MATERIALS

1 Introduction

In 2021, the parts procurement shortages due to the COVID-19 pandemic and the material supply shortages due to natural disasters had a greater impact on the automotive industry than in 2019, making it a year that accelerated development toward the transition to EVs. Such circumstances call for the development of automotive materials that meet new performance requirements such as environmentally friendly technology and weight reduction. The main material trends in 2021 are outlined below.

2 Ferrous Materials

2. 1. Steel Sheets

Efforts to reduce vehicle weight 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.

In contrast, technological development to reduce CO_2 emissions in the steel manufacturing process is progressing, while the manufacturing process is about to enter a period of major transformation highlighted by the use hydrogen reduction blast furnaces, carbon recycling blast furnaces, and electric furnaces.

(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. In addition, cracking is an issue for ultra-high tensile strength steel used in energy absorbing members, and a cracking suppression method based on a resin sandwich structure has been proposed.

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. Since then, 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.

(3) Chassis Parts

Amid the growing need for thinner sheets made from high-strength materials to reduce weight, chassis parts are also required to have high strength reliability because they are subjected to repeated loads during driving. However, the difficulty of ensuring fatigue reliability at arc welded locations is hampering efforts to produce thinner sheets by increasing the strength of the material. In response a process that applies compressive residual stress through a micro-needle (MNP) technique that uses an ultra-narrow diameter pin has been proposed as a method to improve fatigue strength at welded locations.

(4) Motor Parts

The electromagnetic steel sheets used as iron core materials for drive motors for electric vehicles are required to improve the magnetic flux density that contributes to motor performance, reduce the iron loss that affects efficiency, and have the strength to withstand the centrifugal force on the rotor during high-speed rotation. In addition, moving toward decarbonization will require developing compact, lightweight, high-efficiency, and high-power drive motors. Their materials will therefore have to exhibit low iron loss, high magnetic flux density, and high strength. Material development relying on thinner sheets, optimized alloy composition, and control of e texture and grain size is underway to achieve a high level of balance between those properties despite their mutually conflicting nature.

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

Crankshafts and connecting rods, which are primary engine component use non-heat treated carbon steel doped with vanadium and subjected to vanadium carbide precipitation. Non-heat treated steel can reduce heat treatment costs and save energy. In the past, the fatigue strength of the fillet portions of crankshafts was increased by applying compressive residual stress via a surface rolling process. In addition, high-frequency quenching and gas nitrocarburizing are also used to reduce the content of rare metals in steel and ensure strength. Since there is concern about a decrease in machinability as a trade-off due to the increase in strength, pas efforts to improve machinability involved adding sulfur and calcium. More recently, however, adding bismuth, a low-melting-point metal, has been reported to produce a liquid lubrication effect and achieve the same improvement.

(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 terms of carbon neutrality, the issue of mitigating CO_2 emissions during heat treatment must be addressed. The use of waste heat to raise efficiency, as well as of high-speed carburizing, vacuum carburizing, and high-frequency heat sources are also attracting attention.

At the same time, following the recent expansion of electric vehicle models, 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

Wire rods are used in suspension springs and bolts, and alloying elements have been actively added to improve rod properties and balance high strength with the conflicting requirement of preventing hydrogen embrittlement and corrosion fatigue. More recently, high strength suspension springs that reduce cost through refined heat treatment and shot peening processes, as well as steel for low alloy, high strength springs, are also being developed. Bolts are made from carbon steel, manganese boron steel, or alloyed steel, based on their 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. Among exhaust parts, exhaust manifolds are used in a high temperature range, so general-purpose steel SUS429 series (14Cr-Nb) and high heat resistant steel SUS444 series (18Cr-2Mo-Nb) are used. To avoid the surging market prices of rare metals and supply risks, these alloys are being developed to ensure high-temperature properties while replacing additive elements with inexpensive metals such as copper. Similarly, an alloy series with even greater heat resistance than the 444 series is being developed to cope with high exhaust temperatures. Low chromium stainless steel SUS409L (11Cr) is the main material for mufflers, but higher corrosion resistance grades are used in response to the regional characteristics of corrosive conditions and fuel cleanliness. Material optimization is expected to advance in tandem with such environmental conditions.

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 turbo engines have become more common, and heat-resistant cast steel doped with elements such as nickel or niobium is used for turbine housings. For chassis parts, a high-toughness spheroidized graphite cast iron knuckle has been developed and adopted as a technology that reduces both cost and weight. In the cast iron manufacturing process, manufacturers have started replacing cupola furnaces with electric furnaces to reduce CO_2 emissions.

2. 5. Ferrous Sintered Materials

Sintering fills the mold in the shape of the product with metallic powder and heat hardens it after compacting, and presents a good material yield rate since it produces a shape very close to that of the final product. 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. The particularities of this technique are put to use in machine structural parts such as sprockets and clutch hubs, as well as in wear-resistant parts such as valve seats and valve guides.

Many magnetic parts for vehicles are manufactured through sintering. Neodymium sintered magnets, which feature a high level of saturation magnetization, have recently become widely used in electric vehicle drive motors. Heat resistance and magnetic properties have been secured through expensive heavy rare earth elements such as dysprosium. However, in the past several years, concern over resource-related risks have spurred the development of alternative technologies. The resulting application of grain boundary diffusion, grain boundary phase modification, and grain refining technology has led to the commercialization of neodymium magnets that have high-temperature magnetic properties and either greatly reduced or no rare element content.

At the same time, the growing spread of electric vehicles in pursuit of decarbonization makes securing a stable supply of neodymium and other rare earth resources desirable. Development targeting not only the conservation of resources and alternative materials, but also highly efficient recycling technologies, is underway.

3 Nonferrous Metals

3. 1. Aluminum Alloys

Aluminum has a low specific gravity of about one-third that of iron, good corrosion resistance, and excellent thermal conductivity. Various methods such as rolled plate, forging, extrusion, and casting have been put into practical use, and they are widely used because the shape and mechanical properties can be controlled by selecting the alloy type, method, and heat treatment. Aluminum alloys have been used for many years in engine cylinder blocks, cylinder heads, heat exchangers, and road wheels. The recent shift to EVs is creating growing interest in extending the use of lightweight aluminum parts to extend cruising range. In addition, the expected increase in the use of multi-materials for frame members is anticipated to create higher demand for aluminum alloys.

It is important to develop technologies for joining dissimilar materials such as steel and CFRP, and to prevent galvanic corrosion of dissimilar metals, to realize multi-materials. Various developments, including mechanical fastening, fusion bonding, and solid phase bonding, are being vigorously pursued. 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.

The use recycled ingots, which consume less energy than new ingots, is important to reduce CO_2 emissions as part of efforts to achieve carbon neutrality. Recycled ingot aluminum alloys with a thermal fatigue strength equivalent to that of new aluminum alloys have been developed as a material for diesel cylinder heads, which require high thermal fatigue strength.

In addition, the high degree of shaping freedom in provided by aluminum casting was capitalized upon to apply "mega-casting", which integrates multiple main parts into a single part, to improve production efficiency.

3. 2. Magnesium Alloys

Magnesium alloys have a specific gravity of 1.74, which is approximately one-quarter that of iron 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, heat dissipation, electromagnetic wave shielding, vibration absorbency and machinability. Although magnesium alloys are expected to become the next promising 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 and made them less widespread than aluminum alloys. The parts put into practical use are mainly cast products such as die cast parts, such as steering wheel cores, cylinder blocks, and cylinder head covers. The development of flame-retardant magnesium alloys with a melting point higher than that of aluminum alloys, along with the need to reduce the weight of transportation equipment, has been spurring advances in research on the application of magnesium alloys to structural materials. As with aluminum, dissimilar metal joining technology is also required due to the transition to multi-materials. Technology that forms an intermetallic compound at the joining interface contained in a compound layer serving as the medium to join magnesium and steel.

4 Nonmetallic Materials

4. 1. Ceramics

Automotive ceramics consist of parts made from advanced ceramic materials such as zirconia (yttria-stabilized zirconia) and alumina. Ceramics are divided into structural ceramics, functional ceramics and coatings, depending on the characteristics and applications of the material. Ceramics are characterized by high reliability at high temperatures and are more cost effective than metals and other non-ceramic materials. Structural ceramics are hard, have excellent heat resistance and corrosion resistance, and are lighter than iron, leading to the use of silicon nitride in rocker arm tips and turbocharger turbine rotors.

The recent tightening of exhaust gas regulations is raising the level of heat resistance and functionality required for ceramic materials that make up automotive catalysts. In conjunction with high heat resistance requirements due to l = 1 over the entire area, element selection and pore characteristics are being optimized to suppress sintering in noble metal-supported substrates. In addition, the heat capacity of the monolithic carrier is reduced by increasing porosity and thinning the cell walls to promote early activation of the catalyst. Cerium, which controls oxygen adjustment in the catalyst, absorbs and releases oxygen by switching between trivalent and tetravalent oxidation states according to the l atmosphere. In general, compounding with zirconium is used to improve thermal stability, increases oxygen release and absorption capability, and improves responsiveness. Doping with lanthanum, praseodymium, and zinc is being investigated to improve performance in the areas of structural stability, NOx selectivity, and CO oxidation activity.

4. 2. Plastics

Plastic materials are lightweight and have excellent shape flexibility. Their use is expected to increase as the spread of electric vehicles (EVs) expands the scope of their application.

At the same time, addressing carbon neutrality and CASE is leading a major transformation of the SDGs action plan. Technological innovations such as material recycling, chemical recycling, and biomass plastics that can greatly reduce CO_2 emissions are sought to complement extended conventional environmental measures, and the industry as a whole must engage in cross-boundary collaboration.

(1) Exterior Parts

Polypropylene (PP) offers excellent moldability, low specific gravity and good cost performance and has been widely used in bumpers and other exterior parts. Plastic materials are increasingly used in fenders and back doors with the aim of reducing the number of parts by integrally molding them with the surrounding parts and reducing their weight.

There is also an urgent need to review the exterior painting process in terms of offering customers the popular two-tone automobile exterior decoration and environmental considerations such as reducing CO_2, and decorative technology is gaining attention as an alternative to painting. One feature of decorative film is its ability to express various designs (e.g., carbon tones, hairline tones, and texture) in addition to decreasing the number of painting processes.

(2) Interior Parts

In vehicle interior parts, the need for weight reduction is growing in response to the increase in loading weight of batteries stemming from electrification, leading to the adoption of methods such as foam molding. Of those, the adoption of PP core-back foam molding using chemical foaming agents is gaining momentum. Although the physical properties of the material deteriorate after foaming, the ability to increase thickness while suppressing mass increase enables a weight reduction of about 30% with bending rigidity equivalent to that of solid (no foam) parts.

Due to the s low foam retention during foaming that makes PP unsuitable for foam molding, manufacturers have introduced foam-compatible PP with improved melt tension to the market. Additives are also being used to modify PP, and success in making foamed parts using conventional general-purpose grade PP has recently been reported. However, appearance quality is an issue is an issue, and molding conditions have to be optimized.

Efforts to reduce the environmental burden are leading to a growing number of carbon-neutral products such as biomass-derived raw materials, and there are many reports concerning woody biomass materials and mass-balanced materials.

Woody biomass materials are attracting attention as carbon-neutral materials based on the idea that they do not increase the total amount of carbon dioxide on the ground because their use releases an amount of carbon dioxide fixed during tree growth into the atmosphere. They have been used as a resin-reinforced fiber. Door trim base material made of kenaf-mixed resin and resin containing reinforcing fibers of thinned cedar wood has been produced. Biomass raw materials can be found engineering plastics that express piano black tones, as well as in polycarbonate diol, a raw material for polyurethane plastic with improved chemical resistance.

Many plastic manufacturers have recently started to manufacture mass balance materials. Mass balance is an approach that allows products consisting of a mixture of petroleum-derived and non-petroleum-derived raw materials to be declared as non-petroleum-derived raw material products based on the ratio of each type of raw material. Mass-balanced PP and mass-balanced polyetherimide (PEI) made from bio-naphtha are in use. The advantage of mass balance material is that it has exactly the same quality as virgin material. However, the requirement to obtain an International Sustainability & Carbon Certification (ISCC, a certification system for biomass and bioenergy) to declare the use of mass balance materials is an issue.

(2) Powertrain Parts

Most plastic materials used in engine parts have been made of polyamide (PA) or glass fiber reinforced PA due to their heat resistance and strength. Among such parts, plastic intake manifolds use vibration welding to bond the upper and lower molded parts. The resulting high welding strength and exhaust gas recirculation system (EGR) intended to enhance fuel efficiency also requires resistance to the acidic substances contained in exhaust gas. These requirements mean that plastic intake manifolds are made of glass fiber reinforced polyamide (PA-GF).

More recently years, however, glass fiber reinforced polypropylene (PP-GF) for intake manifolds has been developed, and there have been cases of adopting such manifolds outside Japan after optimizing filler and other blends to meet quality requirements. They are about 13% lighter than intake manifolds made of glass fiber reinforced PA.

At the same time, electrification is making the installation of EV batteries more common. Aluminum alloys and metal materials have been used for battery pack casings due to the need for side collision and flame resistance, but weight reduction has become an important theme to extend cruising range. Various structures such as combinations of high-strength steel and plastic are under investigation.

4. 3. Rubber

Since rubber materials have cross-linking points and exhibit unique viscoelastic properties, they have been applied to functional parts that are difficult to replace with other materials, such as the anti-vibration rubber in tires, hoses, and mounts and bushes, as well as weather strips and gasket sealing parts.

A recent trend in weatherstrips is the addition of opening trim weatherstrips in addition to the door weatherstrips made of EPDM in an effort to improve quietness even in compact vehicles as part of a transition toward adopting double seals. However, since the door itself is lighter, the double seal presents the problem of making it difficult to close the door properly. This is addressed by applying TPO materials to the joints of the opening trim weatherstrips, as well as developing and mass-producing products that improve the sense of quality presented by the vehicle without affecting the ability to close its doors.

Glass run materials made from EPDM solid rubber and thermoplastic elastomer (TPE). The demand for lighter parts is also being met by developing a glass run made by foaming TPE material using rubber foaming technology. The next challenge will be to apply that foaming technology to other parts and work on reducing the weight of rubber and thermoplastic elastomer parts.

Automobile hoses can be broadly classified into hoses for the fuel, oil, brake, and air conditioner systems. Rubber materials with low fuel permeability are used for fuel system hoses to cope with the growing use of biofuels. At the same time, rubber hoses are increasingly being replaced with elastomers in response to the demand for weight reduction and integrated parts. Plastic tubes are replacing rubber hoses and metal pipe in fuel system piping. In addition, advances in PA elastomer materials with excellent heat resistance and the blow molding technology that uses those materials (e.g., 3D suction or exchange blow molding), are making it possible to integrate plastic into piping systems such as high-temperature turbo piping that exceeds 150℃.

Anti-vibration rubber must be compact to reduce the weight of parts. Making the rubber bush smaller increases input strain will increase, making it is essential to improve the durability of the rubber material by optimizing the molecular weight between cross-linking points and enhancing filler adhesion.

4. 4. Electrical Insulating Polymeric Materials

Permanent magnet synchronous motors are often used in electric vehicles, while polymeric insulating materials are used for varnish, insulating paper, insulating powder coating, and coil insulating coating for stators.

These insulating materials are subject to deterioration due to multiple environmental loads, such as heat generated during motor operation and contact with mixed water and oils. High oil and heat resistance are required since that deterioration causes a drop in insulating performance (e.g., insulator breakdown voltage, volume resistivity) and material performance (e.g., adhesion, mechanical properties).

Varnishes are generally based on epoxy, alkyd, and polyester resins. The traditional use of volatile organic solvents as thinner has made it difficult to achieve low VOC varnishes. However, recent market trends are leading to the development of low VOC varnishes.

Insulating paper has a composite structure consisting of a highly heat-resistant layer of PEN or PEI or similar material, and a very strong layer or aramid or similar fiber. In addition, various manufacturers have developed foamed insulating paper that also functions as a varnish. The potential for reducing the number of processes is thought to have initiated an increase in the adoption of such paper.

Insulating powder coatings are generally based on epoxy and polyester resins. As with varnishes, efforts are being made to reduce VOCs.

Polyester-imide and polyamide-imide resins are mainly used for the insulation coating of coils. In addition, performance concerns have been spreading the use of rectangular wires for coils. Due to the corners exhibiting more variation in film thickness than in round wires, they require a level of adhesion coatable with a certain film thickness to ensure insulation performance.

4. 5. Structural Adhesives

Vehicle body joints have traditionally been spot-welded, but the use of face-to-face joints using a combination of structural adhesives and spot welding (weld bond method) has recently been spreading in Japan as well. The use of this structural adhesive improves the rigidity of the vehicle body, enhances running stability and enables weight reduction through the application of thinner sheets. Adhesive adoption is also spurring advances in analysis technologies such as the prediction of long-term durability accounting for adhesive deterioration, and the prediction of the optimal placement of adhesives.

In addition, the development of damping adhesives with new functions and their application to parts associated with electrification are being investigated.

4. 6. Paint

The latest automobile paints are expected to be environmentally friendly while offering excellent styling. They are also subject to initiatives adapted to transformations such as CASE.

In the painting process, the paint booth and drying furnace emit a lot of CO_2, leading to a focus achieving carbon neutrality. Examples include eliminating the intermediate coat preheating for waterborne paints, shortening processes using paints integrated based on intermediate coat functions, and reducing air conditioning energy consumption through the use of paints featuring an expanded range of booth temperature and humidity control. Other initiatives involve lowering the temperature of the drying oven by introducing low-temperature curing paints, and reducing CO_2 emissions through not only integrated coating technology for the body and bumper, but also UV curing paints. In addition, alternative coating technologies such as original dyeing resin material and in-mold coating are being studied.

Shorter processes using decorative films and multi-layer coating to produce highly stylish colors are leading to a decrease in CO_2 emissions from highly stylish paints.

CASE and other innovations are expanding the use of plastic for exterior panels to further reduce weight, creating new needs for a transition to multi-material paints, paints that appropriately transmit and reflect sensors signals, and new high-performance paints such as electricity-storing paints for electrification.

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