# MATERIALS

## 1 Introduction

Automotive materials have evolved to meet performance requirements amidst the diversifying demands placed on automobiles by society.

Automotive materials remain the key element for ensuring basic vehicle quality and also, especially in emerging markets, have to adapt to issues such as globalization and the material risk presented by scarce resources, leading to calls for the development of new technologies to improve environmental friendliness, weight reduction, safety, and comfort. This article introduces the technological trends in automotive materials in 2015.

## 2 Ferrous Materials

### 2. 1. Steel sheets

Drastic changes in how automobiles are perceived by society have created demands to reduce costs while making vehicles lighter and safer. Advances have been made in replacing steel sheets with materials that have a low specific gravity as a means of meeting stringent fuel economy targets. Nevertheless, steel sheets still remain the main automotive material due to their excellent cost performance and mature technology solutions. The uses of steel sheets can primarily be classified as follows: (1) parts for the vehicle frame, (2) outer panels, (3) chassis parts, and (4) motor parts.

#### 2. 1. 1. Parts for the vehicle frame

Technologies to greatly increase the strength of the material used for these parts are being developed to both reduce vehicle weight and enhance collision safety (i.e., to absorb energy and secure cabin space after a collision occurs). High strength steel in the 590 MPa and 980 MPa classes have been developed and adopted as material for, respectively, energy absorption (material that deforms in a collision) and the securing of cabin space (material that does not deform in a collision). With the development of high ductility materials, ultra high tensile strength steels are increasingly being adopted in difficult to form parts, including as energy absorbing material, and to raise the strength of cabin space securing material to 1,180 MPa[1][2]. For 1,180 MPa class ultra high tensile strength steel, development of the material is paralleled with the development of spot welding methods to counter the delayed fracture issue unique to ultra high tensile strength materials[3].

At the same time, the increasing globalization of ultra high tensile strength material production[4] is providing a boost to their wider adoption.

The use of hot-stamped materials, where forming and quenching are performed simultaneously in the die after heating the steel sheet, is also increasing, and with the transition from the conventional 1,470 MPa class to the even stronger 1,800 MPa class, the development of hot-stamping forming simulation technology and forming technology[5][6] is increasing their application to products that are difficult to form[7]. Moreover, tailor welded blanks (TWB), which join steel sheets of different strengths and thicknesses prior to forming the realization of partial hot stamping methods is also a factor in the increased use of these materials.

In Europe, a technique using steel sheets called tailor rolled blanks (TRB), which gradually changes the sheet thickness in the direction of rolling, has been commercialized and its use is expected to expand.

#### 2. 1. 2. Outer panels

Ultra low carbon steel is widely used for outer panel parts, which strongly dominate the external design that constitutes one of the crucial aspects of the product appeal of automobiles, due to the high formability and surface quality required to realize a distinctive styling. Due to its effectiveness at reducing weight, bake-hardened type high-strength steel, which increases yield strength through a paint baking process, is adopted in outer panel parts with a large surface area to make the panels lighter while maintaining formability and performance. Although sheets with a strength class of 340 MPa were predominant, the recent development of 440 MPa class material has made the parts even thinner[8], and they have started to be used for door outer panels.

Since side outer panels also function as vehicle frame parts, thick high strength steel 440 MPa class or higher sheets, rather than thinner sheets, are starting to be used to reduce weight as well as the number of reinforcement parts required to secure cabin space. The development of TWB technology has also led to the partial adoption of 590 MPa class steel in outer panels[9].

**2. 1. 3. Chassis parts**

Since chassis parts have strict strength, durability, corrosion resistance and other requirements to ensure reliability as safety-critical parts in terms of vehicle functionality, they do not use of high-strength steel as extensively as vehicle frame parts. However, 590 and 780 MPa class high-strength steel is increasingly used in parts such as lower suspension arms, and 980 MPa class high-strength steel has been adopted for steel wheel rims.

Several types of steel sheets different from those for vehicle frames have been developed as high-strength materials for chassis parts, which are required to have a variety of formability characteristics, including stretch flange-ability and hole expansion[10].

**2. 1. 4. Motor parts**

In terms of high performance steel sheets, the iron core material for electric vehicle motors is pushing the development of automotive steel sheets into a new area as HVs and EVs grow in popularity.

High strength steel sheets featuring both endurance strength and low losses in the high speed range have been developed to reduce the size and weight of motors. To achieve further downsizing, research on technology that balances low iron loss and high strength is attempting to determine the impact of iron loss to reduce it during the nanofabrication stage[11].

**2. 2. Structural steel**

Structural steel is a material that can obtain the required strength through forging and heat treatment. It is mainly used in high-strength parts such as powertrain and chassis parts. Although increased strength for weight reduction purposes can be achieved through the addition of molybdenum or vanadium, cost reduction and material risk concerns have shifted efforts toward the development of material with lower quantities of those expensive elements.

**2. 2. 1. Engine parts**

In crankshafts and connecting rods, which are primary engine component parts, vanadium is added to carbon steel, and microalloyed steel that causes vanadium carbide precipitation is used to reduce heat treatment costs and energy consumption.

In the past, the bending fatigue strength of the fillet parts of crankshafts was increased by applying compressive residual stress via a surface rolling process. Recently, the use of high-frequency induction hardening to increase hardness and residual stress has made it possible to return to the use of standard materials instead of high-strength materials. In contrast, the amount of general purpose manganese was increased and the precipitation of manganese nitride has been used to develop steel for high strength crankshafts manufactured via gas soft nitriding that is about as strong as current high strength materials without relying on the rare metal molybdenum[12].

Initiatives to reduce the inertial force and friction loss of connecting rods through weight reduction are underway, and a high strength steel with good machinability has been developed for connecting rods by adding vanadium to improve strength and the yield ratio, as well as by optimizing the structure and component elements[13].

**2. 2. 2. Drivetrain parts**

For the gears that are a primary component of the transmission, transmission carburized gears are generally used since these have the required dedendum fatigue strength, impact strength, and resistance to pitting. In addition, to rationalize manufacturing processes and reduce costs, cold forging is used to mold gears, and steels that adjust the components to mitigate the abnormal austenite grain growth in the subsequent carburizing process have been developed[14].

A carburized abnormal layer remains on the uppermost surface of case-hardened gears not subject to further treatment after carburized quenching, and research to improve pitting resistance by increasing the silicon and chrome content to form a soft carburized abnormal layer that is removed by wear in the initial stages of service life is being carried out[15]

**2. 2. 3. Chassis parts**

Spring and bolt wire rods are used for springs and bolts, and the proactive addition of alloying elements has been the primary approach to improving properties in response to the demand for higher strength that leads to weight reduction.

In contrast, steels for low alloy high strength springs are being developed to address the issues of cost reduction and procurement of material[16].

### 2. 3. Stainless steel

Stainless steel is a material that combines iron with at least 11% or more chromium. It has excellent heat and corrosion resistance and is often used in the exhaust systems of vehicles and for decorative molding. Ferritic and austenitic stainless steels are the most common materials. Ferritic stainless steel is inexpensive because it does not contain nickel. It also has excellent thermal fatigue characteristics, which is why it is often used for parts in the exhaust system. With the increasing need to further improve fuel efficiency, demand for a material that can withstand the higher exhaust gas temperatures in lighter weight vehicles and engines with improved combustion efficiency has been growing. Vehicle exhaust systems often make use of SUS444, a typical heat-resistant ferritic stainless steel, and a new steel material that achieves heat-resistance capabilities equal to or better than SUS444 by substituting the rare metal molybdenum with the addition of copper was developed. Moreover, a steel with added cooper and a minute quantity of molybdenum that retains a high proof stress even at temperatures of 800° C or higher without losing normal temperature ductility has been commercialized[17].

A type of resource-saving low cost steel with reduced chromium content achieving equivalent corrosion resistance through the addition of minute amounts of tin has also been developed[18].

### 2. 4. Cast iron

Cast iron are widely used for many vehicle parts because they not only offer a high degree of freedom in shape design and enable the mass-production of parts with complex shapes, but also have excellent workability, wear resistance, vibration damping properties, and a low cost.

Cast iron are used for engine parts such as camshafts, manifolds, and turbocharger housings, as well as chassis parts such as knuckles, brake rotors, and various types of arms.

Design requirements concerning cast iron are becoming increasingly stringent, and issues such as obtaining high strength by optimizing component adjustments and heat treatments, or obtaining high toughness, need to be addressed[19]. To reduce weight, a thin knuckle using a high strength 700 MPa class spherical graphite cast iron is being developed.

### 2. 5. Ferrous sintered materials

Since sintering fills the mold in the shape of the product with metallic powder and heat hardens it after compacting, it is superior to other processes in terms of producing products in their final or almost final shape. The particularities of that process are put to good use in manufacturing parts that require wear resistance, such as sprockets or bearings, as well as parts that also require heat resistance, such as valve seats or valve guides.

In addition to connecting rods, sprockets and other mechanical structure parts, magnetic material is another product manufactured using sintering. The drive motors installed in hybrid and electric vehicles require highly efficient, high output magnetic material.

Both magnetic properties and heat resistance, which is essential, can be secured effectively through the use of dysprosium, which is rare and expensive. Consequently, as with other rare metals, material risk concerns are spurring the development of alternative technologies. This makes it crucial to elucidate the coercivity mechanism in magnets, and research to clarify it is being pursued[20].

## 3 Nonferrous Metals

### 3. 1. Aluminum alloys

The characteristics of aluminum include a specific gravity approximately one-third that of steel, excellent corrosion resistance, and high thermal conductivity. Steel materials are increasingly being replaced with other materials to reduce the weight of vehicles, and substituting aluminum alloys for steel generally provides a 30 to 50% reduction in the weight of parts.

In addition to their longstanding use in cast parts such as engine blocks, cylinder heads, and transmissions, aluminum alloys are now also being applied to body and suspension parts. Their use is projected to expand, with a predicted demand for automotive aluminum alloys expected to be approximately double the current amount used by 2025[21].

In vehicle bodies, aluminum alloy sheets are used for parts such as engine hoods, doors, and roofs, while extrusions are used for bumper beams.

Poor formability is a technical challenge with aluminum alloy sheets, and at the materials level, research that involves combining cold rolling and differential speed warm rolling to control texture for the purpose of enhancing deep drawability by improving the r-value is underway[22].

The development of forming simulations that model plastic anisotropy to improve part accuracy has also been reported, and simulations that predict the changes in shape that occur during part assembly are being applied as well[23].

The 6000-series aluminum alloys are the main extruded alloys used in bumper beams, and 7000-series extrusions, which feature both high strength (400 MPa class) and stress corrosion cracking resistance for even greater weight reduction have been announced and are scheduled for mass-production use[24].

In chassis suspension parts, forged 6000-series allows are used in the upper and lower arms, and further improvements in strength and corrosion resistance are being studied. The use of cast and die cast parts in knuckles and suspension members is becoming more common. Reducing the number of parts by producing suspension members as single large die cast parts mitigates cost increases. Casting technologies that meets the stringent quality requirements for such important chassis safety-critical parts, such as vacuum die casting and laminar flow filling have been developed and are being applied.

Joint technology is one of the key applied technologies for aluminum alloys, with friction stir welding used as a technique to join the dissimilar materials in hybrid subframes made of steel and aluminum. At the same time, a technique involving coating with sealant as a measure against galvanic corrosion is being applied in mass production[25].

Other weight reduction efforts involved replacing copper with aluminum as the material for wire harnesses. Using aluminum for the contacts requires removing the tenacious oxide film on the surface of the aluminum, and this is accomplished with a joining technique that makes use of ultrasonic vibrations[26].

### 3. 2. Magnesium alloys

Magnesium alloys have a specific gravity of 1.74, which is approximately one-quarter that of steel and two-thirds that of aluminum alloys, making them the lightest of the structural metal materials. They are also characterized by a high specific strength, as well as superior thermal conductivity, thermal conductivity, electromagnetic wave shielding and vibration absorbency. Although magnesium alloys are expected to become the next lightweight material after aluminum, issues such as ignitability, poor corrosion and heat resistance, inferior plastic workability, and high costs have limited their use as automotive materials.

Parts in which such alloys are applied are mainly die cast or other cast parts such as steering wheel cores, cylinder blocks, and cylinder head covers.

Initiatives to improve the aforementioned plastic workability are underway, and research on the texture weakening mechanism in extruded magnesium alloys containing yttrium is being conducted[27]. A method of enhancing the ductility of AZ91 alloys at room temperature through hot pressing and isothermal holding has been developed[28].

## 4 Nonmetallic Materials

### 4. 1. Ceramics

Ceramic materials used in vehicle parts are classified into structural ceramics, which are used in engine parts, electroceramics, which are used in various sensors, and coatings.

Structural ceramics are hard, have excellent heat and corrosion resistance, and are lighter than steel, leading to the adoption of silicon nitride in parts such as the tips of rocker arms or the turbine rotors in turbochargers.

Electroceramics include materials such as zirconia, which is used in oxygen sensors and lead zirconate titanate, which is used in knock sensors. Structural ceramics and electroceramics have not changed significantly in the past several years.

In terms of coating, chromium nitride coatings applied through physical vapor deposition are used for piston rings, and diamond-like carbon coatings are used on parts such as piston rings[29] and piston pins[30] to improve wear resistance and reduce friction in engine parts. In addition, research into a swing heat insulatia coat made from a porous ceramic coating applied to the walls of the combustion chamber for the purpose of improving thermal efficiency has been attracting attention[31].

### 4. 2. Plastics

Since plastic materials are lightweight and have excellent shape flexibility, the proportion of plastic used in vehicles has been rising, and the amount of plastic materials used is expected to increase as their applications extends to more and more locations.

At the same time, to address both environmental and energy issues the use of plastics derived from recycled materials or plants is also being promoted.

#### 4. 2. 1. Exterior parts

Polypropylene (PP) has superior material properties and formability, and also good cost performance. As a result, PP is often used in bumpers and other exterior parts. In addition, plastic materials are also being used in fenders and back door panels in an effort to expand the scope of weight reduction and shape flexibility. At the same time, carbon fiber reinforced plastic (CFRP), which has been introduced in airplanes, is also attracting attention. Despite issues such as cost and productivity, the benefits of their high strength and low specific gravity are being leveraged for use in roofs and hoods[32]. Moreover, in relation to CFRPs, carbon fiber reinforced thermoplastics (CFRTP), which use thermoplastic resin in an effort to shorten cycle times and improve energy absorption performance, are attracting attention and their use is expected to expand.

#### 4. 2. 2. Interior Parts

Needs associated with interior materials include more comfortable spaces and enhanced textures. Initiatives concerning comfortable spaces include the development of air conditioners that provide fresher air[33] in addition to efforts to reduce the output of volatile organic compounds (VOCs) in the cabin. Given the anticipated advances in automated driving technologies, more and more initiatives to make spaces more comfortable are likely to be undertaken.

Similarly, the development of very bright materials and scratch resistant materials is being pursued as part of initiatives to improve texture, and further advances are expected in that respect since such materials are less expensive and emit fewer VOCs than paints.

In terms of environmental initiatives, efforts to alleviate $CO_2$ emissions throughout the manufacturing-to-disposal life cycle of the products themselves are underway for PET (polyester), which are commonly used in parts such seat and ceiling fabrics and are partially made from plants. They are expected to see greater use due to their low cost.

#### 4. 2. 3. Engine parts

Among plastic materials found in engine parts, polyamide (PA) materials, which have excellent heat resistance have been used in the intake manifold and the radiator tank, and more recently, the development of variations with added low water absorption and calcium chloride resistance has also expanded their use to parts such as intercooler tanks or thermostats. At the same time, to address weight and cost reduction concerns for engine parts, PP materials are being adopted in parts such as radiator supports, air cleaner housings, and resonators[34].

### 4. 3. Rubber

Rubber materials exhibit unique viscoelastic properties and are used in parts such as tires, hoses, weather strips, and vibration-absorbing rubber in mounts and bushings.

For tires, advances in technologies that balance fuel efficiency and wet grip performance have led to the application of dispersant to counter the additional silica content, as well as to the adoption of nano-sized silica[35].

As factors such as smaller engine compartments are increasing the severity of the usage environment, fluororubber (FKM), which exhibits superior durability in high-temperature, high-pressure environments, is being used for rubber hoses.

A low-foaming ethylene-propylene-diene-monomer (EPDM) rubber material is used to reduce weight and cost in weather strips, new materials targeting even greater environmental friendliness, new functionality, and additional properties are being developed.

As the demand for smaller and lighter vibration-absorbing rubber in mounts and bushings has increased, development related to engine mounts is extending beyond simply absorbing vibrations from the engine to cover new structures intended to reduce lateral vibrations during cornering[36].

### 4. 4. Glass

Automotive glass fulfills many functions, including blocking of ultraviolet and infrared light, soundproofing, and repelling water, which are being applied not only to the windshield and front door glass, but also to the rear door and rear window glass.

Moreover, to enhance safety as well as in response to increased IT use in the cabin, an interlayer that allows characters or maps to be displayed on the entire windshield has been developed[37], and is expected to see broader adoption in preparation for the introduction of more IT functions.

At the same time, plastic glass is increasingly being adopted to reduce weight. Polycarbonate (PC) is typically used as a plastic glass material for its transparency and impact resistance, but since that material is lacking in weather and wear resistance, it requires hard coating, which leads to higher costs. Consequently, technologies to substitute for hard coating, such as film transfer are being developed[38] and expected to be adopted at a later date.

**4.5. Paints**

To enhance vehicle product appeal, two-tone paint color variations have been growing, and the lines where separate colors are applied have become increasingly diverse. Efforts to simultaneously obtain colors that are both deep and bright by separating the functions of the two base coat layers and the adoption of colors providing a strong metallic appearance also stand out(39)(41), and development aimed at enhancing textures and expanding color variations is being carried out. Heat-shielding paints are also being used to alleviate temperature rise in the cabin[39].

In terms of environmental measures (lower VOC and $CO_2$), use the water-based "3 wet" paint process is growing, and paints that do not require preheating the primer, as well as primerless paints, are also being used[40][41]. Some plastic parts are also coated with UV cured paints. Anti-rust coating technology is characterized by the growing use of zirconium oxide conversion coatings, which do not contain phosphorus or nickel, as well as of high throwing power electrodeposition coatings that aim to stabilize coating quality and reduce the burden on the environment by reducing the quantity of paint used. Tin-free electrodeposition coatings are also being developed in an effort to eliminate the use of heavy metals.

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