

Advanced Nanotechnologies Applied in Modern Vehicles

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Abstract. The development of automotive technology depends on the development of materials technology, and the now popular use of nanotechnology in automobiles has laid the foundation for the development of new materials technology. Nanoscience has been developing rapidly in recent years, and nanotechnology products are emerging and involving the automotive industry. Nanomaterials, with their unique physical and chemical properties, can significantly improve the safety and durability of vehicles. This paper reviews recent advances in nanotechnology and how this technology can be applied to improve vehicle comfort, safety and environmental friendliness. In addition, the paper systematically examines recent developments and applications of nanotechnology in the vehicle industry, including nanocoatings, glass and mirrors, tires, nanoparticles for automotive lubrication and exhaust gas treatment. In addition, the main challenges for wider applications, such as environmental, health and safety issues, are presented, and trends in the development of nanotechnology in the automotive industry are indicated.

Keywords: Nanotechnology, Nanomaterials, Vehicles.

1. Introduction

As a new type of material, nanomaterials have received extensive attention from governments and researchers since their inception. The special properties of nanomaterials have determined the prospect of a wide range of applications in various fields. Nanomaterials have been widely used and practiced in many fields such as chemical, ceramics, metallurgy, and electronic communication [1]. Nanotechnology has been marketed since as early as 1999 [2], and through the years, the economic and social benefits of nanotechnology have been enormous. Nanotechnology is undoubtedly an important symbol of the development of new technologies in the future.

According to Figure 1 [3], nanotechnology is the manipulation of matter with a size between 0.1 and 100 nanometers. Applications like energy storage and sensors are made possible by the amazing efficiency improvements in photocatalysis, optical sensitivity, and mechanical strength made possible by the physical and chemical characteristics specific to the nanoscale size. By altering the form and size of objects measured in nanometers, nanotechnology helps to design tools and equipment [4, 5]. At the nanoscale, gravity is defeated by electrostatic forces and quantum phenomena, which enhance the characteristics of materials [6].

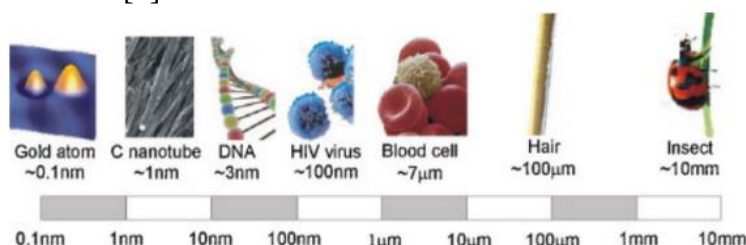


Figure 1 The representation of nanomaterials length measured in nanosize [3].

Nanotechnology is the core technology for the development of automobiles in the new century. Nanotechnology covers almost all aspects of automobiles, such as the body, chassis, interior, tires, transmission system and exhaust system, all of which can have different functional characteristics due to nanotechnology [7]. If nanotechnology is applied to rubber materials, problems such as oil leakage and seepage that plague the automotive world will be solved. Nanoplastics present excellent

physical properties such as high strength, heat resistance and lower density compared to traditional plastics. With nanoparticle sizes smaller than the wavelength of visible light, nanoplastics can display good transparency and high gloss, such that they will have a wide range of uses in automobiles. Some materials treated with nanotechnology are 27 times more wear-resistant than brass and seven times more wear-resistant than steel, and nano-ceramic bearings, for example, are already used in premium cars such as Mercedes-Benz.

The widespread use of nanotechnology in the automotive materials business will lead to a qualitative leap in engines and colorful car tires and improve problems such as vehicle exhaust emissions. Nanocomposites made from a variety of metals or plastics as a base material, reinforced with metal or ceramic nanoparticles or nanosheets, can be up to 100 percent stronger. Even polymer nanofibers can produce considerably thinner, stiffer and lighter automotive parts [8]. This opens up a huge area of research for the coming years.

This paper describes the unique advantages of applying nanotechnology to the automotive industry and explores the contribution of nanotechnology in automotive components to improve safety and environmental performance. It also outlines the challenges and weaknesses that the automotive industry is predicted to face based on the impact of nanotechnology innovations.

2. The distinctive advantages of nanotechnology for modern vehicles

The automotive industry can benefit from nanomaterials in many areas: they can be used in bodywork, interiors, powertrains, coatings, suspension and braking systems, lubricants and coolants, tires, exhaust systems, etc. The various components of a vehicle that the application of nanotechnology can enhance are illustrated in Figure 2 [9]. As described by Presting and Koenig [10], these developments meet social trends and customer demands for improved ecology, safety and comfort, which are nowadays referred to as sustainability.



Figure 2 Development of materials used to construct a mid-sized car [9].

Nanotechnology has a broader scope than other technologies. In recent years it has made its presence felt in various fields with great success, especially in automotive research and development, where nanotechnology has gradually developed into a link between old and new technologies and an incubator. A material's chemical, physical, and biological characteristics will alter in ways that are quite different from those of individual atoms, molecules, or substantial blocks of material when its size is shrunk to the nanometer range [11]. Increased surface area to volume ratio is the cause of these modifications because it exposes more atoms to the surface and generates more surface energy, which results in a material with higher hardness, super elasticity at high temperatures, higher fracture strength, and higher fracture toughness. Due to the reduced grain size, no deformation occurs at this size, which will extend the machine's durability, provide an effective lubrication system, lighter materials, etc. [12].

Specifically, nanotechnology has the following positive effects on automotive research and development [13, 14].

(1) Nanotechnology can be widely used in the production process of automobiles. Nanotechnology can be applied to almost all vehicle parts, including the interior, body, power and drive train, and driving system. There are many different types of materials, including nano-plastics, nano-ceramics, nanocoatings and nano-rubber. For example, nanomaterials can enhance the structure of steel sheets in the bodywork, and nano-painting can make the paintwork shine. All of these materials have strong physical properties and contribute greatly to the safety and environmental protection of the car.

(2) Nanotechnology can reduce the rate of wear and tear of automotive parts. After a long period of use, mechanical parts are prone to wear and corrosion, which can lead to considerable economic losses. Nanolubricants can use their excellent friction characteristics to mix the particles with the oil reasonably to produce a suspension and then form a protective film through adsorption, freeing or diffusion.

(3) Nanotechnology can effectively reduce exhaust emissions. Atmospheric pollution has become an important issue that all countries worldwide attach great importance to and are urgently addressing. The spread of excessive sulfur dioxide, carbon monoxide and nitrogen oxides in the atmosphere can greatly affect humans' physical and mental health. Using new nanomaterials and technologies such as carbon nanotubes and nano-gasoline can help alleviate and solve the problem of harmful gas pollution, thus greatly purifying the air.

3. Nanotechnology for coating

Automotive coatings are the key to the car's beauty, so they must be highly decorative, durable, and stain-resistant. Automotive coatings are divided into two categories: monochrome topcoats and metallic glitter topcoats [15]. In the United States and France, almost all cars are painted with thermosetting acrylic resin monochrome enamels as topcoats. Germany, Sweden and Japan's automotive companies use oil-free polyester / amino resin monochrome topcoats and coconut oil alkyd modified melamine resin products. All countries use thermosetting acrylic non-water dispersions for flash topcoats as the mainstream.

Nanoparticles dispersed in organic polymer skeletons as load-bearing fillers, with their large surface area interacting with the skeletal material, help improve the material's toughness and other mechanical properties. Research shows that 10% of nanoscale TiO_2 particles completely dispersed in the resin can improve the mechanical properties, especially scratch resistance and good appearance, conducive to manufacturing automotive topcoat coatings [16]. Modified nano- CaCO_3 with a mass fraction of 15% into the polyurethane varnish coatings can improve the gloss, leveling, flexibility and coating hardness of varnish coatings.

3.1. Protective Coatings

Of all the indicators and properties that affect the service life of a car, the most important is weather resistance. The paint chosen for exterior parts such as bumpers, fenders and door trim is the most important requirement, as well as good resistance to media and wear. For this reason, it is advisable to use protective coatings for parts of the car that are often subject to friction and impact from external factors.

Using nano-powder materials with strong UV-reflective properties, nano- TiO_2 powder in a certain proportion into the paint can effectively shield the UV from UV damage.

Nano- SiO_2 is an anti-UV radiation material (i.e., anti-aging) with a large specific surface area of very small particles, which can quickly form a network structure when the coating dries while enhancing the strength and reducing the roughness of the coating. Therefore, to improve the anti-aging and reduce the roughness of coatings, the addition of nano- SiO_2 is a key component [17].

The use of nano- SiO_2 , MgO and other transparent and UV absorption properties in the preparation of certain protective materials or products added a small amount (generally no more than 2% of the content) of such nanomaterials would greatly reduce the role of UV damage to these protective

materials or products, making it more durable and transparent. Such coatings can be used as a coating material to prevent aging and loss of transparency.

Polymethylmethacrylate (PMMA) nanocomposites made from kaolin nano-fillers are colorless, transparent, and suitable for manufacturing paint coatings. The PMMA nanocomposite is transparent and absorbs UV light, thus protecting the polymer from degradation due to UV radiation and improving thermal stability.

3.2. Color-Changing Coatings

New color-changing coatings include temperature-sensitive and impact color-changing coatings [18].

Temperature-sensitive color change coatings can change color in response to environmental changes and temperature. For example, if a vehicle is coated with a certain temperature-sensitive color-changing paint, once the weather is cold and the temperature drops, the color of the body will change on its own with the change of environment, so that the driver and the traffic management personnel can easily find out the identification, to avoid car accidents and traffic accidents.

The current paintwork on cars does not change significantly when they are hit, and it is easy to miss the internal damage and leave a hidden problem, which is why the crash color change paint was invented to prevent car crashes from leaving hidden problems. The paint contains microscopic capsules filled with the dye that will rupture in the event of a strong external force, causing the color of the impacted area to change immediately to alert people.

3.3. Anti-Stone Impact Coatings

The part of the car body closest to the ground is often subject to the impact of various stones and rubble, which requires a good performance of anti-stone impact coatings. In the early days, the coating process was generally two coats, i.e., a primer and a topcoat; later on, it developed into a three-coat process, i.e., a primer, an intermediate coat and a topcoat; modern cars are usually developed into four or more coats. Sometimes, to improve the stone impact resistance of the coating, an additional stone impact resistant coating is applied to the intermediate coating.

When studying the impact of stones, it is clear that the angle of impact, the speed and the size of the stone are the main factors, so anti-stone impact coatings should absorb as much energy as possible to reduce the damage to the car. This problem can be solved by developing anti-stone impact polyurethane coatings, which are naturally flexible and have superb resistance to stone impacts. These coatings have a low coefficient of friction and are mainly used in areas of frequent friction and wear, such as window guides. The addition of nano- Al_2O_3 and nano- SiO_2 to the coating increases the surface strength of the coating and improves wear resistance.

Using nano-powder materials with strong UV-reflective properties, nano- TiO_2 powder in a certain proportion into the paint can effectively shield the UV from UV damage.

3.4. Deodorizing Coatings

New cars usually have a bad smell, mainly due to the volatile substances contained in resin additives in the car trim materials. This strange odor has been minimal in recent years due to environmental protection and consumer demands. However, a more serious problem is the car's smell of cigarettes, sweat and other odors. These odors are absorbed by surfaces such as seats and siding and remain in the car, where they are difficult to remove. Recently, measures have been taken to deodorize the vehicle from the surface. In other words, deodorizing paint is made by mixing a strong deodorizing agent into the surface paint for the car. This paint has excellent deodorizing properties and thus quickly eliminates all kinds of odors from the car's interior.

Nanomaterials have a strong antibacterial and deodorizing function and adsorption capacity, so some nanoparticles can be used as carriers to adsorb antibacterial ions for sterilization and antibacterial use on the interior surfaces of cars. For instance, the Japanese Teijin company produced

by ZnO/SiO₂ as deodorant fibers, which can absorb odor, purify the air, and be used for automotive interior textiles.

4. Nanotechnology for glass film

Glass and polymers are used to create a car's headlights and mirrors. When the sun reflects in our car's mirrors and glasses, we get uncomfortable. The headlights of the automobiles in front of us beam in our eyes at night and are a serious inconvenience. The intense light in our eyes makes it difficult for us to see the road or other vehicles, which might cause accidents. Applying sunscreen to the glass is one method being investigated in this field as part of numerous studies and trials. This, however, only partially resolves the issue.

On the surface of the headlights and mirrors, an extremely thin film of aluminum oxide less than 100 nm thick is deposited. This renders the mirror's surface impervious to mud and filthy water. The reflector's surface is coated with a hydrophobic nanolayer using chemical vapor deposition (CVD). Layers of fluorinated organic materials with a thickness of 5-10 nm are mainly used because they have high frictional resistance and are suitable for longer periods. Nanotechnology and electrochromic properties are used together to prevent the problems caused by lights from other vehicles shining into our eyes at night. When the glass is equipped with functional layers of nanocomposites possessing electrochromic properties, the glass's or mirror's optical properties will change. A specific voltage is produced when light is shone on the glass or mirror, and this voltage causes an electrical charge to transfer to the interlayer. As seen in Figure 3, this enables the incident light to be absorbed by the color centers of the ions on the electrodes and just a little quantity of light to be reflected. Just like the charging and discharging of a battery, this glass will return to its original state as the electrodes are changed. The glass is equipped with a sensor that will measure and control the intensity of the light falling on the rear-view mirror. Once this light disappears, the mirror will return to its original state [19].



Figure 3 (a) Conventional mirror and (b) Modern antiglare mirror [19].

5. Nanotechnology for tire

The use of rubber materials in automobiles is greatest in tires (Figure 4). In the production of tire rubber, rubber additives are mostly in powder form, such as carbon black, silica and other reinforcing fillers, accelerators, antioxidants, etc. [20]. In terms of powdered substances, nanomaterials are the main trend in rubber at this stage. Nanomaterials and the rubber industry were originally quite close. The majority of powdered rubber additives particle sizes are in the range of nanomaterials or close to the range of nanomaterials, for example, carbon black particle size of about 11-500 nm, white carbon black particle size in 11-110 nm. Nanotechnology can improve the thermal stability, light stability and chemical stability of the tire so that the ground friction coefficient is greatly improved, the stability of the tire, the stability, anti-slip and high grip properties of the tire will be significantly

improved compared to ordinary tires, and the tire will be more environmentally friendly and less noisy. At the same time, due to the grafting effect between nanotechnology and polymer materials and the volume effect, the polymer density is very high, thus increasing the tire life several times compared to ordinary tires [21].

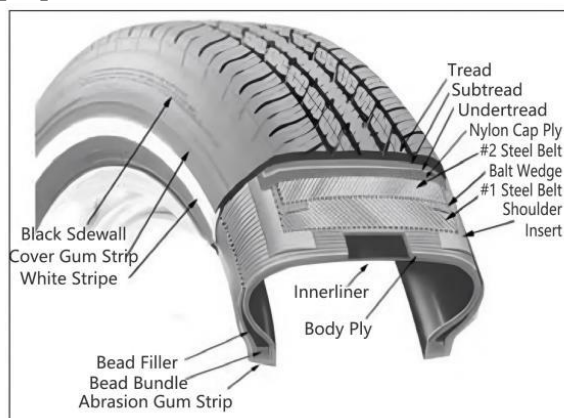


Figure 4 Tire construction [20].

The new generation of nanotechnology has successfully used other nanoparticles as additives, such as zinc oxide, calcium carbonate, aluminum carbonate, aluminum trioxide and titanium dioxide, and is no longer limited to the use of carbon black or silica. Nanopolymers can also be used in tires to achieve energy savings. The Italian company Novamont, in collaboration with Goodyear Tire and Rubber, has developed a nanoparticle-sized starch polymer produced from cereal grains, which can significantly reduce the rolling resistance of tires [22]. The technology blends round nanoparticles of starch polymer with rubber, using an undisclosed petrochemical polymer as a key component, combining the low rolling resistance of the starch with the high elasticity of the petrochemical polymer. The use of Biotred GT3 tires can reduce fuel consumption by 5% compared to tires doped with silicon oxide, equivalent to $7 \text{ gCO}_2/\text{km}$.

6. Nanotechnology In lubricant

Wear, fatigue and corrosion are the three main forms of mechanical material failure. The economic losses caused by wear and tear are enormous and applying nanomaterials to lubrication systems is a new field of research. Nanolubricants can be a good solution to mechanical wear problems. Nanolubricants are pure petroleum products that use nanotechnology to improve the molecular structure of lubricants. They do not have adverse effects on lubricant additives, stabilizers, treatment agents, engine wetting enhancers and wear reducers but only automatically form a pure hydrocarbon single-atom thickness film on the metal surface of the part. As nanomaterials have a large specific surface area, high diffusivity, easy sinterability and reduced melting point, new lubricating materials prepared based on nanomaterials are used in friction systems, which act in a different way to traditional load additives to reduce friction and combat wear. This new lubricating material can not only form a shear film on the friction surface to reduce the coefficient of friction but also can fill and repair the friction surface to a certain extent to play a role in anti-wear. The mutual adsorption between these tiny hydrocarbon molecules can fill the micro-pores on the metal surface and minimize the friction between the metal and the metal micro-pores. Compared to premium lubricants or fixed additives, the extreme pressure can be increased by a factor of 3 to 4 and the wear surface reduced by a factor of 16. Due to the protection of the metal surface, wear is reduced, and the service life is increased exponentially.

The explanation of nanoparticle friction reduction and anti-wear mechanism is mainly based on the pebble model in the boundary lubrication theory, as shown in Figure 5 (a). That is, the size of nanoparticles is small, can be considered nearly spherical, in the friction vice can be like a pebble as free to roll, play a role in supporting the load and make the lubricant film wear resistance increased.

Another mechanism, as shown in Figure 5 (b), is called nanoparticle film lubrication, where the nanoparticles form a film to achieve the lubrication effect.

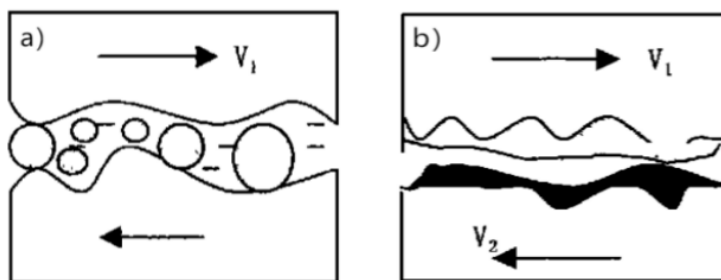


Figure 5 (a) Nanoparticles act as "ball bearings" to support the load, (b) Film lubrication by nanoparticles forming a dense film [23].

7. Nanotechnology for exhaust gas catalyst

The application of nanotechnology in the treatment of automotive exhaust pollution is mainly to use the high catalytic activity and adsorption properties of nanotechnology to remove harmful components (mainly carbon monoxide, hydrocarbons and nitrogen oxides) from automotive exhaust. The mechanism of action is shown in Figure 6 [24]. Currently, most exhaust gas catalytic converters are made of precious metals, while nanotechnology can improve catalytic efficiency, reduce the consumption of precious metals and lower the production cost. The use of nanoscale rare earth materials to replace precious metals as catalysts is one of the current trends. The addition of rare earth materials to precious metal catalysts can significantly improve the anti-toxic properties, and high-temperature stability of precious metal catalysts, so rare earth elements can be considered ideal for automotive exhaust gas catalysts or additives. The replacement of conventional rare-earth compounds with rare-earth nanoparticles in automotive exhaust gas cleaning catalysts has improved the conversion of carbon monoxide, hydrocarbons and nitrogen oxides in exhaust gases.

The latest research results show that nanoscale powders of composite rare earth compounds have extremely strong redox properties, and their application can completely solve the problem of carbon monoxide and nitrogen oxide pollution in vehicle exhausts [25]. The newer generation of nanocatalysts will play a catalytic role in the cylinders of car engines so that no carbon monoxide, hydrocarbons or nitrogen oxides are produced during the combustion of petrol, and no exhaust gas cleaning is required. The addition of rare earth nanomaterials to the catalyst significantly increases the conversion efficiency and effectively reduces the conversion temperature, greatly improving the ability to control vehicle exhaust pollution. Rare earth nanotechnology is a new direction for future exhaust gas cleaning research.

Recent research has found that catalysts made of nano base metals have good effects on automotive exhaust gas purification and can replace precious metals as catalysts for automotive exhaust gas purification [26]. Due to the abundance and low cost of base metal materials, they were once valued by many researchers but have not been widely promoted and applied due to their high ignition temperature, poor thermal stability and low to medium temperature (below 600 °C) activity and easy poisoning.

As nano-rare earth, nano-base metal and nano-precious metal catalysts all have superior catalytic properties, and the deficiencies between the three catalysts are complementary, it is possible to mix the three catalysts in a certain ratio and add a small number of other additives to make automotive exhaust gas purification catalysts. It is foreseeable that as long as suitable ratios and nanotechnology additives can be found for the three nanocatalysts, problems such as high cost, easy sintering and stability of the nanocatalysts can be solved catalysts will dominate the field of automotive exhaust gas catalytic purification shortly.

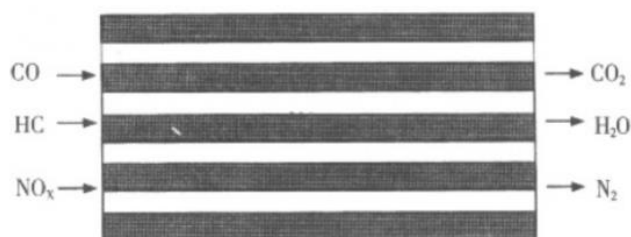


Figure 6 Catalytic conversion of vehicle exhaust fumes [24].

8. Conclusion

Nanotechnology can be used to improve the strength, durability, efficiency, and intelligence of automobiles. This essay covers the literature on the development of automobiles brought about by nanotechnology as well as the environmental, health, and safety concerns connected to the potential widespread use of nanotechnology in the automotive sector. In the automobile sector, adding different nanomaterials like CNT, TiO₂, SiO₂, and carbon black improves the overall performance of paint coatings, engines, body components, mirrors, tires, etc. Numerous elements are still unknown, despite the fact that several significant characteristics, including comfort, safety, and durability, have been recorded about uses of nanotechnology. Additionally, it is necessary to quantitatively evaluate the variations in absorption and toxicity of chemically altered nanoparticles. Since nanomaterials are relatively new to the automotive sector, it is crucial to understand their possible effects on air, soil, and water. the requirement for more investigation into ecologically friendly nanotechnologies.

In summary, the future of automotive technology is closely linked to nanotechnology. Although there are currently only a limited number of automotive components and maintenance products that actually use nanotechnology, there is no doubt that the application of nanotechnology will be an inevitable trend and will also guarantee the upgrading of automotive technology. Future cars with nanotechnology applications will not only have a bright and colorful appearance but will also be able to meet the requirements of high power and low emissions, have surpassing performance and a wide range of design space, and will be substantially harder, tougher and more resistant to vibration, with their safety features increasing in reliability. It is believed that in the near future, nanotechnology will be more widely used in the manufacturing of automobiles.

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