MATERIALS

1 Introduction

The year 2020 was marked not only by a sharp drop in demand for automobiles due to the COVID-19 pandemic, but also by a sudden shift toward a major transformation highlighted by the declaration of carbon neutrality made by Prime Minister Suga and other media reports of industry and corporate initiatives in and outside Japan aimed at reducing life cycle CO_2. Material technologies represents an important field in a position to contribute to that transformation. This article gives an overview of the main automotive material trends in 2020.

2 Ferrous Materials

2. 1. Steel Sheets

Efforts to reduce the weight of automobiles are targeting the use of multi-material structures using lighter materials in suitable locations to complement the already growing adoption of ultra-high tensile strength steel. Nevertheless, considerations such as material cost, molding, welding and other forms of productivity, and recycling result in steel sheets remaining the mainstream material, and the development of ultra-high tensile strength steel, as well as of technologies to maximize the potential of steel sheets, is being extensively pursued. Locations that use steel sheets can be broadly classified into (1) vehicle frame parts, (2) outer panel parts, (3) chassis parts, and (4) motor parts.

(1) Vehicle Frame Parts: The use of high strength materials is growing rapidly to address the increase in vehicle mass brought about by electrification, as well as the ever more stringent safety requirements imposed by various countries. The two technologies used to achieve high strength frame parts are cold-formed ultra-high tensile strength steel, and hot stamping. Compared to 980 MPa or 1,180 MPa class high tensile strength steel, the former led to the use of higher strength high tensile strength steel in the 1,310 MPa class in 2019, and in the 1,470 MPa class in 2020. Material in the 980 MPa class featuring both ductility and localized bendability is found in energy absorbing members.

Conversely, hot stamping, which simultaneously performs forming and rapid quenching within the die after heating the steel sheet, is used in various techniques that achieve different strengths and thicknesses to produce parts with locations that have different requirements. Differences in thickness can be produced with (a) the patchwork blanks method, which involves welding two overlapped blanks before forming, and then applying hot stamping, and (b) the tailor rolled blank method, which gradually changes the thickness by rolling coils. Differences in strength are achieved with (c) partial quenching or partial tempering, and (d) the tailored blank method, which applies laser welding to steel plates of different strengths after quenching. These methods can be used either singly or in combination. Material with a strength of 1,470 MPa after quenching has been widely, and hot stamped material in the 1,800 MPa class was adopted in 2020. Development further targeting classes of 2,000 MPa and beyond is underway.

Among other processes, bumper reinforcements and door beams created via roll forming use 1,700 MPa class high tensile strength steel. Steel pipes formed into a three-dimensional shape have been used in roof rails.

(2) Outer Panels: The expectation for an appealing design in outer panels has led to the broad use of ultra-low carbon steel, which offers the ease of formability required to produce complex shapes. Parts that require specific characteristics to avoid denting easily when the panel is pushed (i.e., tensile stiffness and dent resistance) use 340 MPa or 440 MPa bake-hardened high tensile strength steel, whose yield strength increases during the paint baking process. The resulting thinness makes the material lighter while maintaining formability and performance. There have been no recent advances in terms of materials, and development has centered on stamping technologies designed to realize sharp character lines or prevent live deviations to realize complex shapes.

(3) Chassis Parts: Chassis parts, which form the foundation of dynamic performance and safety, include many safety-critical parts are subject to strict reliability requirements in areas such as strength, stiffness, durability, and corrosion resistance. Since rigidity and corrosion resistance requirements determine thickness, strength increases in frame parts are not as high as in body parts, and hot rolled 440 MPa class high tensile strength steel is the mainstream material. The use of 590 MPa and 780 MPa class hot rolled high tensile strength steel with high hole expansibility is limited to parts such as the lower arms. Efforts to enhance safety has sometimes resulted in making suspension members bear loads in a collision. Hot rolled high tensile strength steel in the 780 MPa class is used for the applicable parts.

(4) Motor Parts: The electromagnetic steel sheets that are used as the iron core material in electric vehicle drive motors are required to improve the magnetic flux density that contributes to motor performance, as well as to reduce the iron loss that affects efficiency. They must also have a high level of strength against the large centrifugal forces that act on the rotor during high speed rotation. Material development that uses thinning, alloy composition optimization, and control of texture and crystal grain size is being pursued to satisfy those diverse requirements. At the same time, amorphous magnetism and nanocrystalline soft magnetism are garnering attention from the standpoint of further reducing iron loss, and their application in motors is being examined.

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 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. A surface rolling process has been used to increase the fatigue strength required by the fillets in crankshafts through the application of compressive residual stress. Recently, high frequency quenching and gas soft nitriding treatments are also applied in some cases. Microalloyed steel doped with carbon, manganese, or vanadium is used in connecting rods. Free-cutting elements such as sulfur or calcium are sometimes added to address the concern of worsened machinability as a countereffect of increased strength.

(2) Drivetrain Parts: Gears, a main component, are made from chromium steel or chromium molybdenum steel with guaranteed hardenability, which carburized to obtain the required high levels of dedendum fatigue strength, impact strength, and resistance to pitting. To reduce cost and energy consumption, the elimination of the heat treatment after hot forging, cold forging, and high temperature carburizing designed to shorten carburizing time has been used to form such gears. However, since this approach is prone to abnormal austenite grain growth, materials that add 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. With the recent spread of electric vehicles, the use of acceleration and deceleration mechanism gears at high rotation speeds has led to research concerning the effect of the gear surface layer structure on friction and wear characteristics.

(3) Chassis Parts: Wires are used in suspension springs and bolts, and alloying elements have been added in an effort to improve the properties intended to balance higher strength with hydrogen embrittlement and corrosion fatigue. More recently, high strength suspension springs that use the SAE 9254 standard steel and reduce cost through refined heat treatment and shot peening processes have been commercialized. Steel for low alloy, high strength springs is also being developed. Bolts are made from carbon steel, manganese boron steel, or alloyed steel, based on the strength class.

2. 3. Stainless Steel

Stainless steel is a material that consists of iron with a chromium content of 10.5% or higher. It is used in exhaust system parts for its excellent heat and corrosion resistance, and in decorative molding or other exterior parts for its high design flexibility. The exhaust manifold is an exhaust system part used at high temperatures. Therefore, SUS 444, which includes added expensive niobium and molybdenum, (18 Cr–2 Mo–Nb) is used. Inexpensive steel and other alternative material with excellent high temperature properties is being developed to avoid high rare metal market prices and the risk of insufficient supply. The low-chromium SUS 409L stainless steel (11 Cr) is the mainstream material in mufflers. However, SUS 430LX with a higher chromium content (18 Cr) or SUS 436L with added molybdenum (18 Cr–1 Mo) have been used in Asia, Central and South America, and other regions were low-quality fuel with a high sulfur and chlorine content. It will be necessary to stay abreast of fuel property improvement in such regions, and select the most cost effective material without compromising quality.

2. 4. Cast Iron & Cast Steel

Castings are widely used in engine, drivetrain and chassis parts due to their high degree of shape flexibility, excellent wear resistance and vibration damping properties. In engines, they are used for sliding parts such as cylinder liners and camshafts, as well as for turbocharger housings and other heat-resistant parts. Downsized turbocharged engines have become more common, and the temperature of exhaust emissions has risen to achieve both fuel efficiency and output, leading to the use of heat-resistant stainless steel with a high amount of added nickel and niobium. In chassis parts, aluminum castings are increasingly used for weight reduction purposes. At the same time, thin ribbed, hollowed, high toughness spherical graphite cast iron knuckles have been developed, and this technology is used to reduce both weight and cost.

2. 5. Ferrous Sintered Materials

(1) Structural and Wear Resistant Parts: 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 close to its 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. 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. At the same time, the use of spraying technology to form a functional coating in the cylinder bore is becoming more prevalent. Research on 3D printing, centering primarily on laser lamination, is also underway. Forming speed has been identified as an issue, but there are nevertheless example prototypes reaching size of cylinder heads or cylinder blocks.

(2) Magnets: Many magnetic parts are manufactured through sintering. Neodymium sintered magnets, which feature a high level of saturation magnetization, are widely used in electric vehicle drive motors. Improved heat resistance has been achieved by adding expensive heavy rare earth elements such as dysprosium to increase the coercive force indicative of such resistance. However, resource-related risks have spurred the development of alternative technologies and active research into the mechanism that generates coercive. The resulting adoption of grain boundary diffusion, grain boundary phase modification, and grain refinement technologies has led to the commercialization of high coercive force neodymium magnets with either greatly reduced or no rare earth element content.

3 Nonferrous Metals

3. 1. Aluminum Alloys

Various manufacturing methods, including rolling, forging, extrusion, and casting, have been commercialized for aluminum. It is widely used as its shape and mechanical properties can be controlled through the selection of alloys, manufacturing method, and heat treatment. While aluminum alloys have been used in engine cylinder blocks, cylinder heads, heat exchangers, and wheels for many years, they have also increasingly been used to replace steel sheets to make vehicle bodies lighter. Bonding technology for dissimilar materials such as steel and CFRP, and preventing galvanic corrosion between dissimilar metals is important to achieve a transition to multi-materials. Intense effort is being put into developing processes such as mechanical fastening, fusion joining and solid phase bonding. Successfully replacing steel sheets with aluminum, which is relatively more expensive, involves drawing on benefits such as reducing the number of parts through the use of large cast parts, and creating high rigidity part designs that maximize the shape flexibility of those castings. Aluminum sheets are used in body panel parts such as the engine hood and doors, and there are continuing calls for the development of materials with greater press formability, as well as for further improvements in the prediction accuracy of forming simulations.

Efforts to achieve carbon neutrality have been intensifying worldwide. The current electrolytic smelting Hall–Héroult process for aluminum consumes a large amount of electricity, efforts to intensify research and development into smelting methods with reduced consumption, and commercialize them, are awaited. Outside Japan, smelting that uses clean energy and new technology to keep CO_2 emissions down has already been introduced. However, since the amount of such bare metals in circulation is still small, it is important to make use of recycled material, which consumes substantially less energy than new ingots. Although initiatives to send stamped scrap material back to aluminum manufacturers and reduce the amount of new ingots used are already underway, a scheme to reuse aluminum parts from recovered end-of-life vehicles will be needed. Research on sorting and recovery technologies, processes to detoxify impurities, and the control of alloy structure will also be crucial.

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 electrolytic corrosion and heat resistance, as well as inferior plastic workability, have limited their use in comparison to aluminum alloys. Magnesium die-cast material presents excellent castability that enable thin, complex shapes. It is used in parts such as steering wheel cores and cockpit modules. In contrast, it only sees limited use as wrought alloy material.

4 Nonmetallic Materials

4. 1. Ceramics

Ceramics used in automotive parts are divided into structural ceramics, functional ceramics, and coatings, depending on their characteristics and applications. Structural ceramics include cordierite, which is used in the catalyst carrier to help purify exhaust gases, silicon carbide, which is used in diesel particulate filters (DPFs), and alumina, which is used in spark plugs. The need to install gasoline particulate filters made from silicon carbide in gasoline vehicles due to increasingly common regulations on ultrafine suspended particulate matter such as PM or PN throughout the world is anticipated to continue to rise.

Among functional ceramics, electroceramics include the zirconia ceramics in oxygen sensors used in engines, and the barium titanate serving as dielectric material in condensers. Ceramics are also seeing increasing use as thermal functional material. Alumit is used to insulate the engine combustion chamber, while silicon nitride and boron nitride are used as high thermal conductivity filler in the thermal transfer interface material of electronic substrates. The latest research has increasingly focused on the single layer graphite material known as graphene, with its use as a carrier for platinum to form nanostructures of that element, in capacitors or heat discharge fillers that draw on its high thermal conductivity are being studied. In coatings, many piston ring or valve lifter wear resistance films are switching from chromium nitride to diamond-like carbon (DLC), which has become a standard material. The application of DCL films is also extending to piston pins. Several suppliers have been announcing new technologies for vehicles, and the application of DLC films is expanded to expand further.

4. 2. Plastics

Plastic materials are lightweight and have excellent shape and design flexibility. Consequently, they account for 10 to 15% of the vehicle mass, primarily in exterior and interior parts. Development and applications of plastic are actively pursued in areas such as making parts thinner by taking advantage of their high fluidity and high strength material properties, reducing weight using composite materials made by optimally adjusting those properties using various reinforcing materials, or achieving part modularization by capitalizing on their superior shape flexibility. At the same time, the use of foam materials, composite materials making use of carbon or glass continuous fibers, and plastic/metal hybrid materials are providing improved part performance through the selection of formulations, structural designs, and processes that capitalize on the strong points of each material. Highly functional plastics with superior optical as well as noise and vibration characteristics are also actively used in members intended to make vehicles more attractive. At the same time, the use of recyclable and plant-derived plastics is also increasing. These materials can be collected within manufacturing processes and from the market when vehicles are scrapped. These materials are seen as environmentally friendly and a way for automakers to address both environmental and energy issues.

(1) Exterior Parts: Electrification and improved fuel efficiency are increasing the need for weight reduction, and polypropylene (PP), the plastic most used in vehicles, has been achieving high fluidity and lower specific gravity. The drop the bending elastic modulus to drop caused by decreasing the amount of filler to obtain a lower specific gravity is being mitigated through approaches such as selecting a highly fluid, highly crystalline base PP. The growing adoption of the core-back foam injection molding also exemplifies the intensification of weight reduction efforts. The use of CFRP in structural parts has been rising, and the development of the C-RTM method enabling production in several minutes compared to the several hours of the previous autoclave method has enabled a significant reduction in cost, which had been an issue.

The use of exterior parts featuring a high gloss black (commonly called piano black) that enhances the stylishness of decorative parts has been rising. Color tones were previously expressed by painting acrylonitrile butadiene styrenes (ABS) or PP. However, environmental and cost considerations have led to selecting polymethyl methacrylate (PMMA) or other high transparency resins, and combining them with jet black pigments or dyes has achieved a level of styling comparable to paints using mold-in color.

(2) Powertrain Parts: Polyamides (PA) are used in intake manifolds, cylinder head covers, radiators and other engine parts due to their superior heat resistance and mechanical properties. Structural optimizations have also been leading to the use of PA materials in parts that are difficult to make with plastics, such as oil pans and chain covers, for the purpose of reducing weight. Since the motor room of an electric vehicle has a lower environmental temperature than an internal combustion engine in the motor room, PP high strength materials are increasingly replacing PA materials to reduce both weight and cost. Given the heat resistance, electrical characteristics, and dimensional stability requirements for the growing the number of electrical and electrical system parts accompanying electrification, the main plastics used consist of polyphenylene sulfide (PPS) and polybutylene terephthalate (PBT). In addition to the above characteristics, flame resistance and electromagnetic shielding is also required to use plastics in high voltage locations or casing components, and materials with even greater functionality are necessary.

4. 3. Rubber

Rubber materials have crosslinking points giving them the unique viscoelastic properties that make them essentially irreplaceable as functional parts in applications that include tires, hoses, vibration-absorbing rubber in mounts and bushings, and seals such as weatherstrips or gaskets. As downsized turbocharged engines became more prevalent and the environmental temperature of rubber hoses rose, it was originally necessary to use expensive heat resistant materials such as fluorocarbon rubber (FKM) or silicone rubber (VMQ). However, advances in polymers and material blending technologies has improved the heat resistance of ethylene propylene diene rubber (EPDM) and acrylic rubber (ACM), which are increasing used as substitutes.

Growing demand for smaller, lighter parts has been leading to shrinking the rubber volume in the vibration-absorbing rubber for mounts and bushings, subjecting those materials to stronger input strain and requiring them to have high durability. Fractures from repeated inputs originate from minute cracking generated at the interface between the rubber and the filler, an issue that has prompted the development of high durability rubber with enhanced bonding force at the interface.

For seals, the low permanent deformation, low compression reaction force and low specific gravity characteristics of foam rubber or leveraged for seals used in the waterproof sealing portions of electrical parts housings, which have become more common lately.

4. 4. Interior Materials

The interior parts used in the passenger space are not only expected to provide comfort to occupants, but also to exhibit high durability with respect to operation and severe use environments. Health has also become a greater concern, and a focus on vehicle compartment air quality has been giving momentum to the adoption of low-odor, low-VOC materials.

Interior parts that can be touched directly use materials with a pleasant tactile feel or skin materials that are stain-resistant to provide enhanced comfort. Refinements are not only applied to base material characteristics, but also to the surface grain shape and surface treatment agents, and tactile sense measuring methods have been used to develop materials with a highly improved tactile field. Stain-resistant base materials and more durable decorative materials are being adopted in response to enhanced styling and changes in the way vehicles are used. Skin materials with water repellent and hydrophilic properties, or with a structure that limits dust adhesion are used to improve performance against darkening or other dirt sticking to such materials. In the area of improved durability, material that uses additives to achieve #superior scratching resistance.

Initiatives to improve air quality, and notably reduce odors, include modifying the components of solvents used in paints or surface treatment agents for parts, adopting water-based paints, and modifying or refining the additives that evaporate from the base material.

4. 5. Structural Adhesives

Weight reduction through the application of thin steel sheets is achieved by improving body rigidity with continuous joining that uses structural adhesives concurrently with the well-established spot welding single-point joining technology. Although loss of functionality caused by hydrolysis is an issue with structural adhesives, a new epoxy-based adhesive with improved humidity resistance has been developed, and is being adopted in vehicle body locations that require long-term durability. Aluminum and composite materials are being considered as replacement body materials to further reduce weight, and efforts to develop adhesives for new adherends are underway. Moreover, the progress of electrification in increasing the demand for improved damping, and imparting functionality other than rigidity in structural adhesives will be the next challenge.

4. 6. Electrical Insulating Polymeric Materials

Enamel resin with higher heat resistance and a low dielectric constant is being developed for the coil in electric vehicle drive motors as systems gain higher voltages and become both more compact and performant. Dispersing air bubbles uniformly in polyimide resin with the temperature index set to 250° C and the dielectric constant set to 2.4 reduces film thickness and increases conductor area while maintaining insulation has successfully decreased motor loss by five percent compared to the current ratio.

4. 7. Paint

The roles of vehicle paints include styling, functionality, and undercoat protection, and their performance, quality, cost, and productivity, notably in terms of environmental friendliness, and need for high levels of styling rises year after year. As part of efforts to protect the environment, the three-layer wet paint process designed to reduce VOC and CO_2 emissions during painting is becoming more common. More recently, technology that further reduces CO_2 by enabling simultaneous painting of the bumpers through the use of low-temperature baking after painting the vehicle body has been introduced. Similarly, the CAFE and GHG regulations issued by the EPA in the U.S. have introduced an off-cycle credit system for solar reflective surface coatings stipulated as technologies that enhance fuel efficiency.

In styling and design, the adoption of two-tone colors continues to grow. Manufactures are actively developing highly stylish colors, including red, blue, orange and other high chroma colors, as well as paints with metallic tones featuring a strong contrast between highlights and shading. At the same time, advances in automated driving and electrification technologies will make compatibility with millimeter wave radar, lidar or other sensors essential, and the key to future development will be to balance styling with electromagnetic wave transparency.

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