature. The next option is to use Cr(III) which is comparatively less toxic in nature but the efficiency is low. To improve its efficiency nanotechnology has been applied. A three layer system consisting of SiO_2 nanoparticles, a Cr(III) enriched layer and a zinc layer is used for this purpose. Due to the higher negative potential of zinc than iron, it produces electrons required for cathode reaction and prevents the oxidation of iron. As a result of this, a positive charge is developed at the surface due to the zinc cations and since SiO_2 nanoparticles have negative charge, they move to the corroded surface and deposit on it Fig. 2. This process is called as self- healing by nano passivation (Kantamneni et al., 2013). Many recent works have been done on anticorrosion field (Saravanan et al., 2016; Dias et al., 2015; Alam et al., 2017; Ates, 2016) which promise us a nanocomposite based effective anticorrosion coating.

Most of the conventional flame retardant coatings like melamine and ammonium polyphosphate lost their fire retardant effectiveness due to their reduced char formation and mechanical properties in fire and hence easily detach from their substrate. Silicon based coatings have the ability to resist temperature up to 1000 °C, but such coatings are very expensive (Mohseni et al., 2012). Some developments in flame retardant coating like titanium esters with aluminium flakes dispersed into binders that can resist temperature up to 400 °C have been reported (Kwaambwa, 2013). "Burn off" occurs above this temperature which leads to the formation of a complex coating of titanium aluminium that deposits on the surface and it enhances the thermal resistance up to 800 °C. But it is not enough to hold the devasting temperature of fire and results in great damage to vehicles and lives. Therefore need for better fire resistant coatings are constantly growing (Gangotri and Chaware, 2004). Mechanical and chemical properties of flame retardant coatings can be improved by incorporating concentrates of nanosized magnesium aluminium layered double hydroxides (LDH). When a specific amount of LDH nanoparticles is dispersed with the paint solution, it improves the char formation and fire resistant properties of the coating. The nano LDH will absorb the heat and sent out carbon dioxide and water when burns and thereby reduces the temperature of the surface in addition with enhancement in char formation (Gangotri and Chaware, 2004; Khanna, 2008).

Nanoparticles such as ZrO_2, AlOOH, and SiO_2 are embedded in ultra violet curable lacquers which resulting in improved abrasion resistance. Using nanoparticles of titania or zinc oxide will help to improve UV resistance property by not only absorbing but also reflecting those harmful rays (Seubert et al., 2008). Nanoparticles in combination with fluoro methyl group in coatings increase its surface area and pore volume, which in turn increase the surface roughness. Even though nanocoatings have many advantages over conventional coatings there are some issues in which further developments are required. Main issues in nanocoatings are; dispersion and stability of nanoparticles, pigments may lose their color and hardening problems of ultrafine powder (Kwaambwa, 2013).

2.1.2. Scratch resistance with nano-varnish

The new looking of automobile body shell should be guaranteed after several washes and many years of operations. Scratch and or abrasion on the surface will damage the coatings. They may also damage the underlying coating layers. It is a challenge for scientists and researchers to develop scratch and abrasion resistant coatings without affecting their other properties. In conventional method, by imparting large number of cross links in the binder

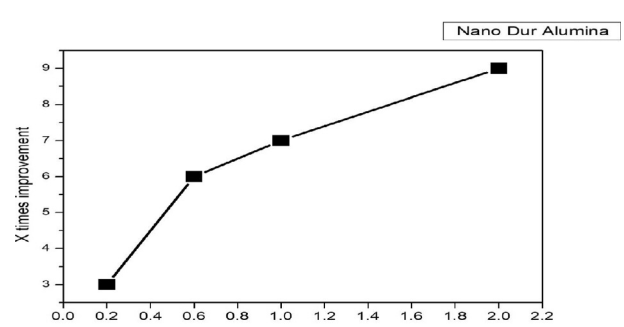
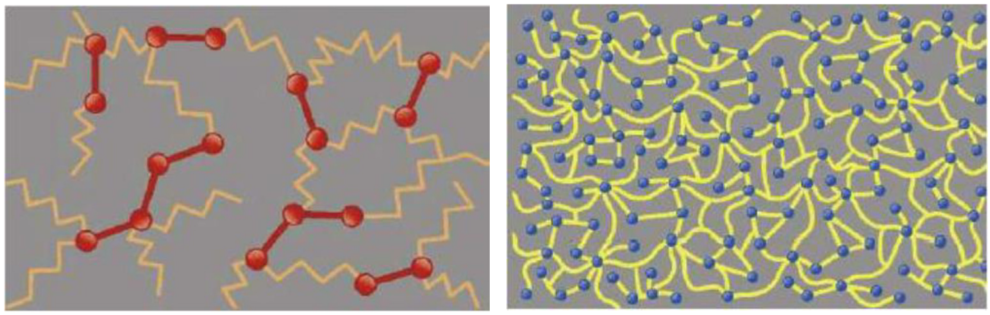


Fig. 3. Scratch resistant performance of alumina nanoparticles in UV curable coatings.



(a) (b)

Fig. 4. (a) Conventional paints (Mohseni et al., 2012). (b) Nanopaints (Mohseni et al., 2012).

of the coatings can improve the scratch resistance but they have very low impact resistance due to their less flexibility. On the other hand, a less cross linked coatings will have better performances like anti- fingerprint and resistance to impact but will have less abrasion and scratch resistance (Mathiazhagan and Joseph, 2011). Thus we cannot attain a good scratch and abrasion coatings without sacrificing some other properties and here comes the role of nanotechnology.

The use of siloxane encapsulated SiO_2 nanoparticles to produce a scratch and abrasion resistant films have been reported by Glasel et al. (2000). Due to the homogeneous distribution of nanoparticles in the polymer, scratch resistance property can be improved without sacrificing any other properties. Nano alumina have also shown positive response in this aspect. The performance of scratch resistant property of alumina nps in a coating was studied as shown in Fig. 3. Variable amount of alumina nps between 0.2 to 2 wt% was dispersed in a UV curable coating and was subjected to scratch test by means of measuring the increase in haze due to the scratch. The performance of the alumina nps dispersed coating was compared with the neat coating and is expressed as X times improvement with the neat coating. It is clear that the alumina nps significantly improve the performance of the coating, up to nine times, even at very low concentration of alumina dispersed in the composite coating (Khanna, 2008).

Fig. 4(a) shows the binders (in the orange) and the cross linker agent (in the red) of conventional paints. Fig. 4(b) shows how the binders having high elasticity (yellow) and inorganic nanoparticles having high strength (blue) in nanopaints. The binders and the inorganic nanoparticles are strongly linked to each other giving them high elasticity and high strength. The tightly packed nanoparticles introduce scratch resistant property to the paint (Matthias et al., 2008; Mohseni et al., 2012).

With respect to the conventional paints, nano-varnish results in higher scratch resistance and good paint brilliance. The reason for this technological effect is the embedded ceramic particles which are added to the varnish layer in nanometer range. The most commonly used nanoparticles in the varnish is Degussa's AEROSIL R9200 and this accounts to improve the scratch resistance property of the automobile body shell (Matthias et al., 2008). It is nothing but special type of silica nanostructured powder in gaseous phase which synthesis in flame and therefore called as pyrogenic constitute. Silica tetrachloride is the best suited pyrogenic constitute. If the paint is liquid, the particles can be randomly distributed in solution. At the time of drying and hardening processes, the particles crosslink with each other deeply and gives the paint matrix molecular structure (Seubert et al., 2008). These types of nanopaints are already being used in different models of Mercedes Benz.

2.1.3. Light weight body parts

Weight reduction of vehicles is one of the most discussed topic in the automobile research field. On the one hand, by reducing the weight we can increase the fuel efficiency, reduce CO_2 emissions and production cost. It is estimated that by reducing the weight of an automobile by 10% there will be fuel economy of 7% (Coelho et al., 2012; Rohit et al., 2014). On the other hand, while reducing the weight there will be problem related to stability, crash resistance and smooth working which is great concern to the safety of the vehicle. Many developments had done in this field like reducing the number of engine components and using less weight parts, but they failed to coordinate both the efficiency and safety.

The materials near to the engine parts should possess high thermal resistance, whereas the exterior and structural parts should be made of materials that have high mechanical strengths. However commonly used materials like thermoplastics have limited mechanical properties and thermal resistance; therefore it can be used only after modified by reinforcements. Carbon nanotubes (CNT) have very less weight and around 150 times stronger than that of steel. Therefore CNTs are good substitute for steel in automobile parts which give us more strength and weight reduction (Steevan, 2015). Addition of nanoscale clay in a polymer matrix can develop a nanocomposite which is used to manufacture automobile parts near to the engine as they have good thermal properties. Clay nanocomposites with PP (Polypropylene), PA (Polyamide), PB (Poly butylene terephthalate), and PC (Polycarbonates) are the commonly used polymer nanocomposites (Lyu and Choi, 2015). When this nanoscale clays are mixed with polymers, their flame retardance and thermal resistance will increase (Seubert et al., 2008).

Magnesium and its alloy (light weight) dispersed with nanosize reinforcements shown improved mechanical properties without much reduction in its other properties (Luo et al., 2014). Nanoparticles of Y_2O_3 or Al_2O_3 are added to magnesium either by agitating molten melt or by mixing the magnesium powder and nano reinforcements in the required composition by mechanical alloying or simple blending. Cu nanoparticles were also imparted to the magnesium which gave an improvement of 104% in 0.2% yield strength with a slight reduction in its ductility. The main reasons for these increments are (a) increase in the dislocation density in magnesium matrix due to elastic modulus and CTE mismatch between the reinforcement and matrix (b) presence of harder ceramic/ metallic nanoparticles as reinforcement (c) reduction in grain size. These magnesium nanocomposites provide improved tensile, hardness, dynamic, compressive, high temperature, fatigue and wear properties over conventional composites of magnesium and can be widely used in engine blocks and gear housings of vehicles which help to reduce the weight and improve other properties compared to conventional materials.

The commonly used 900 kg of steel and other types of metals in vehicles can be reduced by up to 300 kg by the use of nanocomposites and hybrid solutions. Nanocomposite plastics offer 25% weight savings on average over highly filled plastics and 80% over steel. LFRT (Long Fiber Reinforced Thermoplastic) offers high strength to weight ratio, good design flexibility, and high impact resistance and corrosion reduction when compared with metals (Coelho et al., 2012). At present German Motors are using 45.4 kg of thermoplastics in the hoods and doors in some of its model and Tesla sport cars use high power to weight ratio tanks and sink of lightweight carbon fiber/ epoxy composites. Volkswagen uses LFRT in Golf plus model, leading to the elimination of metals and processing steps which results in weight reduction of about 8 kg and lower production cost.

2.2. Engines

In modern automobiles around 10 to 15 per cent of the fuel energy is consumed by the friction of the moving mechanical parts of the engine. Piston, cylinder wall, crank drive elements like connecting rod, crank shaft and bearings and valve drive system including the valves and the cam shaft are the major friction causing parts of the engine. Among these, piston and cylinder wall aggregate are the major parts of mechanical frictional loss. Heat generation by the engine and its cooling is another problem that we are facing in the automobiles. At present, to overcome these problems we use engine oils in between the moving parts to reduce the friction, radiator and coolant to reduce the heat generated and cool the engines. The functions of the engine oils, radiator and coolant can be increased by the application of the nanotechnology (Srinivasan and Kumar, 2016).

By coating the cylinder wall with nanocrystalline materials we can reduce abrasion and friction and in turn the fuel consumption. There are research projects going on which aim to directly coat tracks of aluminum crankcase with nanomaterials. Iron carbide and boride nanocrystals with size 50 nm to 120 nm are used to coat the engine parts which result in extremely hard surface with very low friction (Matthias et al., 2008).

Radiator is used to remove heat from the engine. For this purpose, we use conventional heat transfer fluids like water, ethylene glycol and mineral oil. But these are not as efficient to remove all the heat generated. There are researches and discussions going on how to increase the heat transfer rate. By adding nanofluids into the coolant improve its heat transfer rate significantly. Nanofluids of CuO, alumina, carbon nanotube, silica, and titanium oxide dispersed in carrier liquid enhance heat transfer rate of the resultant coolant compared to the carrier liquid alone (Satyamkumar et al., 2015). Al_2O_3 nanoparticles in water coolant improves the heat carrying capacity rate and it depends on the amount of nanoparticles adding to the coolant. Fig. 5 compares the heat transfer rate of Al_2O_3 nanoparticle added to the coolant at various concentrations and pure water as coolant. At the concentration of 1 volume% in Al_2O_3 nanoparticles, there is an increase of around 25% in the heat transfer rate compared to pure water. Brownian motion of the nanoparticles added to the coolant is the main factor for the enhancement of heat transfer from the engine (Peyghambarzadeh and Hassan, 2011; Vikas et al., 2014).

Table 1
Comparison of COF between lubricating oil without TiO_2 and with TiO_2 for 4 kg and 6 kg load.

Load (kg)/ force (N)	COF (engine oil)	COF (engine oil + 0.4% TiO_2)	Percentage decrease (%)
39.226 N (4 kg)	0.111	0.053	52
58.839 N (6 kg)	0.142	0.109	23

Lubricants are used as engine oils to reduce the friction and wear between two surfaces in contact and having relative motion. Resistive force arises as a result of relative motion between two machine parts is called as friction and it is an unwanted force which reduces the efficiency of the machine. It can be reduced by introducing a substance having low shear strength in between the moving surfaces. This process of reducing the friction is called lubrication and the substance used is called lubricant. Lubricants are made of base oils like petroleum oil, mineral oil, silicones, esters etc. and small amount of additives to impart certain characteristic properties. Many nanoparticle additives like CuO_2, TiO_2, MoS_2 nanosheets and nanodiamond are added to the lubricant and their effects were studied (Shahnazar et al., 2015; Rajendhran et al., 2017; Gornickaa et al., 2010). From various studies, it found that by adding TiO_2 nanoparticles to the lubricant, the coefficient of friction (COF) was reduced by 52% as compared to oil without TiO_2 nanoparticles for load of 4 kg as shown in Table 1.

The size of TiO_2 nanoparticles varies from 10 nm to 25 nm. The reduction in COF by adding TiO_2 is due to the rolling action of the sphere shaped nanoparticles in between the rubbing surfaces. By increasing the concentration of TiO_2 in lubricant, its properties increase only up to certain level, after that its effect decreases as a result of agglomeration of TiO_2 nanoparticles (Laad and Jatti, 2018).

2.3. Tyres

Tyres are the most cited part of automobile in which nanotechnology is applied. Tyres are not made of a single material, but by combining and mixing many elements like rubber, steel threads, reinforced fillers etc. Important properties of tyres are exhibited by rubber mixtures. It determines the performance of the tyre

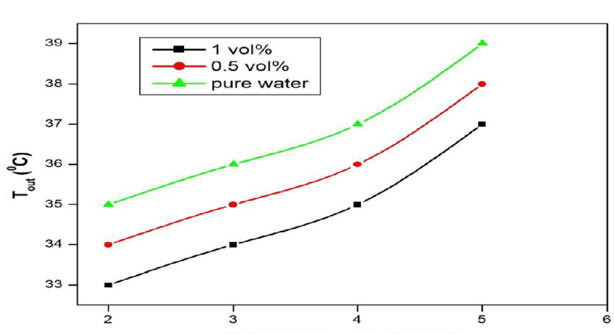


Fig. 5. Comparison of cooling performance using nanofluid and pure water.

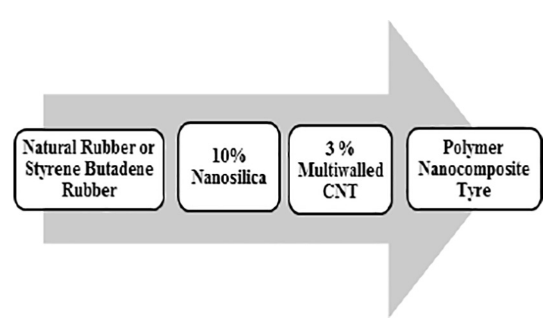


Fig. 6. Nanomaterials that are added to the tyre.

cover that contacts with the road. Around 30% of the rubber mixture consists of reinforcing fillers which give the tyres their specific properties like abrasion resistance, grip, resistance to initial tear and propagation of tear. A good tyre should have low rolling friction but at the same time it should have good grip. The properties of tyres are mainly depending upon the chemical and physical interactions between the filler material and the rubber. Carbon black, soot, silica and organosilica are added to the rubber mixtures to improve its properties and lifetime. By adding these particles in nanoscale, the tyre properties are seem to show significant improvement.

The first nanomaterial that added to the tyre was carbon black as a reinforcing element and pigment. Silica and soot are the most important ingredients used in the tyres as reinforcing element. By adding soot in nanoscale higher fuel efficiency and prolonged durability is achieved as they have coarser surface than those we use in ordinary tyres. As nanoparticles have high surface energy, interaction of the soot nanoparticles with natural rubber in the tyres is high which leads to better rolling resistance and reduced inner friction (Tomar, 2012; Matthias et al., 2008). Wear resistance and grip can be increased by adding 10% of nanosilica to the natural rubber or SBR (styrene butadiene rubber). It is proved that by adding 3% of multiwall carbon nanotube (MWCNT) to the natural rubber or SBR its hardness and tensile strength is increased as shown in Fig. 6. Also by adding 3% of montmorillonite clay, the equal performance in both longitudinal and lateral directions, better tradeoff between comfort and handling and isentropic behavior of the tyre can be increased (Giftson Felix and Sivakumar, 2014).

2.4. Ultra reflecting mirrors and glasses

The mirrors and headlights of the automobiles are made of glass and polymer components. While driving we feel discomfort when the sunlight falls on our eyes through the mirrors and glasses of our vehicle. During night journey, the lights from the vehicle opposite to us that falls on our eyes create a great problem. We cannot see the road or other vehicles properly because of the intensity of the light that falls on our eyes and this can lead to accidents. Several researches and experiments are going in this field and one of the methods to reduce this problem is to coat the glasses with sunlight protectors. But this solves the problem only up to certain limits.

Ultra reflecting thin layer of aluminum oxide having thickness less than 100 nm is applied to the surface of mirrors and headlights. This makes the mirrors to equip surfaces with fat, dirty water and repellant features. Hydrophobic and oelophobic nanometer layers are applied over the surface of the mirrors by chemical vapor deposition (CVD) method. Mainly fluoro organic material layers of thickness 5–10 nm are using as they have high resistance against friction and are applicable for longer times. To prevent the problems created by the light of other vehicles falling on our eyes at night, nanotechnology and electrochromic properties are applied together. When the glasses are equipped with functional layer nanocomposite having electrochromic properties, the optical properties of the glass or mirrors change. As the light falls on the glass or mirrors, a certain voltage is generated and this voltage makes the charges to move to the intermediate layers. This allows the incoming light to be absorbed by the color centers of ions at the electrodes and as a result only a small quantity of light is reflected back as shown in Fig. 7(a) and (b). Like the charging and discharging of a battery, this glass will get back to the original state as the poles change. The sensor that is equipped to the glass will measure and control the intensity of light that falls on the mirror. As soon as this light disappears the mirror will go back to its original condition (Mohseni et al., 2012).

(a)

(b)

Fig. 7. (a) Conventional mirror (Mohseni et al., 2012). (b) Modern antiglare mirror (Mohseni et al., 2012).

2.5. Interior of the automobile

We interact mostly with the interior parts of the automobile such as seats, door paddings, dashboard, air bags, seat belts, boot carpets etc. These are the place where microbial and bacterial infections are most common. Since interior is the place of an automobile where we interact mostly, it should be free from all bacterial and microbial infections. Because of the problems caused by these infections and our hygiene concern various antimicrobial agents like oxidizing agents (aldehydes, halogens), radical formers (isothiazones, peroxo compounds), and chitosan and ammonium compounds have been used. As most of these agents have some side effects and toxic in nature it cannot be used (Matthias et al., 2008). Several researches are currently going on in this field to find the best suited antimicrobial agent that can be used in the interior of the automobiles.

Nanotechnology has promised good agents that can be used without any side effects. The most important nanostructured antibacterial and antimicrobial agents are silver, gold, titanium oxide, zinc oxide, titania nanotubes, gallium, liposomes loaded nanoparticles and copper nanoparticles (Suresh et al., 2016; Dakal et al., 2016; Prabhu and Poulose, 2012; Sirelkhatim et al., 2015). They are commonly used as incorporated nanoparticles in a matrix such as silica network. The action of these nanoparticles is initiated either by a photocatalytic reaction or by biocidal process. Titania based nanoparticles are activated by the absorption of light, a photocatalytic reaction, as a result exited charge carriers are developed and it forms hyperoxide radicals by reacting with oxygen. These radicals oxidize and attack the cell membranes of bacterial and microbial agents thereby killing the microorganisms. The action of silver and gold nanoparticles based antimicrobial agent is by biocidal process. Here the microorganisms are killed by the interaction of the negatively charged cell membrane of the microorganism and the positively charged biocide. Silver nanoparticles are the most commonly used antibacterial and antimicrobial agent because of its potential advantages like high degree of biocompatibility, high resistivity to sterilization conditions and its efficiency (Mohseni et al., 2012).

One of the main reasons for dust and dirt accumulation on the compartment of vehicles are generation of static electricity.

Accumulation of static energy in insulators may lead to fire and even explosions of automobiles. Static electricity is caused due to imbalance of electric charges on the surface of materials and due to this effect, we may experience shock while touching on door handle, filing cabinet and window frames. To reduce this effect, various antistatic agents like long chain aliphatic amines and amides, ammonium salts, esters of phosphoric acid or polyols are used, but their efficiency to reduce static effect is less. Antistatic properties of these polymers can be increased by incorporation of various nanoparticles (Jafari et al., 2014; Liu et al., 2013; New developments in antistatic and conductive additives, 2008). Silver nanoparticles added at 1.3 wt% improved their ability to drain the charges away from the surface due to Coulomb blockade effect (Wang et al., 2016). CNTs are very strong, light weight and can be made conductive. All these properties make them the most suited one in automobile parts and are widely used as fillers in different polymers to introduce antistatic properties to them (He et al., 2017).

Nanoscale ionic materials having OH groups (NSiF-Hs) were synthesized and were used as crosslink reagent in polyurethane (PU) system to act as antistatic polymer (Joshi and Chatterjee, 2016). At ambient temperature, NSiF-Hs has liquid like behaviour and can be used as supramolecular cross linking agent in PU. This PU hybrid shows permanent antistatic property due to their ionic bond and can be used as a novel nanomaterial for antistatic in automobiles and aerospace interior.

2.6. Other applications

The other important applications of nanotechnology in the field of automobile industry include fuel cells, batteries, nanofilters for air cleaning, reduction in exhaust emission, cooling systems, braking and damping systems and NEMS (Nanoelectronic Mechanical System) (Malani et al., 2016). Carbon nanotubes are used to store hydrogen fuel in the fuel cells as it can store large amount of hydrogen and can be retrieve it easily. In batteries, by making the metal electrode of the lithium ion batteries with nanoparticles the efficiency of the battery can be increased up to 15%. Smooth and powerful braking and damping can be achieved by the application of MR (magnetorheological) fluids. MR fluids have magnetic nanoparticles dispersed in a solvent and when a small magnetic field or pressure change occurs the particles will align and as a result the viscosity of the fluid increases (Kumbhar et al., 2015; Poznić et al., 2012; Presting and Konig, 2003; Armand and Tarascon, 2008).

3. Applications of nanotechnology in aerospace

A large number of companies rely on the aerospace transportation as it has ability to ship large amount of goods and people around the world with minimum time which can be only imagined by other modes of transportation. Aerospace requires high security and high perfection as small defects in manufacturing or operation will risk lives of many and therefore heavy investment and at most care are taken in these industries. The materials using in aircraft should possess high yield strength, high tensile strength and resistance to corrosion with low density. The major focuses in current R&D of aerospace are on construction of light materials with high strength and developing efficient engines with less pollution.

Table 2
Nanomaterials and their functional properties in aerospace.

Nanomaterials	Functional properties
SiO_2, Al_2O_3, ZrO_2	Scratch resistance
Nanoclay, graphene	Gas barrier
CuO, TiO_2, ZnO	Antimicrobial
Nanoclay	Corrosion and fire retardant
TiO_2, ZnO, $BaSO_4$, CeO_2, graphene	Ultraviolet stability
SiO_2, $CaSiO_3$, CNTs, TiO_2	Impact resistance
CNTs, ZrO_2, nanoclay	Heat resistance
SnO_2, CNTs, graphene	Electrical conductivity

The applications of nanotechnology in aerospace include low weight nanocomposites, high strength nanomaterials, improved electronics and displays with less power consumption, multifunctional materials with sensors, advanced filters and membranes for air purification and numerous others (Meyyappan, 2007). Incorporation of certain nanoparticles with bulk metals are already being used in aircraft industries. Different nanomaterials and their properties and applications in aerospace is highlighted in Table 2 (Baibhav, 2017). The most widely used nanomaterials are carbon nanotubes, nanoclay, graphene and nanofibers. Carbon based nanomaterials are usually used as fillers in various polymers because of its exceptional toughness, stiffness and unique properties which can open the opportunity for multifunctional materials. The resulting nanocomposites are strong and light weight with enhanced thermal, mechanical, and electrical properties. It can be used for developing superior aircraft brake discs that can dissipate heat efficiently, self-healing composites, and interactive and strong windscreens. Apart from increase in strength, CNTs are electrically conductive and therefore improve the conductivity of the composite panel which allows current to pass through it and into the surrounding structures. This property makes the aircraft less expose to the damage from electrical discharge (Will, 2012).

Nanomaterials like single walled CNTs are using for shielding sensitive components of aircraft from electromagnetic radiations. In airplanes vibrations cause discomfort to the passengers and severe vibrations of engines can damage sensitive components. Researchers found that high vibration damping can achieve with inclusion of nanomaterials which can instantly dissipate vibrations through halting slip motion (Kireitseu et al., 2005; Suhr et al., 2008; McNally, 2010). Surface degradation of coatings as they are exposed to moisture, sunlight and oxygen is another common problem facing in aerospace vehicles. By the addition of various nanoparticles we can reduce the surface degradation while keeping the original properties of the coating. Inclusion of multi walled CNTs, TiO_2, SiO_2 nanoparticles and graphene to polymeric coating lessen surface cracks, reduces UV degradation and increases the lifespan of it. Addition of nanoclay to paints in aircraft gives high flame retardant properties and high scratch resistant (Asmatulu et al., 2007, 2011).

Engines of aircraft are made to be excellent heat resistant by the addition of nanoclay and nanoparticles of ZrO associated with Y_2O_3 to the composite. Coating of the engine components with nanofilms will promote self-cleaning and reduce friction. Nanosensors and NEMS installed in the aircraft give detailed readings of varying pressure and heat (Haynes and Asmatulu, 2013).

4. Applications of nanotechnology in marine transportation

The function of marine transportation ranges from passenger traveling, weapon carrying platform, cargo carrier and numerous others. The main problem in marine transportation is corrosion of the ship by sea water and atmosphere. Sea water has high salinity which enhance the metal corrosion and fouling in the ships. Stainless steel which is a good corrosion resistant in normal atmosphere even will undergo partial corrosion in sea atmosphere. Another problem in water transportation is the marine microbial fouling and erosion in the bottom of the ship and waterline area due to long soak in water. All these will adversely affect the reliability of the ship, environmental adaptability, life span of hull and

Table 3
Importance of various nanoparticles and their effect in transportation.

	Application	nano-particles	Property imparted	Advantages	Disadvantages
Automobiles	Paint coating	SiO_2	Anticorrosion, scratch resistant	Reduce toxicity of the paint and promotes self-healing	Uniform dispersion is difficult to attain
		LDH	Flame retardant	Improves char formation and absorbs heat	Stability issues
		Titania, ZnO	UV resistant	Absorbs harmful UV rays	Hardening problems
	Light weight body parts	CNT	Substitute for steel parts	Much stronger and less weight compared to steel	Costly
		LFRT nanocomposite	Substitute for plastics	High strength and high impact resistance	Manufacturing is difficult
	Engines	Nanofluids of CuO, Al_2O_3, CNT, silica, TiO_2	Heat transfer	Improves heat transfer coefficient	Chances of agglomeration
		CuO_2, TiO_2, MoS_2 nanosheets	Lubrication	COF can be reduced up to 50%	Short lifetime
	Tyres	Carbon black, soot, silica	Better rolling resistance and reduce inner friction	Prolonged durability and higher fuel efficiency	Uniform dispersion is difficult
	Interior	Ag, Au, TiO_2, ZnO, Cu, CNT	Antimicrobial and antistatic	Non-toxic and high efficiency	Comparatively costly
Aerospace	Light weight	CNT	Enhanced thermal, mechanical and electrical properties	High strength and very light weight	Costly
	Engines	ZrO, nanoclay	Heat resistant	High heat resistance even when added in small amount	Loss its property after some period of time
	Communication	SnO_2, graphene, CNT	High sensitivity	Accurate measure of pressure and temperature	High manufacturing precision is required
Marine	Coating	Nanostructured zirconia coating	Scratch and abrasion resistance	Provides good scratch and abrasion resistance for longer period of time	Coating is difficult
	Body parts (Hull)	Al	Light and tough	High strength and light weight by cyromilling	Comparatively costly
		Nanoclay, Al	Anticorrosion, flame retardant	High heat resistant and imparts self-healing to prevent corrosion	Uniform dispersion is difficult
		TiO_2, ZnO, MgO, Al_2O_3	Antimicrobial and UV resistant	High anti biofouling activity	Costly

survivability at sea. Many developments are made to prevent corrosion and fouling, but it seems not to be much effective. However, researches and studies on the application of nanotechnology promise us good results in this field.

US based researchers have found that usage of advanced nanoscience technology of 'cyromilling' in processing of aluminium gives superior material for light and tough applications. Cyromilling process introduces nanosized aluminium in the conventional one and forms nanoscale aluminium oxide and nitride particles which makes them stronger and stabilizes its microscopic structure and orientation which makes them an efficient alternative for making aluminum hull where high strength and light weight are highly desirable (Jiang et al., 2011). Metal oxide nanoparticles of TiO_2; ZnO, MgO and Al_2O_3 added to paint coatings and fibers increase the ultraviolet blocking and antimicrobial properties which can be used for better coatings and fibers. Incorporation of nanoclay to the composite used to make ships impart flame retardant and anti-corrosive behaviour. These composites are usually used to make sturdier sails and hulls of the ship. Carbon nanotubes are added to the polymers to develop explosion proof structures, electromagnetic shielding and safety harness especially in load bearing applications and various rigs in the sea. Compare to traditional zirconia coating, nanostructured zirconia coatings on the outfit of the ship has improved scratch and abrasion resistance for long period of time (Szewczyk, 2010).

5. Summary

Nanotechnology has brought tremendous changes in the transportation industries which are transforming their outlook. By the application of nanotechnology it is made possible to make transportations more efficient, smart looking, stronger and durable. This paper has outlined the major evolution of various mode of transportations by nanoengineering which is summarized in Table 3. Comfort, safety and economy are the three factors that we all consider while choosing a transport and nanotechnology improves these three factors simultaneously.

In automobiles, the functionality and durability of paint coatings, body parts, engines, tyres and compartments are improved by the incorporation of various nanotechnology and nanoparticles like CNTs, Al_2O_3, TiO_2, carbon black to them. Strength, light weight, flame retardance and UV resistant of aerospace are significantly increased by the use of nanoclay and nanoparticles such as TiO_2, SiO_2, graphene and CNTs. Metal corrosion and fouling on the ships are taken care by coating their surface by paints dispersed with metal oxide nanoparticles such as TiO_2, ZnO, MgO and Al_2O_3. The weight of the ship is reduced and the strength is increased by making the hull with aluminium nanoparticles and carbon nanotubes. The production scale of vehicles has increased by the significant usage of nanotechnology. In the near future, transportation industries will be in the hands of nanotechnology as nanoengines, nanomotors and nanostructures are already developed and it can be widely used in developing smart vehicles.

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