Influence of Automotive Manufacturing Materials on the Performance of Car

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Abstract. Today, the development of the automotive industry is advancing rapidly, with new technologies constantly emerging. The automotive industry is transforming electrification, intelligence, and digitisation. In the current booming development of automobiles, sustainable development, low-carbon environmental protection, energy conservation and emission reduction have become major issues facing the development of automobiles, especially in the manufacturing materials of automobiles, which cannot be ignored. Automotive materials refer to the materials used in the production and manufacturing process of automobiles, usually divided into metallic materials, non-metallic materials, etc. This article systematically summarises automotive materials and their inherent characteristics through a classification and grading method. It analyses the specific effects and impacts of different types of materials on automotive performance, including but not limited to vehicle quality, durability, safety, and energy efficiency. The key research explored the importance of selecting automotive materials in improving overall performance, extending lifespan, and reducing costs, providing a reference for material optimization design in the automotive industry.

Keywords: Automotive manufacturing materials; Material classification; Lightweight.

1. Introduction

With the increasing global awareness of environmental protection, the automotive industry, as a major consumer of energy and emitter of pollutants, is facing enormous environmental pressure. The development of environmentally friendly materials for automobiles aims to reduce the environmental impact during production and operation and improve the overall performance of automobiles. The Chinese government attaches great importance to the research and application of environmentally friendly materials for automobiles, aiming to promote the green transformation of the automotive industry.

The materials used in automobile manufacturing have gone through a development process from wood to high-tech materials. Automobiles have gone through nearly 150 years of history since their invention today. The materials used in automobile manufacturing have also evolved from the most primitive materials to various black technologies that have been incorporated today. Every step of development and upgrade of materials used in this process has brought a qualitative leap to the automobile industry. The main problems currently faced by automotive manufacturing materials include performance limitations, weight issues, environmental requirements, and cost factors. Each type of automotive manufacturing material has its advantages and disadvantages. The research method of this article is to scientifically classify some materials through a systematic classification and grading method and make reasonable predictions. With the development of automotive technology, composite materials and nanomaterials will also be widely used, and the research and application of new automotive materials will be further strengthened.

Therefore, the research and development of automotive materials may involve multiple disciplinary fields such as materials science, chemical engineering, and machinery, requiring interdisciplinary collaborative research. During the research and development process, it is necessary to pay attention to the performance, cost, processing technology, and other aspects of materials to meet the actual performance requirements. The application of new materials in automobiles is mainly concentrated in the fields of body, interior, seats, etc., which can reduce the overall energy consumption and pollutant emissions of automobiles. Automobile manufacturers will also continuously adopt new materials to improve the performance and safety of cars, reduce fuel consumption and emissions, and achieve environmental protection and energy conservation goals. Therefore, the research objective of this article is to develop lightweight, intelligent, and multifunctional materials, which will be one of the important research directions in the future automotive field for the study and application of new automotive materials.

2. Classification and New Developments of Automotive Materials

2.1. Automotive Metal Manufacturing Materials

2.1.1. Steel Materials

Among metal materials, steel and aluminium are the most widely used materials. As shown in Fig.1, steel is currently the main manufacturing material for automobiles. This is mainly due to the excellent chemical, physical, and mechanical properties of steel, which plays an important role in the structural components of car bodies with high strength and plasticity. In addition, the supply of steel is sufficient, relatively cheap, and abundant, so it is widely used in the automobile manufacturing process, especially in the body structure, hood, and door panels. The main material of automotive steel is 65Mn, also known as 65 manganese steel. The chemical composition of 65 manganese steel endows it with excellent mechanical properties, such as high strength, high toughness, and excellent wear resistance, which can meet the performance requirements of automotive components in complex working environments. Therefore, it is widely used in automotive manufacturing.

Fig 1. The main steel structure of a car [1].

2.1.2. Light Metal Materials

In automotive metal manufacturing materials, the processed AZ31B aluminium magnesium alloy has a strength 50% higher than aluminium and a strength 168% higher than copper [2]. Aluminium magnesium titanium alloy has excellent corrosion resistance, especially in environments with strong acidity, alkalinity, and high temperatures [2]. Aluminium magnesium titanium alloy is easy to process and weld and can be welded using conventional welding methods to obtain high-quality welds. In addition, due to its weldability, it can be repaired to extend its service life.

At present, in the automotive industry, the demand for lightweight materials is increasing. Due to their strong corrosion resistance, fast heat dissipation, strong load capacity, lightweight, and good energy efficiency, they are gradually replacing some steel and have been widely used in body and engine components. Research data shows that using lightweight materials can improve fuel economy, especially with the rapid development of new energy vehicles and renewable energy fields. For example, compared to carbon steel bodies, aluminium alloy bodies can reduce vehicle weight by about 20% to 30%, improve fuel efficiency by about 5% to 7%, and achieve energy conservation and emission reduction [2].

2.1.3. Foam metal materials

As shown in Fig.2, foam aluminium is a kind of material with multiple bubble-type cavity structures, which is mainly made of aluminium. It has the characteristics of lightweight, low density, high specific stiffness, high specific strength, strong energy absorption capacity, and good damping and shock absorption performance. At the same time, foam aluminium also has the characteristics of corrosion resistance, high-temperature resistance and easy processing. The density of foam aluminium is 0.25~0.6g/cm ^{3}, which is only 10%~40% of aluminium and 3%~8% of steel [3]. However, its bending stiffness is 1.5 times that of steel. Assembling foam aluminium structural parts in the body sheet metal assembly can significantly improve the strength and stiffness of the body assembly. Foam aluminium can be applied to body structural parts, battery case, etc., such as energy absorption box, anti-collision beam, AB column, battery case, etc. Take the Audi model as an example: in this model, the connection mode of foam aluminium parts and other body sheet metal parts is bonding, and the experimenter conducts a tensile strength test on the interface strength of the connection according to the inspection method of GB/T7124-2008/ISO4587:2003, reaching the specified specific stiffness and specific strength [4].

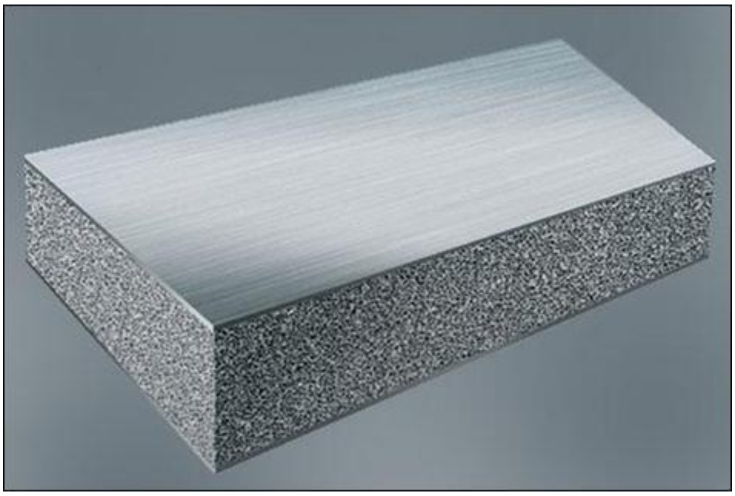

Fig 2. Foam Aluminium.

In the process of automobile design, the application of foam aluminium generally has two forms. One is to fill foam aluminium in the middle of the two layers to form a sandwich structure. This material can ensure high strength, lightweight, and shock absorption, achieving multiple benefits. It can replace some cold-stamped steel plate parts. The sandwich foam aluminium can be connected to the car body through bonding, screw connection, clamping and other forms. Another technology is to fill foam aluminium into the body cavity or hollow tube. Through test verification, the interface bonding strength is strong, and the failure mode is the fracture of the foam aluminium sample, which indicates that foam aluminium can meet the connection strength requirements of automobile manufacturing through the connection of structural adhesive and body, as shown in Fig.3.

Fig 3. Foam aluminium components of automobiles.

2.2. Non-metallic materials for automobiles

2.2.1. Carbon fibre, glass fibre, and organic glass

Carbon fibre composite is a new type of material made of carbon fibre-reinforced materials and resin-based materials, which have excellent properties such as lightweight, high strength, and high stiffness [5]. In automobile manufacturing, carbon fibre composite materials are often used for the manufacturing of lightweight body components, such as roofs, engine covers, doors, etc. For example, the doors and roof of Tesla's Model S are made of carbon fibre composite materials, reducing the body weight by about 100 kilograms [5].

Organic glass composite material is a composite material made with organic glass as the reinforcing material and thermosetting resin or thermoplastic resin as the matrix material. They have the characteristics of a beautiful appearance, rich colours, and good transparency. In automobile manufacturing, organic glass composite materials are often used to manufacture components such as front and rear lampshades, interior panels, etc.

2.2.2. Polymer Materials

Polymer materials are widely used in the interior and exterior coverings of automobiles. Common polymers include polypropylene (PP), polyurethane (PU), and polyethylene (PE). Polypropylene is widely used for exterior and interior parts of automobiles due to its excellent impact strength, chemical resistance, and low moulding cost. The polyurethane material has high elasticity and good wear resistance, is suitable for use as a covering material for seats and interiors and can typically withstand temperature changes from -30 ℃ to 70 ℃. Polyethylene is widely used in oil tanks and other containers due to its good toughness and processability, but its heat resistance is poor.

2.2.3. Ceramic Materials

With the continuous expansion of application fields, advanced ceramic materials, as a structural/functional material, are becoming increasingly important in the entire industrial manufacturing industry. Especially with the advancement of technology and the unique and excellent comprehensive performance of ceramic materials, ceramic materials have gradually been widely used in the automotive industry in recent years.

Ceramic materials are often used for high-temperature, high-wear components such as brake pads and engine cylinders due to their high hardness and wear resistance [6]. Modern ceramic materials are often composite materials such as zirconia and silicon nitride, which can withstand temperatures up to 1000 ℃ and maintain good performance under high load conditions. The density of ceramic materials is usually lower than that of metal materials, and their thermal conductivity is extremely low, which can effectively reduce energy loss.

From the current perspective, the application of ceramic materials in automobiles is quite common, whether it is key functional components or important structural parts. Ceramic materials have various advantages such as heat resistance, wear resistance, corrosion resistance, low density, and strong thermal insulation. Using ceramic materials in the preparation of ceramic-insulated engines can effectively prevent the loss of heat energy inside the cylinder. The weight of ceramic engines can be made lighter than that of metal engines. Among them, high-performance ceramic membranes are the main research direction, and currently, the most studied ceramic membrane materials include high-purity alumina and boehmite.

3. Automotive Composite Materials and Nanomaterials

3.1. Composite Materials

Composite materials combine the advantages of multiple materials and are new materials made from two or more materials with different properties through composite processes. Their comprehensive performance is superior to the original constituent materials to meet various requirements. It is usually composed of a matrix material and a reinforcing material. Glass fibre-reinforced plastic and carbon fibre-reinforced plastic (CFRP) are gradually being promoted and applied in high-performance automotive components. Among them, CFRP has a strength of up to 700 MPa and a density of less than 1.5 g/cm ^{3}, making it an ideal choice for racetracks and high-end car models due to its extremely high strength-to-weight ratio [7]. The advanced composite materials currently leading the innovation of automotive materials are composed of fibres, resins, and reinforcement materials, especially represented by carbon fibre reinforced polymer (CFRP), which provides unparalleled strength, lightweight, and corrosion resistance. Integrating these materials can reduce vehicle weight, and improve fuel efficiency, safety, and design flexibility. Meanwhile, research has shown that the recovery rate of composite materials has increased to about 50% -80%. This is of great significance for achieving sustainability throughout the entire lifecycle of automobiles. However, the cost of composite materials is relatively high, and overcoming challenges such as production costs remains the key focus in unleashing their full potential.

3.2. Nanomaterials

Nanomaterials include both metallic and non-metallic materials. Nanomaterials refer to materials with at least one dimension between 1-100 nanometres in three-dimensional space. Materials within this size range have many unique physical and chemical properties, making them widely used in many fields.

The application of nanotechnology in the automotive field mainly includes the following aspects [8].

Energy saving and emission reduction of automobiles: Nanotechnology can effectively reduce automobile exhaust emissions and fuel consumption. For example, as a desulfurization catalyst, nano titanium oxide drills can significantly reduce the harmful gases produced during gasoline combustion, thereby protecting the environment. In addition, nano photocatalytic technology can decompose nitrogen oxides and sulphur oxides in automobile exhaust, further reducing pollutant emissions.

Automotive surface treatment: Nano coating technology can form a layer of silicon dioxide glass on the surface of the car that is difficult to detect by the naked eye. It has functions such as acid rain resistance, dirt resistance, UV resistance, high-temperature resistance, anti-static, and oxidation resistance, significantly improving the protective performance and aesthetics of the vehicle.

Production and manufacturing: Nanomaterials are also widely used in automotive manufacturing. For example, nano plastics have excellent physical properties such as high strength, strong heat resistance, and low specific gravity, and are suitable for automotive interior and exterior parts, such as instrument panels, interior panels, airbag materials, etc. In addition, nano-rubber materials also have important applications in tyre manufacturing, which can improve the performance and durability of tyres [9].

Self-repair of automobile surface: Self-repair polymer coating can automatically repair and restore the original state of the surface when scratches appear on the automobile surface, especially suitable for cameras and sensors of autonomous vehicles. This technology not only protects the surface of the equipment but also ensures its clarity and accuracy.

The application of nanotechnology in the automotive field covers multiple aspects such as environmental protection, materials science, surface treatment, self-healing materials, and energy utilization, significantly improving the environmental performance, durability, and intelligence level of automobiles [10].

4. The Influence of Materials on Automotive Performance

The selection of materials plays a crucial role in studying the performance of automobiles. The material properties are not only directly related to the safety, economy, and durability of vehicles, but also have an indispensable impact on achieving environmental standards and technological innovation. Starting from the analysis of material characteristics, this paper discusses the impact of materials on automotive performance and gradually determines the comprehensive impact of materials on the overall performance of vehicles through mechanical, thermal, and environmental adaptability tests.

The mechanical properties of materials, such as yield strength, tensile strength, elastic modulus, and fatigue limit, determine the load-bearing capacity and reliability of vehicles under different working conditions. For thermal performance evaluation, the coefficient of thermal expansion (CTE) and thermal conductivity characterize the stability and heat dissipation ability of materials under temperature changes. The environmental adaptability analysis considers the material's resistance to environmental factors such as temperature, humidity, and chemicals. We adopt a comprehensive evaluation method to integrate and analyse the results of various tests, to determine the impact of material selection on automotive performance.

With the help of the "Usage and Performance Table of Various Automotive Sheet Materials", it is possible to intuitively compare the performance indicators of different materials [11]. For example, high-strength steel plates are widely used in vehicle structural components due to their high yield strength and tensile strength, while lightweight aluminium alloy plates are used for engine covers and wheel hubs due to their low density and sufficient mechanical properties. In addition, material density has a direct impact on the total mass of a car, and the formula for calculating the total mass of a car is

$$M = \sum_{i=1}^{n} m_i \tag{1}$$

Table 1 reveals that the density and elongation of ordinary low-carbon steel plates are the highest; the yield strength, tensile strength, elastic modulus, fatigue limit, and impact resistance of carbon fibre composite materials are the highest; the CTE value of magnesium alloy sheet is the highest. By selecting materials with lower density, vehicle weight can be effectively reduced, thereby improving fuel economy and dynamic performance.

Table 1. Application and Performance Table of Some Automotive Sheet Materials [11].

Type of board	Application site	Density /(g/cm³)	Elongation rate/%	Yield strength /MPa	Tensile strength /MPa	Elastic modulus /GPa	Fatigue limit /MPa	Value of shock resistance/Ak/J·cm²	CTE ×10⁻⁶/°C
Ordinary low-carbon steel plate	Vehicle exterior panel	7.85	25	210	380	200	220	270	12
High-strength steel plate	Body structural components	7.80	15	420	820	200	210	120	11
Aluminium alloy plate	Engine hood, wheel hub	2.70	14	130	310	70	130	45	23
Magnesium alloy sheet	Instrument panel support	1.80	8	160	240	45	95	35	25
Glass fiber composite material	Vehicle exterior panel	1.90	2.2	1000	1250	50	340	330	17
Carbon fibre composite material	Roof and wings	1.55	1.5	1500	2500	230	600	500	7.7

5. Conclusion

The challenges faced by new automotive materials mainly lie in the fact that the initial cost of lightweight materials remains high compared to traditional steel and aluminium alloy materials, which to some extent limits their large-scale application in economical vehicle models; the recycling and reuse of new materials still face many technical and economic obstacles. How to establish an efficient, environmentally friendly, and economically feasible recycling system is a major issue that the entire industry urgently needs to overcome; the manufacturing process is relatively complex, requiring high-precision equipment and professional technicians to operate, which not only increases production costs but also poses severe challenges to the technical strength and management level of production enterprises. In the future, we look forward to achieving more revolutionary technological breakthroughs in key areas such as material performance, manufacturing processes, and recycling. With the continuous advancement of technology and further cost reduction, composite materials are expected to achieve comprehensive popularization in the automotive market. Automobile manufacturers, material suppliers, research institutions, and government departments should strengthen cooperation and form a close industrial collaborative innovation system. By sharing resources, conducting joint research and development, and sharing risks, the widespread application and rapid development of materials in the automotive industry can be achieved, creating a win-win industrial ecological environment.

In summary, future automotive manufacturing should primarily focus on the research of high-performance lightweight materials to enhance their potential in improving vehicle safety, fuel efficiency, and design flexibility, which is crucial in the modern automotive industry. Therefore, the research and analysis in this article can provide useful theoretical and practical insights for understanding and utilizing the impact of materials science on automotive performance.

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