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Research on the Applications of Nanotechnology in Automobile Body Panels and Their Advantages

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Abstract:

This article introduces the combination of nanotechnology and automobile car body panels. The growing demand of electric vehicles(EV) have emphasized the limitations of traditional material, such as limited battery lifecycles, overweight of body panels, and durability concerns. Nanotechnology can vary the physical, mechanical and chemical properties of the material, which brings more possibilities during the manufacture. This article focuses on metal based, carbon based, and polymer nanocomposites applied to EV body structures and paintings. Carbon nanotubes, graphene reinforced materials, and carbon fiber has greatly contributed to the strength-to-weight ratio and modulus, making car panels lighter and increase the driving range. Aluminum and stainless-steel based nanocomposites boost oxidation resistance and hardness. Polymer nanocomposites modified the paintings to increase scratch resistance, surface hardness and stain removability. Companies like BMW, Tesla has already applied such materials in use. While challenges still exist for the industry, the irreplaceable advantages of nanotechnology in optimizing EV body panels have been proven, and it undoubtedly has a bright and promising future in this field.

Keywords: Nanotechnology, Automobile body panels, Nanomaterial, Electric Vehicle.

1. Introduction

The demand for environmentally friendly transportation has greatly increased, causing the market of EV to expand rapidly. Governments also publish stricter regulations of carbon emissions to achieve sustainable development. For consumers, the increase in price level of fossil fuels and decrease in living standard due to emission also cause a shift in market demand for vehicles. However, comparing to combustion engines, electrical vehicles still have lots of shortages. It faces various problems, including limited battery life span and endurance, extra vehicle weight, strength of panels, durability of tires. Such limitations of traditional materials directly result in lower efficiency and sustainability, higher cost, safety

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concerns and shorter driving ranges which creates kinds of issues for consumers. This makes the search for advanced materials and technologies both urgent and highly relevant.

Nanotechnology, which is a study and creation of material structures at nanoscale from 1 to 100 nanometers, changes the physical and chemical property after combining with traditional materials. Such technology creates infinite possibilities and brings innovations and more probabilities for EV. For EV the nanotechnology can create components with stronger strength, durability and modulus, more efficient thermal conductivity and longer battery lifespan. This improves the performance impact of EV making it more popular among the consumers.

Researcher and scholars have already done kinds of studies about nanotechnology increasing the performance of materials. This essay mainly focuses on the combination of nanotechnology and current materials. Instead of conducting new experiments, studies relied on a review-based method, drawing from academic papers and examples from companies like Tesla, BMW, and Toyota. This helped to build the connection between theory and actual product development. It studied the mechanical and physical property increase of materials comparing to its original form, while revealing certain challenges scientists are facing at current stages.

2. Application of Carbon-based Nanocomposite Materials in Car Bodies

The combination of nanomaterials and car body panels exhibits unique physical, chemical, and mechanical behaviors, offering significant enhancements in fracture resistance, durability, lubrication, and weight reduction. Nanoparticle with chemicals finishes linking stuff network to stabilize the uniformly spread nano-domains, which is attributed to the stable and uniform distribution of nanoparticles within the entire matrix. Carbon nanotubes(CNT) networks in polymers can boost toughness by 470%. With a low CNT volume percentage of 6.5 vol% in aluminum can increase hardness by 333% and tensile strength by 184% [1]. CNT-polymer composites show up to 150% increase in tensile strength and 80% higher modulus than neat polymers. CNT enables the fabrication of lightweight body panels with exponential strength-to-weight ratios. It delivers impressive tensile strength exceeding steel (up to 1.5 GPa vs. 300-600 MPa), while significant weight reduction of 50%. This translates directly into fuel efficiency with potential gains up to 20% [2].

Another material is made from carbon fiber reinforced polymer (CFRP), which is made from high-strength carbon fiber volume fraction of around 60 to 65 percent. Tensile for CFRP is around 1500-1700MPa and Young Modulus 140-160GPa. This material is often seen in doors, roofs and bumpers. The BMW i3 is one of the cars that uses such material. It reduces passenger cell weight by 250 kg compared to steel equivalents. Total vehicle curb weight is about 1195kg.

Tesla Model S Plaid is the first production EV with a carbon fiber-wrapped rotor. Carbon wrapping prevents the permanent magnet rotor from disintegrating due to centrifugal forces, extremely high RPMs up to 19000 rpm at 200 mph. Carbon fiber is electrically insulating, avoiding eddy current losses common with metal sleeves.

Graphene-based nanomaterials can be combined with metals to enhance the chemical and mechanical performance. Graphene-reinforced aluminum matrix composites is one example. Pure aluminum can mix with 0.3 wt% of graphene nanosheets (GNS)-Al nanocomposite can increase 62% of tensile strength while the ductility is reduced almost half that of the pure aluminum sample. Theoretical predictions estimate that the actual increase can be up to 500MPa using the rule of mixture. However, brittle particles of aluminum carbide (Al_4C_3) are produced during the process, which adversely affects the strength of the composite. Moreover, calculations are done using 125GPa as the fracture strength of a single layer of graphene. In the experiments, GNS has more than 1 layer, so it causes a reduction in strength [3].

A simplification method is used to avoid PVA by relying on the electrostatic interaction between the graphene oxide and the aluminum flakes. This results in a modulus increase of 18% and a hardness increase of 17%. 1 wt% of GNS also reduced the coefficient of friction due to the self-lubricating graphene film [3].

Briggs Automotive Company has already applied such techniques to their vehicles; they used graphene-enhanced carbon fiber instead of pure aluminum. Graphene makes the requirement of carbon layers decrease from 3 to 2, lowering the set weight from 41kg to 32kg, a 22% reduction in weight.

3. Application of Metal-based Nanocomposite Materials in Car Bodies

Nanomaterials can be used in stainless steel. Oxidation behavior of nanocomposite materials made of 316L stainless steel reinforced with 10 vol% of nanocrystalline titanium carbide with an average crystallite size of 40 nm, fabricated by Selective Laser Sintering/Melting. The nanocomposite showed uniform TiC particle dispersion in the steel matrix and resulting in hardness improvement

compared to pure 316L steel. The onset of oxidation for the nanocomposite is 936K, which is earlier than that of pure 316L steel (1107K). For pure 316L steel, products are mostly iron oxide, which results in rich porous rust layers with poor adhesion. But for the nanocomposite, it followed a different mechanism. It produced a thin, adherent passive oxide layer. An additional product of chromium oxide is formed. It is dense, stable, and adherent to the substrate. It blocks oxygen diffusion and stops further oxidation. It transforms the surface layer from a porous "scale" to a compact, protective passive film. This is why nanocomposites showed higher oxidation resistance at high temperatures. However, in the powder mixture, no Cr_2O_3 was found. Instead, TiO_2 (rutile) is formed, and oxidation started ~240 K earlier than in the sintered nanocomposite—demonstrating that without Cr_2O_3, protection was much weaker [4].

Tesla uses Ultra-Hard 30X Cold-Rolled Stainless Steel with a thickness of 3mm, hardness of 420-500HV, yield strength exceeding 1100MPa, corrosion potential of 520-800mV in 3% NaCl solution, and ductility with more than a 60° bend angle at 1.8mm thickness.

Reducing vehicle weight lowers the fuel consumption and emissions while maintaining safety and comfort. The hardest part of the car is the body shell, which makes around 40% of its total weight. Aluminum as very light materials is used as the main matrix element in the production of composite materials referred to as aluminum metal matrix composite. Such material improved strength-to-weight ratio. It has good ductility, strength and high elastic modulus with low thermal expansion. Cylinder linear used Al 6063 mixed with ZrO2, SiC and graphite with mass fraction of 2.25% each. It provides high in-cylinder pressure, improves efficiency, and reduce smoke emissions. Aluminum can mix with SiC and CNTs to make piston rings. 2 wt% of CNT provides the best mechanical and tribological performance while 6 wt% provides best abrasion resistance. It is used in further areas such as connecting rods, brake discus and camshafts by combining with other materials. Toyota Camry (1991) first used nanocomposite in timing belt cover. Application has extended to more areas which provide optimized performance across different parts [5].

4. Application of Polymer Nanocomposites in Car Body Coatings

SiO2 has contributed to the corrosion protection and water resistance of the automobile surfaces.

It was observed that 5 wt% of silicone polyacrylate in the neat PU showed 95% of stain removability. Such material shows great graffiti resistance but poor mechanical properties. Therefore, modifications are done by incorporating nanoparticles of size 25nm. The concentration of nanoparticles was optimized for surface mechanical properties such as surface hardness, elastic modulus and scratch resistance. FEG-TEM reveals that with nano-silica particles are uniformly distributed over the surface. 5 wt% of nano-silica particle additions in PU-5% silicon polyacrylate base showed superior mechanical properties than other concentrations. Results show that polyurethane-based anti-graffiti coating was optimized using 5 wt% OH-functional silicone polyacrylate. By increasing the contact angle, it can achieve 95% stain removability. However, the anti-graffiti property decreased beyond 5 wt% due to the accumulation of the siliconated component, resulting in saturation. 5 wt% nano-silica particles were added to enhance mechanical properties. Results show that surface hardness increases from 52MPa to 430MPa, elastic modulus increases from 0.7GPa to 14GPa, coefficient of friction decreases from 3.32 to 0.32, which is directly linked to the improvement of scratch resistance, and doesn't change the effect on graffiti resistance [6].

5. Expectation

Integration of nanotechnology into EVs shows remarkable impact and potential to overcome the problems existing by using the traditional materials, resulting in greater efficiency and increase in market demand. Combination of nanotechnology and current raw materials enhances the construction of EVs. In the future, there might be stricter restrictions about the combustion of fossil fuel. This will cause an increase in consumption of EVs. The combination of nanotechnology and car body panels reduces the mass and increase the driving range, bring more convenience to our daily life, contributing to a brighter future. Ultimately, the expectation is to demonstrate that nanomaterials not only solve many of the limitations of traditional EV components but also pave the way for sustainable, efficient, and safer transportation in the future.

6. Conclusion

Nanotechnology has brought about revolutionary changes in the field of material science. It can be seen that carbon-based nanocomposites, including CNT, graphene-reinforced polymers and metals, presents significant impact on strength-to-weight ratios, durability, thermal stability and so on. Similarly, application in stainless steel and aluminum-based composites show obvious enhances in oxidation resistance, hardness, and tribological performance. All these benefits contribute to safer, lighter and more sustainable body panels. Moreover, combination of

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nanomaterials with car body coatings seems impressive as well, showing great graffiti and scratch resistance.Despite all of the advantages, problems of using nanotechnology still exist. For example, brittle particles of aluminum carbide is produced during the production of graphene-reinforced aluminum matrix leading to and opposite effect of the material.

Overall, nanotechnology has been proven that it brings significant convenience to the car industry, particularly with EVs. Several companies already applied such technology into use. Even if there are small difficulties existing, the will soon be sorted out and solved with the advance and mature of the nanotechnology. Continued interdisciplinary research and industrial application are essential to fully unlock its potential and translate laboratory-scale innovations into commercially viable and environmentally beneficial solutions.

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