MATERIALS

1 Introduction

Although signs that the pandemic was abating made 2022 was a year of anticipated recovery for an economy stagnant since 2020, the year was also fraught with major upheaval in global socioeconomic conditions due to the crisis in Ukraine. The trade instability induced by frequent natural disasters, as well as a wave of concerns such as geopolitical issues, decarbonization, and reducing the burden on the environment, was intensified by that crisis. In combination with the ongoing shift toward electrification, intelligence, and information, that instability amplified the uncertainty regarding the procurement of the resources, parts, and materials used in automobiles, and had a major impact on automotive production. These circumstances are setting expectations for the development of resource saving, high performance material technologies that counteract such issues. The following sections introduce the trends in automotive materials seen in 2022.

2 Ferrous Materials

2. 1. Steel Sheets

Weight reduction through multi-materials, which involve the concurrent use of materials other than steel sheets to reduce weight or enhance various characteristics and functions for the purpose of improving automobile fuel efficiency, have been an area of focus for some time. Although some observers anticipate a decrease in the amount of steel used as 2040 approaches, the abundance of steel as a resource, along with its recyclability and the advantages it offers in areas such as price make a majority of observers lean toward Japan using steel to the fullest. In fact, as demonstrated by the Innovative Structural Materials Association (ISMA), there is active research and development on highly functional steels. Steel sheet use can primarily be classified as follows: (a) parts for the vehicle frame, (b) outer panels, (c) chassis parts, and (d) motor parts. The rapid electrification of the last few years is creating higher expectations regarding motor parts.

(1) Vehicle Frame Parts

In terms of protecting occupants in the event of a collision, vehicle frame parts are classified into energy absorption parts, deformation control parts, and shape maintenance parts, and a suitable grade of steel is applied to each of these parts.

Steel in the 1,180 MPa-class is often used for cold press forming, and 1,310 MPa- to 1,470 MPa-class steel is also found in some applications.

Reports of the use of transformation induced plasticity (TRIP) steel to achieve high levels of both strength and formability have been followed by reports discussing liquid metal embrittlement (LME) cracks that occur in spot welds and are attributed to large amount of additive element content and potential solutions. There is also a growing need to develop applied technology in conjunction with the development of materials.

Hot stamping, in which a heated steel plate is pressed with a die and mold and then cooled and quenched while the upper and lower molds are still closed, is also used for many parts). 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. Differences in strength are achieved with (b) partial quenching or partial tempering, and (c) the tailored blank method, which applies laser welding to steel plates of different strengths after quenching. Those methods can be used either singly or in combination. Tensile strength in the 2,000 MPa class is also used for quenching strength. Delayed fractures due to residual stress imparted in the mechanical trimming process is a concern in many products manufactured through hot stamping. Therefore, the use of laser trimming has become the norm.

(2) Outer Panels

Outer panel parts require a high degree of formability and excellent surface quality to realize beautiful designs. Until now, ultra-low carbon steel was widely used because it possesses the required formability, but aluminum or plastic is being used in an increasing number of vehicles. Nevertheless, there are also examples of reducing weight using thinner steel sheets or, conversely, eliminating reinforcement parts by making the sheet thicker. There are also examples of using bake-hardened steel in the 440 MPa class in addition to the 340 MPa class to reduce weight with thinner sheets without sacrificing formability or performance.

(3) Chassis Parts

In terms of vehicle functionality, chassis parts are safety-critical parts with strict strength, durability, corrosion resistance and other requirements to ensure their reliability, and therefore do not use ultra-high tensile 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 arms. The requirement for chassis parts to have various forming characteristics, such as stretch-flanging ability and hole expandability, has also led to developing high tensile strength material adapted to specific uses, as well as to initiatives to improve the anti-corrosion performance of arc welds.

(4) Motor Parts

For the electromagnetic steel sheets used as the iron core material in the drive motors of electric-powered vehicles, it is necessary to enhance the magnetic flux density that contributes to vehicle torque and is related to motor performance, and to reduce the iron loss that affects cruising range and battery size, and is also related to motor efficiency. Those sheets must also have a high level of mechanical strength against the large centrifugal forces that act on the rotor during high speed rotation. Material development that uses approaches such as thinning, alloy composition optimization, control of texture and crystal grain size, and the reduction of impurities, is being pursued to satisfy those diverse requirements.

At the same time, the application of amorphous magnetic materials and nanocrystalline soft magnetic materials is being studied from the standpoint of further reducing iron loss.

2. 2. Structural Steel

Structural steel is widely used in high-strength parts such as powertrain and chassis parts. The material is combined with processes such as forging, heat treatment, or surface treatments to acquire the required characteristics, and the development of optimized materials has been pursued in conjunction with the latest advances in process technologies.

(1) Engine Parts

Crankshafts and connecting rods, which are primary engine components, must have high strength. In crankshafts, fillets require high fatigue strength, and high frequency quenching is partially applied to enhance that strength. There are also instances where gas nitrocarburizing is used to achieve high strength. In connecting rods, untempered carbon steel doped with vanadium is typically used to reduce heat treatment costs. The development of forging technology capable of imparting different strengths within a part by controlling the forging temperature and cooling speed has made it possible to ensure strength and formability at the necessary locations. In addition, high strength steel that optimizes the structure and component elements to provide good machinability has been developed for connecting rods.

(2) Drivetrain Parts

Gears, the main components of the transmission, are usually carburized gears due to the high levels of dedendum fatigue strength, impact strength, and resistance to pitting that are required.

Although forming these gears via cold forging and high-temperature carburizing has been favored to rationalize the manufacturing process and reduce costs, this approach is unfortunately prone to abnormal austenite grain growth. To counter that problem, manufacturers are regulating components such as titanium or niobium, which are effective at suppressing abnormal grain growth, while also developing materials that have the required strength at a reasonable cost by replacing the expensive elements used until now with inexpensive alternative elements.

In a different vein, a combined high frequency quenching and vacuum carburizing heat treatment intended to streamline and shorten the process, as well as reduce its energy consumption, has been developed. Using dedicated material, that treatment has succeeded in reducing the number of alloying elements and improving strength.

(3) Chassis Parts

Spring and bolt wire rods are used for the suspension springs and bolts, whose characteristics have been improved by adding alloys to increase their strength while reducing their weight. However, in light of recent concerns about costs and the ease of procuring material, particularly for suspension springs, materials that can eliminate the soft annealing process by adjusting components and applying controlled rolling during wire rod manufacturing have been developed. Low-nickel, vanadium-free inexpensive springs with a 1,300 MPa shear strength achieved in combination with composite shot peening are also used more frequently.

2. 3. Stainless Steel

Stainless steel is widely used in many automobile parts because of its excellent heat and corrosion resistance. In particular, ferritic stainless steel is often used for exhaust system parts because it does not contain nickel, has a low coefficient of linear thermal expansion, and has excellent heat fatigue characteristics. Manufacturers have been transitioning to copper variations with a lower content of rare metals such as molybdenum or niobium in an effort to reduce costs. In contrast, austenitic stainless steel contains nickel and is used in parts that require more corrosion resistance, such as exhaust gas recirculation (EGR) coolers. Most recently, it is also applied to parts (e.g., receptacles, high pressure hydrogen pipes, and reducing valves) used in the high pressure hydrogen environment of fuel cell electric vehicles (FCEVs). However, cost is an issue with SUS316L, in which the higher nickel content due to the addition of molybdenum suppresses the formation of strain-induced martensite and delta ferrite to withstand hydrogen embrittlement in a high pressure hydrogen environment of −40℃. Therefore, low cost material with reduced rare metal content is being developed for future expanded adoption in FCEVs.

2. 4. Cast Iron & Cast Steel

Cast iron and cast steel 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.

The turbine housings of gasoline turbocharged engines use heat-resistant cast steel doped with elements such as nickel or niobium. The ongoing trend toward electrification has, however, decreased the use of cast steel.

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

Sintered materials are created using powder metallurgy, a process in which the metal material in powdered form is poured into a mold in the shape of the desired part, compacted at high pressure, and then sintered. This results in a product that is in its final or almost final shape. Therefore, it has excellent material yield, and provides a high degree of freedom in the material design. However, resource-related risks have spurred the development of technologies that provide an alternative to the nickel used in high strength sintered materials. More recently, laser has been used to melt a copper-based powder and pad the cylinder head in laser clad valve seats for the purpose of improving engine performance.

At the same time, many magnetic parts are manufactured by sintering. For example, neodymium sintered magnets that possess a high level of saturation magnetization are widely used for in-vehicle motors, including the drive motors in electric vehicles. Until now, 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 and other risks have spurred the active development of alternative technologies as well as research on the mechanism that generates the coercive force forming the basis of those technologies. Advances in the development of grain boundary phase modification and grain refinement technologies, in particular, have 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

Aluminum has a low specific gravity about one-third that of iron, as well as excellent corrosion resistance and 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 electrification is creating growing interest in expanding the use of lightweight aluminum parts to extend cruising range. In addition, the use of multi-materials for frame members is expected to increase.

It is important to develop technologies for joining dissimilar materials such as steel and CFRP, and to prevent contact between 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.

Recycled material, which consumes substantially less energy than new ingots, in increasingly used to mitigate CO_2 emissions during material manufacturing as part of measures to achieve carbon neutrality. Sources of material to recycle include the press scrap produced in press factories and the process scrap material produced at aluminum manufacturer facilities. Aluminum sheets using such materials are gradually being mass produced.

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

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 are viewed as promising lightweight structural materials due to their high specific strength and specific rigidity, the many challenges they present, such as poor corrosion and heat resistance, as well as inferior plastic workability, have limited their adoption in comparison to aluminum alloys. Steering wheel cores, cylinder head covers, engine oil pans, and other die cast parts represent the main parts using magnesium alloys. They only see extremely limited use as wrought material in parts such as roofs. Industry–academia collaborative research aimed at spreading their adoption is taking place, creating expectations that the various issues will be resolved through, for example, the development of alloys that enhance the formability of wrought materials.

4 Nonmetallic Materials

4. 1. Ceramics

Ceramic materials used in automotive parts are classified into structural and functional ceramics depending on their characteristics and applications.

Structural ceramics are silicon nitride and other materials with characteristics such as excellent wear, heat, and corrosion resistance. They are used, for example, in the turbine rotors in turbochargers and the tips of rocker arms.

Functional ceramics usage has expanded beyond the electroceramics providing the high insulation, high electrical conductivity (ionic conductivity), piezoelectric, and other characteristics of sensors such as oxygen, NO_x, and knock sensors to include, more recently, functional materials that fulfill roles such as the high thermal conductivity filler in the thermal transfer interface material of electronic substrates.

Cordierite, with its excellent thermal shock resistance (low thermal expansion), and silicon carbide, with its excellent thermal shock resistance and high thermal conductivity, are the main ceramic materials used in catalyst carriers for exhaust gas treatment and in particulate collection filters.

4. 2. Plastics

Plastic materials are lightweight and have excellent shape flexibility, and even more sophisticated material compositions, structural designs, and processing methods are being developed and applied as vehicle electrification and weight reduction expands the number of locations where plastics are used.

At the same time, the need to address carbon neutrality, the circular economy, and CASE is prompting 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 take a step beyond conventional environmental action, 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.

In the exterior painting process, offering customers the popular two-tone colors, as well as environmental considerations such as reducing CO_2 are drawing attention to pigmentation and decorative film as technologies that provide an alternative to painting. Both pigmentation and decorative film decrease the number of painting processes, and also distinguish themselves by their design expression potential, such as piano black tones for pigmentation, and carbon tones, hairline tones, and texture for decorative film.

(2) Interior Parts

In vehicle interior parts, the need for weight reduction is growing in response to the increase in the 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 becoming more common.

Due to the slow 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, 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 viewed as carbon neutral compared to materials using petroleum as a raw material because they use a woody raw material that only releases the fixed amount of carbon dioxide absorbed during tree growth into the atmosphere. Currently, ways to use them as resin-reinforced fiber have been reported. Door trim base material made of kenaf-mixed resin and resin containing reinforcing fibers of thinned cedar wood has been produced. Biomass raw materials have entered the market in the form of 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 some products consisting of a mixture of petroleum-derived and non-petroleum-derived raw materials to be declared as non-petroleum-derived material products based on the amount of non-petroleum-derived raw materials used. In addition to mass-balanced polypropylene (PP) and polyethylene (PE) made from bio-naphtha, mass-balanced polycarbonates (PC) have also been introduced into the market.

Plastic materials obtained from material or chemical recycling are also an area of focus in response to demand for both carbon neutrality and the circular economy as part of measures to reduce the burden on the environment. A growing number of parts is making use of recycled materials.

(3) Powertrain and Electric Drive Unit Parts

Among plastics, polyamide (PA) offers a relatively high heat resistance and is therefore used for some engine parts such as intake manifolds and radiator tanks. In the transmission as well, some models are switching to plastic for parts such as side covers in an attempt to reduce weight.

Various kinds of plastics are also used in FCEV fuel cell units, which show promise as next-generation powertrains. In particular, the majority of hydrogen tanks used to store high-pressure liquid hydrogen are made of CFRPs. The tank known as Type 4 used in some FCEVs also uses plastic materials in the liner that serves as a barrier for the hydrogen. Making FCEVs more widespread will require lowering the cost of those materials, as well as making further performance enhancements.

Many plastic materials are also used around batteries for BEV. Some water-based cooling systems use high resistance cooling fluid, and the plastic for the pipes require low elution material that prevents ion elution to maintain the resistance of the cooling fluid.

4. 3. Rubber

Rubber materials have unique viscoelastic properties and constitute an irreplaceable material for functional parts. Examples include vibration-absorbing rubber in parts such as tires, hoses, weather strips, mounts, and bushes, and seals in parts such as O-rings and gaskets.

The requirements for tires include a longer service life, as well as balancing the contradictory demands of both reduced rolling resistance and improved wet grip performance. With the ongoing electrification of vehicles, the downsizing of tires (larger diameters and narrower width) is now perceived as necessary to improve both fuel economy (low electricity consumption) performance and the quietness performance that suppresses road noise. Tire manufacturers are working hard to achieve those required tire performances, with development starting at the raw material stage. Technologies that improve silica dispersion characteristics based on polymer denaturation and other technologies will be key to improving the above tire characteristics.

The tightening of vehicle exterior noise regulations has raised the expected value on rubber products intended to reduce noise. Hood seal use in engine compartments, which are the primary source of noise, is becoming more common, and there is also demand for tires that produce less noise.

Gaskets made of EPDM are used in the seals for the cells in the FC stacks used in FCEVs. However, mass-production capability and cost reduction considerations are also bringing about a switch to plastic three-layer seats. Faster rubber production will be a challenge in terms of making FCEVs more widespread.

4. 4. Glass

In addition to basic performance such as safety and visibility, the development of automotive glass is also expected to provide advanced functions such as weight reduction, appealing design, and greater in-vehicle comfort with respect to CASE and MaaS. In that context, glass offering excellent soundproofing, glass with high infrared light blocking performance, glass with both superior ultraviolet light blocking performance (approximately 99%) and infrared light blocking performance, glass featuring electric control of incident light, windshield glass capable of displaying information, and other types of glass, have been developed and commercialized. There are also cases where the design characteristics of chemically tempered glass have led to applying it to interior decoration or on-board display screens.

Resin is also starting to be used in for the glass in parts such as large panoramic roofs and rear windows for the purpose of reducing weight. At the same time, low-cost coating technologies are being developed to address issues such as weather, scratch, and wear resistance.

4. 5. Paint

Automotive painting is not only expected to offer design and functionality, but also to address environmental issues and adapt to CASE, and is even prompting calls for initiatives to build a new value chain.

Even as highly stylish colors and matte tone styling that target high orientation pigments continue to be developed and perfected, the goal of achieving carbon neutrality is leading to efforts to introduce paints that only use one preheating step to shorten processes, low temperature curing paints to lower the drying furnace temperature, and paints that reduce the need for air conditioning to decrease air conditioner energy consumption. In parallel, possibilities such as films and in-mold painting technologies providing an alternative to paint, as well as pre-colored resin technology, are being explored.

Similarly, life cycle assessment considerations have prompted initiatives to develop paints that use biomass raw material to reduce the CO_2 emitted by materials and manufacturing.

Adapting to CASE involves tackling the challenge of balancing styling with painting technologies compatible with other technologies such as plastic outer panels, or lidar and millimeter wave radar.

Paints that can be applied and removed, as well as ultra water repellent paints, are also being studied for the purposes of creating added value in subscriptions and building a new value chain.

Resource recycling technology is one of the new technologies that will be required to realize a circular economy.

4. 6. Structural Adhesives

Vehicle body joints no longer consist only of spot welds. Using a combination of structural adhesives and weld bonding has recently been spreading in Japan as well. The concurrent use of those structural adhesives helps improve vehicle body rigidity as well as aspects of vehicle performance that enhance running stability. More recently, structural adhesives offering new functionality in the form of damping properties that help reduce vibration are coming into use. Due to their viscoelastic and insulating properties, structural adhesives represent a promising means of achieving weight reduction, or joining dissimilar materials in electric-powered vehicles. Studies to improve durability and other aspects of reliability, as well as to contribute to achieving carbon neutrality and a circular economy, have been initiated.

References

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