Materials

1 Introduction

The Japanese automotive industry has faced repeated hardships in recent years, starting with the financial crisis that occurred in the wake of the collapse of the Lehman Brothers financial services firm in 2008, the Great East Japan Earthquake, and the extreme appreciation of the yen. However, in 2013, the underlying appreciation of the yen underwent a correction and the Japanese economy appears to finally be back on course toward recovery. Materials are still the key element for ensuring basic vehicle quality. However, there are also strong demands for the development of new materials technologies to help improve environmental performance, reduce weight, enhance safety, and improve comfort. At the same time, there is great expansion in the local procurement of materials, especially in emerging markets. This article outlines the technological trends in automotive materials in 2013.

2 Ferrous Materials

2. 1. Steel sheets

Steel sheets are one of the most important automotive materials and account for approximately 40% of the entire vehicle weight. The uses of steel sheets can be broadly classified as follows: (1) parts for the vehicle frame, (2) outer panels, (3) chassis and drivetrain parts, and (4) motor parts.

2. 1. 1. Body frames

Technologies to greatly increase the strength of these parts have been developed and adopted to reduce vehicle weight while enhancing collision safety. Steel sheets for cold stamping been gradually developed and 590, 780, and 980 MPa class high-strength steel sheets are now available. In particular, there has been increasing use of 980 MPa class high-strength steel sheets to reinforce center pillars and roof side rails. Another development is ultra-high-strength 1,180 MPa class steel sheets with ductility at least equal to 980 MPa class high-strength steel sheets. These have also been adopted in some cases. 980 MPa class high-strength steel sheets and 1,470 MPa class ultra-high-strength steel sheets with almost the same formability as 590 MPa class steel sheets have also been developed. The use of increasingly high-strength steel is expected to expand even further. In addition, Europe is leading the way in the hot stamping of very high strength 1,470 MPa class steel sheets. In this case, the metal is formed while it is extremely hot and then quenched through contact with the die. The issue of low productivity has been addressed by a direct quenching method that passes quenching water between the surface of the die and the sheet. This method has been adopted for forming center pillar reinforcements. European manufacturers have also adopted a method of hot stamping and steel sheets with different strengths and joining the sheets by laser welding. Japanese manufacturers are also increasingly adopting 1,800 MPa class hot stamping steel sheets for bumper beams. In addition, high-frequency induction hardening technology has been developed for three-dimensional hot bending of 1,470 MPa class steel pipes. This material has been adopted for cross member frames. Technologies such as this, which do not require a die, will likely become noteworthy trends in the near future.

2. 1. 2. Outer panels

Outer panels are required to have a high degree of formability and surface quality to realize an appealing design. Interstitial free (IF) steel has been widely adopted to meet these requirements due to the low amount of impurities and the high formability of IF steel sheets. In contrast, parts requiring good dent resistance have adopted bake-hardening type high-strength steel, which increases yield strength through a paint baking process, to help reduce vehicle weight. This material mainly consists of 340 MPa class steel sheets, but 440 MPa class steel has also been adopted and steady progress is being made to further reduce material thickness.

2. 1. 3. Chassis and drivetrain parts

Chassis parts are safety-critical and have strict requirements for strength, stiffness, durability, and corrosion resistance. However, the use of high-strength steel sheets is not as widespread in these parts as in vehicle frame parts. 590 and 780 MPa class high-strength steel sheets is used for lower suspension arms due to its high hole expandability, while 980 MPa class high-strength steel sheets has been adopted for use in steel wheel rims. However, 440 MPa class steel sheets are still the main materials used for chassis parts. Several types of steel sheets have been developed as high-strength materials for chassis parts since these materials are required to have a variety of formability characteristics, including stretch flangeability and hole expandability.

In the case of drivetrain parts, hydroforming technology has been used to form an integrated axle housing from a single steel pipe and reduce weight. The use of triple tube expansion technology to integrally form welded structural components with steel pipes has achieved a 10% reduction in weight.

2. 1. 4. Motor parts

High-strength electrical steel sheets are key materials for motors in EV, HEV. A type of this material with both good endurance strength and low core loss at high rotation speeds has been developed to reduce motor size and weight. Additional development that aims to further improve performance and reduce size is also being promoted.

2. 2. Structural steel

Structural steel is machined after forging and then subjected to a combination of heat treatments and other processes to ensure that the parts have the required strength, toughness, and durability before being used in powertrain and suspension components. In the past, technologies were developed to combine rare metals with steel to increase strength and eliminate quenching and tempering (microalloyed steel). This approach was changed due to escalating prices of rare metals, and now materials are being developed that greatly reduce or eliminate the rare metal content without adversely affecting the strength of other characteristics of the steel.

2. 2. 1. Engine parts

The use of induction hardening on the fillet parts of crankshafts is advancing. Conventionally, a surface rolling process was used to bend the parts and increase fatigue strength through compressive residual stress. More recently, these parts are reinforced using high residual stress through induction hardening. As a result, standard materials can be used instead of high strength materials. Molybdenum was also added to high-strength crankshaft parts manufactured by a gas soft nitriding trentment. However, a high-strength gas soft nitriding steel that does not rely on the addition of molybdenum was adopted by increasing the amount of general purpose manganese and achieving precipitation hardening through manganese nitride. The addition of turbochargers and other parts to diesel engines has created a more severe environment for the sliding parts in those engines. Therefore, these parts are precipitation hardening by adding molybdenum and vanadium to the steel during the soft nitriding process. This was done to increase wear resistance and strength, while also considering part formability.

2. 2. 2. Drivetrain parts

Conventionally, rare metals, such as nickel and molybdenum, were added to carburized gear steel to increase strength. However, a review of hardening methods and the optimization of chemical camposition led to the development of a new high-strength structual steel for gears that contains no rare metals and has the same strength as conventional rare-metal steel. The addition of aluminum and vanadium to gas soft nitriding steel slightly decreases the gear tooth surface fatigue limit compared to carburized parts, but a high-strength gas soft nitriding steel with equal gear tooth root bending fatigue strength has been developed. Vacuum carburizing has also been introduced in Japan as a method to streamline the heat treatment line. A small-lot heat treatment furnace was developed that makes it economically viable to carry out heat treatments on small amounts of parts in a short time.

2. 2. 3. Chassis parts

An inexpensive steel spring with shear strength in the 1,200 MPa class that contains low amounts of nickel and is completely vanadium free was adopted by optimizing the chemical composition of high-strength suspension spring steel. In addition, further material development to increase strength is still in progress.

2. 3. Stainless steel

Since stainless steel has excellent heat and corrosion resistance, it is often used in the exhaust system and for decorative molding. Ferritic and austenitic stainless steels are the most common materials. Ferritic stainless steel is inexpensive because it does not contain nickel. It also has excellent heat fatigue characteristics, which is why it is often used for parts in the exhaust system. The ferritic stainless steel used for the exhaust manifold is precipitation hardening through the addition of copper. This greatly reduces the amount of molybdenum without any reduction in high-temperature strength. Highly formable stainless steel sheets using this material to save resources have been put into practical use. SUS444 is well known for its resistance to high exhaust temperatures and poor formability. However, it was found that formability could be improved by adding a combination of niobium and titanium and controlling the microstructure. This material has now been adopted.

Austenitic stainless steel is used in places such as the interior of double-pipe exhaust manifolds and exhaust gas recirculation (EGR) coolers, where even higher high-temperature strength and corrosion resistance characteristics are required.

2. 4. Cast materials

Castings can be easily shaped into a variety of forms, and parts with complex shapes can be mass-produced. Castings are also inexpensive and have excellent formability, wear resistance, and damping properties. As a result, these materials are widely used for powertrain and chassis parts.

Castings are used for powertrain parts such as cylinder sleeves, camshafts, and crankshafts, as well as chassis parts such as knuckles, brake rotors, and various types of arms. For chassis parts, a 600 MPa class spheroidal graphite cast iran with high strength and toughness has been adopted for suspension arms, while other efforts have been made to greatly reduce the weight of parts that use 380 MPa class material. Conventionally, 380 MPa class materials were often used for toughness, but modifications to the chemical composition, such as silicon, manganese, and copper, as well as the application of heat treatments have achieved materials with both high strength and toughness.

2. 5. Ferrous powder metals

The molding and sintering of powder metal directly into the final product or a shape that is very close to that of the final product is well-known. Sintering is also regarded as an economical manufacturing process since it enables a large degree of freedom in the composition of alloys and material microstructures. Utilizing these advantages, sintered materials are often used in mechanical structural parts, heat and wear resistant parts, and magnetic parts.

Some examples of mechanical structural parts that use sintered powder metals are connecting rods, planetary carriers, and clutch hubs. Examples of sintered heat and wear resistant parts are valve seats and axle bearings. Sintered magnetic parts are used in motor cores and magnets of motors for EV, HEV.

Conventionally, rare metals such as nickel and molybdenum were often added to increase the strength of materials used for mechanical structural parts. However, the development of new materials is advancing and the effective use of chromium is being promoted as an alternative, low-cost element. Although it was difficult to use sintered parts for heat and wear resistant parts due to the high temperature usage environments of these parts, the development of new materials has made this possible. Recent developments have also improved the magnetic characteristics of magnetic parts and the development of a method to form a motor core into a difficult near net-like shape has also been making progress.

Motors used in EV, HEV require magnets, and a new neodymium magnet has been developed with equal or superior high-temperature performance to other magnets without the use of dysprosium which is rare earth metals. The next aim is to adopt these magnets in motors within three years.

3 Nonferrous Metals

3. 1. Aluminum alloys

Aluminum alloys have a specific gravity approximately one-third that of steel, high thermal conductivity, and excellent corrosion resistance. As a result, these materials are used in body, power plant, and chassis parts, and the number of aluminum alloy parts is expected to continue increasing. Aluminum alloy sheets used for body parts include 5000 series alloys, which have good formability, and 6000 series alloys, which can be bake hardening. These alloys are used for vehicle hoods, doors, and roofs. Conventionally, research focused on improving the formability and strength of these alloys. However, in recent years, the focus has switched to reducing energy usage and CO_2 emissions during manufacturing. A new continuous casting process that reduces energy usage by approximately 30% is now used to manufacture aluminum alloy sheets. This aluminum alloy has been adopted for use in hood inner panels. When aluminum alloy sheets are used for body parts, the dissimilan metal joining for steel sheets. must be considered. Currently, mechanical joining plus an adhesive and friction stir spot welding have been adopted as the easiest countermeasures against galvanic corrosion. However, the delta spot resistance welding method adopted in Europe has attracted attention in Japan as a new metal joining method with good joint interface strength.

The material used for diesel engine cylinder heads must have a high thermal fatigue strength. A recycled alloy ingot with the same thermal fatigue strength as a new ingot of aluminum alloy has been developed by optimizing the amounts of added copper and magnesium. The application of structural aluminum bolts for drivetrain parts is advancing in Europe, and these parts have even been adopted in Japan for fastening parts such as transmission cases. It is possible to use the same number of aluminum bolts for fastening as steel bolts, but with a weight reduction benefit of 300 grams.

In the case of chassis parts, castings are mainly used for knuckles, while forgings are mainly used for lower and upper arms. A 6000 series alloy with excellent strength and corrosion resistance has been adopted as a forging material to help reduce weight. This alloy was then further strengthened to give it a tensile strength of 400 MPa. Additional research is now under way into manufacturing technologies andded element adjustment to increase the strength of this alloy even further. In addition, a friction stir welding technique was applied to join together the sub-frame of a hybrid structure using steel and aluminum. Consequently, a hybrid sub-frame was adopted that is lighter and stiffer than a structure fastened using bolts.

3. 2. Magnesium alloys

Magnesium alloys have a specific gravity that is one-quarter that of steel and two-thirds that of aluminum alloys. It is the lightest automotive structural metallic material. These alloys have a high specific strength, as well as excellent thermal conductivity, heat dissipation, electromagnetic shielding, vibration absorption, and recyclability. However, issues include flammability, poor corrosion and heat resistance, low plastic formability, and high cost. Consequently, magnesium alloys have not become as popular and widely used as aluminum alloys. The majority of practically adopted magnesium alloy parts are die castings (a high-pressure casting method). In addition, other cast parts also use the thixomolding method (a semi-solid injection molding method). Automotive parts that use magnesium alloys include steering wheel cores, cylinder head covers, and oil pans.

A cast and forge method has been developed that casts the magnesium alloy into a preformed shape close to the desired final shape and then uses forging to finish the piece and increase strength. A low-temperature forging technology was developed that uses a forging temperature of 200℃ to reduce cost, improve the precision of the forging process, and enable the use of this material in heat sinks and other parts. A low-cost manufacturing method was also developed that applies a highly productive continuous casting process. Since there is a strong continuing need to reduce the weight of various parts, magnesium alloys will be adopted for applications that take advantage of the merits of these materials. The use of such alloys is likely to continue to gradually increase.

4 Nonmetallic Materials

4. 1. Ceramics

Ceramics used in automotive parts are largely classified into structural ceramics, which are used in engine parts, and electroceramics, which are used in various sensor components.

Structural ceramics are hard, have excellent heat and corrosion resistance, and are lighter that steel. As a result ceramics have been adopted in glow plugs, turbocharger turbine rotors, and tappets. Structural ceramics are made from silicon nitride.

Electroceramics have been adopted for use in spark plugs, oxygen sensors, NOx sensors, and knock sensors. Materials such as alumina-zirconia are used.

Porous cordierite is used for the honeycomb catalyst used to treat exhaust gases due to its excellent temperature elevation capability and thermal shock resistance. Cordierite and silicon carbide, among other materials, are used in diesel particulate filters (DPFs) due to the excellent heat resistance of these materials.

The main automotive applications of ceramic materials are in parts related to the exhaust system. Although shipments of these parts have expanded greatly, the number of structural ceramic parts has declined. Further research and development is expected in the future.

4. 2. Plastics

The usage-to-weight ratio of plastics in a passenger car is around 10% and is likely to continue increasing due to the lightness and excellent design properties of plastics. In particular, parts modularization is advancing by utilizing the many advantages of plastics, such as high stiffness and strength, thin structures due to high fluidity, and shape design flexibility.

The use of recyclable and plant-derived plastics is also increasing as these materials are seen as environmentally friendly and a way for automakers to address environmental and energy issues.

Carbon fiber is a promising future lightweight material for vehicles. Active research is taking place to develop composite materials using carbon fiber for structural components.

4. 2. 1. Exterior parts

Materials made from polypropylene (PP) have good formability, cost performance, and an easily adjustable balance of physical properties. As a result, PP has been adopted for use in bumpers and a wide range of exterior parts. Although Japanese manufacturers make less use of these materials in outer panels than in the U.S. and Europe, PP materials have been adopted in some fender, hood, and back door panels.

The development of surface treatment technologies that enhance scratch and weather resistance is advancing, and polycarbonate (PC) materials have now been adopted for use in some sunroofs and quarter glass. This material is likely to be adopted in an expanding range of parts in the future as hard coating manufacturing technologies continue to evolve and further improvements in abrasion resistance are achieved.

Additionally, sheet molding compounds (SMC) and carbon fiber reinforced plastics (CFRP) are being adopted for use in some parts with horizontal surfaces that require good stiffness, such as hoods and roofs. In particular, CFRP is being used for both outer body panels and structural body members. Further technological development is aiming to reduce material cost and shorten forming lead-times, which will help to expand the application of CFRP to mass-production vehicles.

4. 2. 2. Engine parts

The development of polyamide (PA) materials with excellent heat resistance has enabled the application of plastic materials to engine parts such as the intake manifold, cylinder head cover, and parts surrounding the thermostat. In recent years there has also been greater application of plastic materials to air intake and cooling system parts to reduce cost and weight. PP materials have also been widely adopted in parts that do not require good heat resistance.

Research and development is also underway to apply materials such as aromatic PA and polyphenylene sulfide (PPS) to functional parts since these materials are capable of withstanding even harsher usage environments. In some cases, these materials have been adopted for use in intercooler tanks and electronic throttles.

4. 3. Interior materials

The development of interior plastic materials is aiming to improve the feel of material textures to offer a more comfortable interior space. Low-gloss materials with good scratch resistance and a better tactile sensation are being developed along with a variety of surface treatment technologies. Weight reduction measures are also making progress to help improve fuel efficiency. Plastic materials with good stiffness and high fluidity that can help to reduce product thickness are being developed along with suitable materials for injection foam molding.

The development and application of carbon-neutral plant-derived materials is also making progress. In some cases, polylactic acid-based plastics are being adopted after improving certain properties, such as heat and impact resistance. Other materials such as bio-polyethylene terephthalate (bio-PET) have also been developed after improving durability, and adopted in items such as seat fabrics and carpeting. Plant-derived plastic materials do not have as long a history as petroleum-based plastics, and there are still many issues to be resolved related to supply systems and cost. However, these materials are expected become more widely used in the future.

4. 4. Rubber

Rubber has unique viscoelastic properties and is an irreplaceable material for functional parts. For example, rubber is used for tires, hoses, and weather stripping, while vibration isolating rubber is used for engine mounts and bushings.

In tires, the rubber mixture is designed to generate a viscoelasticity that reduces heat generation and rolling resistance, while the development of fuel-efficient tires with improved wet grip performance has also made progress. In 2013 a 100% petroleum-free tire made only from natural resources was developed without relying on fossil-fuel resources such as oil and coal, which are the main raw materials of current tires.

Conventionally, fuel system hoses were made from metal pipes. Plastics have now been adopted to reduce weight, and efforts are also underway to improve compatibility with biofuels.

For weather stripping, low-foaming ethylene-propylene-diene-monomer (EPDM) rubber parts have been widely adopted to reduce weight and cost. This material helps to reduce the size of weather strips and enables the use of thinner metal inserts.

Automotive mountings and bushings use vibration isolating rubber materials, and there are increasing demands for smaller and lighter versions of these parts. The development of highly durable rubber materials is progressing. Vehicle markets are extending into regions with very harsh and hot environments, resulting in growing demand for rubber parts with better durability and reliability, as well as additional functions such as vibration and noise reduction.

4. 5. Glass

The basic functions of automotive glass include collision safety and visibility. Development is also focusing on occupant-friendly functions such as the blocking of ultraviolet and infrared light. In recent years, strong ultraviolet and infrared light blocking capabilities have been applied to front door glass as well as windshield glass by combining glass with special films. In 2013 the application of this technology was expanded to all vehicle models, from standard mid-size vehicles to small vehicles and mini-vehicles.

Some vehicle models use a large plastic panorama roof to reduce weight. Many other ideas have been put forward that take advantage of the merits of plastics. These include generating electricity via solar cells incorporated into a plastic roof and improving the design of the vehicle through the integral molding of a plastic roof, shark fin-style antenna, and high-mounted brake lights into a single piece.

4. 6. Paint

Recent years have seen an expansion in the use of design-specific exterior colors and two-tone roofs to enhance the product appeal of vehicles. Combinations of different colored interior and exterior parts have also grown in popularity, and are mostly found on mini-vehicles. This demonstrates the growing importance of paint.

There has been a change in the chemical conversion treatment of electrodeposition coatings used on body painting lines. A zirconium oxide-based chemical conversion coating agent that does not contain phosphorous and nickel has been adopted. This change has been expanding gradually, mostly in the U.S. and Europe. The adoption of electrodeposition coatings with high throwing power is also being advanced to help ensure quality.

In the case of primer and top coats, a more environmentally friendly (low volatile organic compounds (VOCs) and CO_2) waterborne wet-on-wet process has been adopted. Top coat bases that also function as a primer have been developed, thereby promoting the elimination of the primer and the development of primer-free painting processes. In 2013, top coat bases with even more advanced functions have been developed that are compatible with all paint colors.