MATERIALS

1 Introduction

As worldwide demand for automobiles stagnates due to anxiety over global socioeconomic conditions, the industry is facing a once-in-a-hundred-years transformation that not only requires adapting to new technologies such as MaaS and CASE, but also to increasingly stringent environmental regulations all around the world. Many new initiatives are being carried out in the field of material technologies, and this article gives an overview of the main automotive material trends in 2019.

2 Ferrous Materials

2. 1. Steel Sheets

The use of lightweight materials such as aluminum and carbon fiber reinforced plastic (CFRP) as part of multi-materials in appropriate locations to reduce the weight of the vehicle has been drawing a lot of attention, but steel materials, by virtue of their abundance of resources, recyclability, and superior cost effectiveness remain the primary material used in automobiles today. Steel manufactures have a particularly strong presence in Japan, and the idea of using steel to the fullest is well entrenched.

(1) Vehicle Frame Parts

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 performance. The main technologies involved are cold-formed ultrahigh-tensile strength steel sheets (ultra high-tensile steel) and hot stamping. Members using ultra high tensile strength steel in the 1,180 MPa class to prevent deformation in an impact and secure cabin space are seeing increasing use, and the first vehicle body structural 1,310 MPa class material was used in 2019[1]. Material in the 980 MPa class featuring both ductility and localized bendability is now found in energy-absorbing members, and efforts to expand its applicable locations are underway. The Innovative Structural Materials Association (ISMA) has been working on developing a breakthrough steel material with a tensile strength of 1,500 MPa and an elongation of 20%, prompting parallel research on the issues of corrosion, and the analysis and evaluation hydrogen embrittlement that arise when strength is increased[2].

Similarly, hot stamping, which involves simultaneously molding and quenching of the heated steel plate in the die, has produced commercial 1.8 GPa class material in addition to the existing 1.5 GPa class material. The development of even stronger 2 GPa class material is also underway[3]. Hot stamping is being combined with the tailor welded blanks technique, in which sheets of steel of different thicknesses and strengths are joined before forming, and the tailor rolled blanks technique, which applies a continuous thickness transition in the rolling direction. The development of technologies that control the temperature during cooling in the die or rely on lasers to provide different levels of strength in different portions of the sheet is expanding the use of steel sheets in large components and energy-absorbing members[4].

(2) Outer Panels

Ultra-low carbon steel sheets are highly formable and therefore widely used for outer panels, where a high level of formability and surface quality is required to achieve appealing styling. The use of aluminum and plastic has been increasing, but new lightweight door structures using even thinner steel sheets with low tensile stiffness have also been proposed[5]. In addition, internal reinforcement members are being eliminated by strengthening locations where weight can be reduced through approaches such as applying tailored blanks to make partial use of 590 MPa or 780 MPa class material in side outer panels or adopting 1,180 MPa class material in the outer part of the center pillar.

(3) Chassis Parts

Many chassis parts are critical safety parts that support the basic vehicle functions of running, turning and stopping. Therefore, they must be highly reliable in terms of strength, rigidity, durability, corrosion resistance, and other requirements. The steel sheets used in chassis parts must also have a variety of formability characteristics, including stretch flanging and hole expandability. Consequently, they do not use high-strength steel as extensively as vehicle frame parts. However, 590 and 780 MPa-class material is increasingly used in parts such as lower suspension arms, and 980 MPa-class material is finding its way in some frame parts. Initiatives to optimize the welding wire and shielding gas, and to refine electrodeposition coating to improve fatigue strength in arc welded portions and corrosion resistance after painting for the purpose of producing even stronger and thinner material are underway. More recently, the use of shot blasting has also been proposed(6).

(4) Motor Parts

The electromagnetic steel sheets that are widely used as the iron core material in electric vehicle drive motors are required to be durable at high rotation speeds, as well as to reduce the iron loss that affects motor efficiency. To satisfy those requirements, research on materials relying on the adjustment of alloy composition, control of the crystal orientation, or control of the grain size is being conducted. Materials based on amorphous magnetism and nanocrystalline soft magnetism are also garnering attention. At the same time, the development of analysis and evaluation technologies has raised the precision of iron loss analysis and of the measurement of magnetic properties(7).

2. 2. Structural Steel

Structural steel is a material that obtains the required properties through forging and heat treatment. It is mainly used in high-strength parts such as powertrain and chassis parts. Until now, material design has relied on the addition of expensive base elements such as molybdenum or vanadium but cost reduction and material procurement concerns have been spurring the development and use of materials with a lower content of such base elements.

(1) Engine Parts

In crankshafts and connecting rods, which are primary engine component parts, carbon steel is doped with vanadium and non-heat treated steel subjected to vanadium carbide precipitation is widely used to reduce heat treatment costs and energy consumption.

Until now, a surface rolling process was used to increase the fatigue strength required by the fillet parts of crankshafts through the application of compressive residual stress. Recently, however, partial strengthening through high frequency quenching has made it possible to increase fatigue strength in standard materials as well. Gas soft nitriding is also used to increase fatigue strength, but it requires correcting even the minor bending that results from soft nitriding. The development of tempered nitrocarburized steel for crankshafts offering a high level of both fatigue strength and bending correction by optimizing the steel material composition and heat treatment conditions to obtain a microstructure is being carried out(8).

(2) Drivetrain Parts

Gears, a main component, are usually carburized gears due to the high level of dedendum fatigue strength, impact strength, and resistance to pitting that are required.

To reduce cost and energy consumption, cold forging and high temperature carburizing has been used to form such gears. Since this approach is prone to abnormal austenite grain growth, steels that adjust titanium, niobium or other components effective at suppressing grain growth are being developed. In addition, a mild carburizing treatment that both reduces alloy use and improves fatigue strength by combining the strong points of vacuum carburizing and high-frequency quenching is being developed. The use of higher temperatures in vacuum carburizing has been further increasing strength(9).

For CVT pulleys, which must be wear resistant, steel material that enhances surface hardness by forming high-carbon residual austenite on the surface layer through carburizing and response induced martensitic transformation from contact with the belt is being developed(10).

(3) Chassis Parts

Spring and bolt wire rods are used for springs and bolts, and the addition of alloying elements has been used to improve properties in efforts seeking to reduce weight by balancing higher strength with hydrogen embrittlement and corrosion fatigue. However, as part of measures to reduce spring costs, refinements to heat treatments and shot peening have led to examples of applying the existing SAE 9254 standard steel in stronger springs. Steel for low alloy high strength springs are also under development(11).

2. 3. Stainless Steel

Stainless steel is a material that combines iron with a chromium content of 10.5% or higher. It has excellent heat and corrosion resistance and is used in exhaust system parts, decorative molding and, more recently, battery cell cases.

Ferritic stainless steel is the primary steel type, and a material with added niobium or molybdenum rare metal content is set in the exhaust manifold, which is used at high temperatures. Recently, materials that secure high temperature properties while reducing the amount of expensive rare metals have been commercialized. In contrast, inexpensive SUS 409 stainless steel is used in the exhaust pipe downstream of the exhaust manifold. However, it is also prone to brown rust formation when exposed to high temperatures and an external corrosive environment. Therefore, ferritic stainless steels with a high-chromium content, such as SUS 439 or SUS 436 are being adopted more often to improve appearance.

2. 4. Cast Iron Materials

Castings are widely used for powertrain and chassis parts due to their high degree of shape flexibility, excellent wear resistance and vibration damping properties, and relatively low price.

In engine parts, they are used for sliding parts such as cylinder liners and camshafts, for heat-resistant parts, such as exhaust manifolds and turbocharger housings, and for differential cases and other drivetrain parts. Engine downsizing has led to an increase in the installation of turbochargers, and the higher exhaust gas temperatures call for further heat resistance improvements in cast iron materials.

In chassis parts, they are used for the brake rotors and calipers, as well as the steering knuckles and suspension arms. Recently, in response to weight reduction needs, CAE has been brought to bear to leverage the shape flexibility of cast iron and develop hollowed high toughness spherical graphite cast knuckles, which are increasingly being adopted(12).

2. 5. Ferrous Sintered Materials

Sintering is a process that involves filling a mold with metallic powder and heat hardening it after compacting. It has excellent material yield since the resulting product is in its final or almost final shape. It also offers a high degree of material design flexibility that makes it possible to express various properties by adjusting the raw material powder blend.

Taking advantage of the benefits, these materials are used in mechanical structural parts such as sprockets and clutch hubs, as well as in wear resistant parts such as valve seat or valve guides. Various initiatives have been undertaken, including reducing costs via processing in powder form before sintering, and the development of a process to join combinations of different materials in powder form during sintering.

At the same time, many magnetic parts are manufactured by sintering, including the neodymium sintered magnets that are widely used for the drive motors for electric vehicles. Concerns over the supply of rare earth elements has made the development of low rare earth motors a crucial issue, and motors with extremely efficiently placed energy-saving neodymium or ferrite magnets are under development. Advances in high compression forming technology, the purification of the powder, and ultra-fine powder technology have enabled the manufacturing of high-density magnetic parts. Base power with a two-layer structure is also being developed.

3 Nonferrous Metals

3. 1. Aluminum alloys

Compared to other nonferrous metals, aluminum is amenable to a wide range of forming techniques, including rolling, forging, extrusion, and casting, and has therefore been replacing steel materials in various automobile parts to reduce vehicle weight. The amount of aluminum used in a single vehicle is also increasing. Advances are also being made in methods to join dissimilar materials such as steels and CFRP or other plastic materials(14) and in technologies to prevent electrolytic corrosion as part of recent efforts to transition to multi-materials, which use a combination of appropriate materials in appropriate locations.

In addition to their longstanding use in cast parts such as cylinder blocks and transmission cases and panel parts such as engine hoods or doors, thin, large-sized casting parts manufactured via high pressure die casting are also increasing used in frame or chassis parts. Using this method helps avoid cost increases thanks to part consolidation, and also makes the design of highly space efficient and high rigidity parts possible via the application of rib structures and hollowing.

As materials themselves become stronger, materials that balance the increase in strength with the conflicting issues of formability and stress corrosion cracking are being developed, and design structures are being studied.

3. 2. Magnesium Alloys

Magnesium alloys have a low specific gravity that is one-quarter that of steel and two-thirds that of aluminum alloys, making them the lightest of the practical metal materials. Although they have been long been viewed as promising lightweight structural materials due to their high specific strength and specific rigidity, issues such as poor corrosion and heat resistance, as well as inferior plastic workability have limited their use in comparison to aluminum alloys. Most commercialized parts are cast parts made through processes such as die casting, and include steering wheel cores and cylinder head covers. In contrast, use as a wrought alloy is limited to an extremely small number of parts such as roofs.

Joint industry-academia research and development on expanding their eventual application is in progress, and includes research on improving the formability of wrought alloys[15].

4 Nonmetallic Materials

4. 1. Ceramics

With regulations concerning automobiles have become stricter on a global scale, as well as the computerization of vehicles highlighted by CASE and other technologies, and the growing use of electric and electronic components, requirements for automotive ceramics are undergoing major changes. To comply with emissions regulations, ceramics have long be used in the form of cordierite honeycomb catalysts use to purify emissions. However, as the world follows Europe's lead in imposing ever stricter emissions regulations, the installation of diesel particulate filters (DPF) relying on honeycombs made of silicon carbide (SiC), which represent a new application of ceramics in the control of diesel vehicle particulate matter (PM) emissions, is becoming more common worldwide. While an emissions scandal involving diesel vehicles at a European OEM has triggered a drop in sales of such vehicles in Europe, countries such as China and India have strengthened their measures against PM based on the installation of DPFs, and their use is increasing. At the same time, the European Euro 6 and North American LEV III regulations impose PM measures on gasoline vehicles, which are consequently required to be equipped with silicon carbide gasoline particulate filters (GPFs). With Japan and other regions working on introducing similar measures, demand for silicon carbide GPFs is anticipated to rise.

As electrification and the use of electronics becomes more prevalent in automobiles, the demand for ceramics is rising in conjunction with increased demand for barium titanate ($BaTiO_3$) condensers. Moreover, measures against heat radiation are becoming urgently required as electrification leads to a greater number of power devices. In that context, thermal conductive fillers made of compounds such as silicon nitride (Si_3N_4) or boron nitride (BN) are mixed with epoxy or silicon in thermal interface material for electronic substrates. Since a small quantity is sufficient to provide that functionality, they are gaining in importance. Building on the high added value offered by electroceramics, the total sum spent on ceramics is predicted to become a strong market driving force.

4. 2. Plastics

Thanks to their low specific gravity and superior forming flexibility, plastics are anticipated to see greater use in reducing weight, achieving modularization, and producing highly stylish vehicle bodies or parts.

At the same time, development targeting the more advanced requirements imposed on plastic as their use increases, including improved performance, lower costs, and environmental measures such as recycling, is underway.

(1) Exterior Parts

Polypropylene (PP), which has low specific gravity and is inexpensive, is frequently used in bumpers and other exterior parts, and initiatives involving making thinner material through optimal control of PP, talc and rubber ternary compounds, or foam molding, are paving the way for weight reduction efforts.

Due to their excellent adhesion, acrylonitrile butadiene styrene (ABS) plastics are commonly used in paints, plating or other decorations. However, the painting and plating processes are complex and impose a significant burden on the environment. Consequently, the use of decorations made of material that preserves coloring properties and high gloss without using paint, or of plating substitute obtained by hot stamping a metallic film, is spreading.

With respect to the application of plastic in structural parts, CFRP combined with high rigidity, high strength carbon fiber (CF) is being assessed. Although cost and recyclability issues currently still need to be resolved, plastics allowing shorter manufacturing times such as carbon fiber reinforced thermoplastics (CFRTPs) have become available[16], and there are high expectations on development that will allow their general use. At the same time, the need to ensure adhesion and bonding with adjacent metal panels or parts represents a major hurdle hampering their use in vehicles.

The rising demand for electric or fuel cell vehicles is highlighting the need for materials that not only release the large amount of heat produced by electric components such as motors and inverters, but also offer insulation and formability. It is more important than ever for automakers and plastic manufacturers to take the lead in coordinating development with parts suppliers.

(2) Interior Parts

The interior materials used in automotive parts must satisfy the high durability requirements (scratch, heat, and light resistance) imposed on such parts. They are also expected to impart a sense of luxury and provide high levels of occupant comfort. Therefore, various surface decorative technologies are being developed. At the same time, China is leading the way in drawing more attention to VOCs, odors, and other aspects of cabin air quality, and the shift toward low-odor, low-VOC materials is gaining momentum.

Intensifying calls for a sense of luxury have led to the growing use, especially in luxury vehicles, of authentic decorations, which encompasses textures such as the tactile warm or cool feel that are provided by the adoption of real aluminum or wood and not found in painted, plated, or film-coated decorations. This trend is gathering attention. Unlike in past parts that relied on combining plastics with surface painting or grain (a pattern on the surface of the plastic), technologies that impart a sense of luxury while emphasizing the balance of cost and feel are being incorporated in the light- and medium-duty vehicles that reflect that emphasis. These technologies include decorative curved surface printing technology with little distortion of patterns even on curved portions, TOM forming technology that offers a high degree of flexibility for film surface textures and can be applied to parts with a high curvature, and materials that can be used on paintless mirror surfaces while preserving their high luster and high scratch resistance.

Technologies that digitize and visualize vague human emotions (technology that quantifies affective regions and sensory evaluations) to make objective evaluations of the sense of luxury and the desire for authenticity are being developed in the field of kansei engineering. This will be a trend to keep an eye on when evaluating the course of future interior materials development.

(3) Powertrain and Electric Drive Unit Parts

Due to its mechanical properties and heat resistance, polyamide (PA) is the mainstream plastic material used near the engine for parts such as the intake manifold and the radiator tank. Low moisture absorption polyamide is used in locations exposed to water as a measure against degradation from snow melting agent (calcium chloride) absorption. Based on environment temperature as well as weight and cost reduction considerations, PP is used in air intake system parts such as the air cleaner and air ducts.

The high-pressure hydrogen tanks in FCVs use CFRP, with Type 4 as the mainstream due to safety and weight reduction concerns.

Given requirements to make units smaller, lighter and more powerful, and the trend toward strengthening the sound insulation design of engine compartments to comply with sound regulations, powertrain system parts will be expected to become even lighter and exhibit greater heat resistance.

(4) Environmentally-Friendly Materials (Bioplastics)

To address global warming and resource depletion, Toyota started mass-producing the world's first spare tire cover made entirety from plant-derived material in 2003. Since then, manufacturers have also been using that material in interior parts and radiator tanks. More recent applications go beyond simple replacement and strive to improve performance and styling. Examples include door trim material that is both lighter and achieves an improvement of about 20% in impact characteristics through the nano-level control of bioplastic and PP[17], and a gear shift panel with a high level of styling made by combining bioengineered and engineering plastics[18].

In 2019, to meet its COP 21 and SDG targets, Japan drafted a strategy on the recycling of plastic resources[19] that set the goal of introducing 2 million tons of biomass plastics by 2030. In automobiles, making the highly-used PP petroleum-free will be a key point, and there is currently no commercial plant-based PP. Mitsui Chemicals has announced plans to commercialize plant-based PP by 2024[20], and upcoming trends will be monitored closely.

4. 3. Rubber

The unique viscoelastic properties of rubber materials lead to their use in tires, hoses, and weather strips, as well as in the vibration-absorbing rubber in mounts and bushings. The downsizing, turbocharging and higher output of engines is creating an ever more severe thermal environment.

Highly heat resistant ethylene propylene diene rubber (EPDM), acrylic rubber (ACM), and fluorocarbon rubber (FKM) is used in rubber hoses, and the types of inner and outer rubber are chosen based on the use environment, performance requirements, cost, and other factors. In air conditioner hoses, compatibility with the new R1234y refrigerant is achieved by complementing the gas barrier properties with making the inner layer acid resistant. Nitrile rubbers (NBRs), with their superior fuel oil resistance, and FKM rubbers, which block evaporative emissions, are the mainstream materials in fuel hoses. However, the recent distribution of fatty acid methyl ester (FAME) blended fuel in ASEAN nations is making it necessary to take ultra high biodiesel concentrations into account for fuel hose rubber components[21].

With stronger emissions regulations requiring the installation of DPF or GPF aftertreatment systems, ethylene propylene diene monomer or ultra high heat resistance silicone rubber (VMQ) is chosen as the muffler hanger rubber in exhaust systems based on the environment temperature.

4. 4. Glass

Stricter regulations and adaptation to CASE is bringing major changes to glass materials as well. As regulations on reducing CO_2 emissions from running vehicles—improving fuel efficiency, in short—become more stringent on a global scale, and in light of the possibility of using off-cycle fuel economy improvements that cannot be reflected in running mode as CAFE credits, adding heat insulation functionality to glass, a major contributor to the temperature inside the cabin, is a useful approach to significantly reducing fuel consumption due to air conditioner use in the summer. In electric vehicles, the substitution of engine for motors eliminates engine noise is making wind and road noises stand out while driving. A comfortable cabin can be obtained by integrating sound insulation capabilities in glass, which constitutes the largest portion of the cabin surface area.

Moreover, growing numbers of autonomous vehicles are leading to an exponential increase in the amount of information presented to the driver. Consequently, an area to display that information using a head-up display (HUD) is necessary, and high expectations are being placed on technology enabling light emission in full color in the intermediate film of the glass to display that information on the windshield.

Using glass made of resin to reduce automobile weight is one way to reduce CO_2 emissions while driving. However, a hard coating must be applied due to the poor wear and scratch resistance of resin glass, and the cost of the agent combined with the long manufacturing takt time lead to higher costs. Automakers are therefore reluctant to adopt this material. In China, integrated molding was applied to the outer pillar garnish, and resin glass that reached a cost breakeven point was adopted. The Shanghai GM Buick[22] GL 8 minivan uses an integrated resin glass C pillar garnish[23], and manufactured 280,000 vehicles over the three years up to the end of 2019. This illustration of the lead Chinese suppliers have started to take in manufacturing innovation creates expectations that Japanese manufacturing will not be outdone and start making great strides forward.

4. 5. Paint

In addition to conventional product appeal and performance requirements, automobile paints must now also adapt to CASE, comply with regulations, and be environmentally friendly.

Work on developing paints compatible with autonomous driving sensors is underway, but it is currently difficult to make metallic paint colors transparent to millimeter waves. Understanding and controlling the characteristics of paint at specific wavelengths be key to moving development forward.

The increasing use of plastic outer panels is directing weight reduction efforts toward studying the integrated painting of the vehicle body and plastic. Reducing the paint baking temperature enables integrated painting with plastic parts such as bumpers. This approach offers the promising environmental and quality benefits of reducing CO_2 emissions and energy consumption, and eliminating the need to match the color of the vehicle body and the plastic parts.

The U.S. CAFE and GHG regulations include stipulations on solar reflective paint as a technology to reduce CO_2. Only white paints currently meet the standard, but the development of expanded applications is anticipated.

While the use of highly decorative paint (e.g., high brightness, metallic, shading) and two-tone paints is expanding, matte paints are also being introduced for styling purposes.

References

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