Materials

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1 Introduction

The business environment of the Japanese automotive industry is undergoing a period of major change heralded by the extreme appreciation of the yen after the global financial crisis in 2008, the Great East Japan Earthquake in 2011, the expansion of production and sales in emerging markets, and the growing popularity of next-generation environmentally friendly vehicles such as hybrid, plug-in hybrid, electric, and fuel cell vehicles. The field of automotive materials is also adapting to these changes. In addition to the conventional requirements for materials as the basic building blocks of a vehicle, new technological development has become necessary to meet the need for higher levels of local procurement, reduced usage of scarce resources and controlled materials, identification of replacement materials, and so on. Consequently, materials are playing an even greater role in vehicle development than ever before. This article outlines automotive material trends in 2012.

2 Ferrous Materials

2. 1. Steel sheets

Steel sheets remain the most important automotive material type, accounting for 40% of a vehicle's weight. In general terms, the aims of material development are to reduce weight and ensure collision safety performance while simultaneously reducing costs. One particular focus of recent papers is technical development that does not depend on material replacement. This incorporates efforts to optimize structures and includes the proposal of next-generation environmentally friendly vehicles using high-strength steel for 97% of the white body (1)(2). In this development, applicable components for steel materials are broadly divided into four categories: (1) parts for the vehicle frame, (2) outer panels, (3) chassis parts, and (4) motor parts.

The vehicle frame must be deformation-resistant to absorb the energy of an impact and to ensure the cabin space. For this reason, high-strength steel with a tensile strength in excess of 340 MPa is commonly used. In addition to conventional dual phase materials, transformation induced plasticity (TRIP) steel sheets using retained austenite, and steel with a trip aided bainitic ferrite (TBF) microstructure have also been recently developed. These advances are primarily for 590 MPa class materials, but also include 780 MPa and 980 MPa class materials (3). There is also growing application of hot stamping materials (i.e., steel that can be heated and then simultaneously formed in a die and quenched). One report describes the use of 1,800 MPa class hot stamping steel for bumper beams (4). Research is also examining how to control the microstructure of 2,000 MPa ultra high-strength steel (5). In Europe, more parts are incorporating tailored rolled blanks (TRB), which are capable of modifying part thicknesses at the appropriate locations (6).

Outer panels require high formability and surface quality to achieve attractive designs. Interstitial free (IF) steel is widely used to meet these requirements due to the low amount of impurities and high formability of IF steel sheets. Since some exterior parts must be dent resistant, bake hardened high-strength steel sheets are used for these parts. The yield strength of this steel is increased in a bake hardening process after forming. Making these sheets thinner is one way of reducing weight. These sheets mainly use 340 MPa class materials, with some already adopting 440 MPa class materials.

Chassis parts are safety-critical and have strict requirements for strength, stiffness, durability, and corrosion resistance. The use of high-strength steel is not as widespread as in the vehicle frame. Most chassis parts use 440 MPa class materials, with some using 590 MPa or 780 MPa class materials. At the same time, forming processes for chassis parts frequently include bending, stretch flanging, and hole expansion. Therefore, in addition to precipitation hardened steel, high-strength chassis

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materials are manufactured by controlling the microstructure and fine precipitates to achieve both ductility and localized stretching (i.e., hole expansion formability).

Magnetic steel used in the drive motors of hybrid and electric vehicles requires good formability and high strength in addition to magnetic properties such as a high magnetic flux density and low iron loss. Therefore, development is aiming to improve performance by adjusting alloying components, controlling crystal orientation and size, and so on.

Another recent characteristic of steel sheets is globalization. As demand increases in Asia and other emerging markets, Japanese and Korean steel manufacturers (including technological tie ups with other companies) are steadily building more plating lines (continuous galvanizing lines (CGL)) and continuous annealing lines in Thailand and India.

2. 2. Structural steel

Structural steel has an excellent balance between material properties (such as strength and reliability) and cost. This type of steel is mainly used for strength parts in the powertrain, suspension, and the like. In addition to the use of higher strength steel to reduce weight, recent trends include a switch from special steels with a high content of rare metals such as molybdenum (Mo), niobium (Nb), and vanadium (V) to standardized steels with a low additive content to reduce costs.

For engine parts, efforts are aiming to reduce heat treatment costs and CO_2 emissions in the manufacturing process by adopting microalloyed steel for heavy individual parts such as the crankshaft. However, fillet parts that require high fatigue strength are partially hardened in after-treatment processes such as surface rolling, nitriding, or induction hardening. Technology is being developed to lower the manufacturing cost of connecting rods. These efforts include the adoption of heat cracking to reduce the number of processes, and improving the accuracy of the matching surface between the engine and transmission by adopting a heat cracking fracture surface to eliminate the use of positioning pins (7).

In addition to the adoption of stronger materials, the development of drive system parts is focusing on increasing the number of transmission shift speeds to enhance product appeal, and the reduction of size and weight. Gears are one of the critical parts in a transmission and efforts are being made to improve the fatigue strength of the bottom of gear teeth, and the pitching resistance and wear resistance of gear teeth surfaces. These include the development of new steel materials, heat treatments such as vacuum carburizing and high-carbon carburizing, and surface reforming technology such as shot peening. Furthermore, as belt-driven CVTs become more widely adopted, it is important to improve the reliability of metal CVT belts. Although conventional metal belts use tough maraging steels, efforts are under way to improve fatigue strength by reducing the particle size of the titanium nitrides contained in the steel (8).

Spring steels used in the suspension, engine, and the like require particularly high fatigue strength. Shot peening is a key process for these steels to generate compressive residual stress. Further increasing and deepening the area of compressive residual stress is a multi-stage process and requires two or even three applications of shot peening. Spring steels that use fewer rare metals are also being developed (9).

2. 3. Stainless steel

Since stainless steel has excellent heat and corrosion resistance, this material is generally used for the exhaust manifold, parts in the exhaust gas recirculation (EGR) system, as well as for the muffler and other exhaust system components.

Ferrous stainless steel is inexpensive since it contains no Ni. It also has high thermal fatigue strength, which means it is widely used in the exhaust system. In contrast, austenitic stainless steel is used for parts that require higher temperature strength and greater corrosion resistance (such as the inner pipe of double-pipe exhaust manifolds, EGR coolers, and the like).

However, elements such as chromium (Cr), Ni, and Mo used in stainless steel are expensive. Consequently, recent developments have concentrated on lower cost materials that use additives such as copper (Cu) and tin (Sn) to reduce the rare metal content. Greater adoption of these materials is likely in the future (10).

2. 4. Cast materials

Castings have a high degree-of-freedom (DOF) for shape design and excellent formability. In addition, castings are also reasonably priced and have excellent wear resistance and damping properties. Consequently, castings are widely used for engine, drive train, and chassis parts.

Engine castings include turbine housings, crankshafts, camshafts, and the like. Drivetrain castings include the differential case, and chassis castings commonly include

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brake rotors, arms, and the like. However, rapidly cooling molten cast materials causes brittleness and the formation of white cast iron microstructures with large heat shrinkage. For this reason, castings are regarded as challenging to weld. Therefore, research and development is under way into joining methods such as solid-phase bonding using friction stir welding, which takes place at below the melting point of the material (11). Welded structures featuring drivetrain parts (ring gears) and the differential case have recently been developed.

In the case of spheroidal graphite cast iron, spheroidizing and inoculation agents used to create the spheroidal graphite play a key role in increasing productivity and quality by extending the fading time of welding, suppressing chilling, increasing the number of graphite grains, and so on. Issues such as rising prices and the difficulty of securing stable supplies of rare earths, such as cerium and lanthanum, which are included in these spheroidizing and inoculation agents, have accelerated studies into ways of reducing rare earth usage and the identification of alternatives.

2. 5. Ferrous sintered materials

Sintered materials are compatible with near net shape forming, which allows the number of processes to be reduced. Sintered materials also have a high DOF for the configuration of the material by changing the raw material powder composition. Taking advantage of these merits, sintered materials are used for mechanical structural parts such as connecting rods, planetary gears, clutch hubs, sprockets, parts requiring abrasion resistance such as valve seats and bearings, as well as for magnetic parts. In addition to further reducing the number of processes for mechanical structural parts (12), the addition of plastic working is being studied to help resolve the issue of lower strength compared to molten metals in gears.

For parts requiring abrasion resistance, sintered materials with greater corrosion resistance against types of gasoline used outside Japan that contain a higher proportion of impurities such as sulfur are also being used in bearings (13).

For magnetic parts, sintered magnets that use 40% less dysprosium (a rare earth used as an additive to improve heat resistance) are being used in electric vehicle motors (14).

3 Nonferrous Metals

3. 1. Aluminum alloys

Aluminum alloys have a specific gravity of around 2.7, which is around one-third that of steel. These materials have various other merits, such as good thermal conductivity, formability, corrosion resistance, and recyclability. However, since the manufacturing costs of aluminum alloys are higher than steel, these materials are being phased in gradually. Initially, this means parts that can substantially enhance the product appeal of the vehicle by taking advantage of the unique material properties of aluminum. The adoption of aluminum alloys as an alternative to steel has spread in recent years to reduce vehicle weight. High-quality and low-cost technology to allow the adoption of aluminum alloy frame parts continues to be studied (19).

Since aluminum castings are comparatively high strength and have few internal defects, this technique is adopted for suspension parts such as arms and knuckles that require toughness and reliability. These parts mainly use 6000 series alloys with excellent strength and corrosion resistance. Efforts are under way to increase material strength to achieve further weight reduction.

Various types of lightweight materials including aluminum alloys are adopted in particular places around the vehicle to reduce weight, creating a multi-material structure. Consequently, the importance of technology to join aluminum alloys with other materials (i.e., dissimilar material welding) is increasing. In addition to conventional resistance spot welding, self-piercing rivets, and the like, other methods under development include friction stir welding (20), adhesive bonding (21), and so on.

3. 2. Magnesium alloys

Magnesium is the lightest practical automotive material. It has a specific gravity one-quarter that of steel and two-thirds that of aluminum. It is also useful in weight-saving designs due to its high specific strength and stiffness. For these reasons, it has been used in certain vehicles for some time. However, the practical adoption of magnesium is hampered by various technical issues such as corrosion resistance (galvanic corrosion), heat resistance, formability, and so on, which have limited possible applications. Countermeasures include the adoption of coating processes to improve corrosion resistance, applying surface treatment to steel bolts used for joining, and the interposition of aluminum washers

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with a smaller potential difference than magnesium. A common countermeasure in Europe against galvanic corrosion is to use aluminum bolts. Materials with higher heat and creep resistance (AE44, MRI153M, and the like) have been developed and adopted by adding calcium (Ca) or rare earths (22). Examples of current commercially available parts include steering wheel cores (AM60B) and cylinder head covers (AZ91D) that use generally available multi-purpose materials. In addition, a luxury sports car launched in 2007 also adopted an oil pan using a special heat-resistant material (MRI153M) (23). Some automakers are actively developing heat-resistant materials and adopting these materials in large parts. Examples include transmission cases (AS21), engine blocks (AJ62X), suspension members (AE44), and the like (22)(23), which are all die-cast products. However, there are still relatively few applications of magnesium since the cost of wrought materials such as sheets, extrusions, castings, and the like is extremely high, and the crystalline structure of magnesium complicates plastic working. However, in 2011, Semcon AB developed a new magnesium alloy called MnE21 and created a prototype center pillar and panels using hot stamping (24). General Motors (GM) also created a prototype rear deck inner panel using a 450°C hot stamping process in 2012 (25). These trends will likely draw attention in the future. Ongoing research and development includes studies into normal-temperature magnesium forming (26) and anodic oxidation to enable high corrosion resistance through self-reparability (27). Consequently, magnesium is still regarded as having the potential to meet the need for automotive weight reduction.

4 Nonmetallic Materials

4. 1. Ceramics

Ceramics used in automotive parts can be categorized as structural ceramics and electroceramics.

Structural ceramics are made from silicon nitride and have excellent wear, heat, and corrosion resistance. These materials are used in turbocharger turbines, rocker arm tips, diesel engine swirl chambers, and so on.

Electroceramics are made from alumina, zirconia, and the like, and have high resistance, electroconductance (ionic conductivity), and piezoelectric properties. These materials are used in spark plugs, oxygen sensors, NOx sensors (28), knock sensors, and so on.

Other materials include cordierite, which has excellent thermal shock resistance (i.e., low thermal expansion properties) and is used in the carriers of emissions treatment catalysts, and silicon carbide, which has excellent thermal shock resistance and thermal conductivity and is mainly used in diesel particulate filter traps.

4. 2. Plastics

The utilization of plastics in vehicles is steadily increasing due to the growing importance of mass reduction, the need for greater design DOF, lower costs, and so on. The DOF of shape design is a particular merit of plastics. In addition to interior and exterior style parts, more plastics are being used in functional parts as part modularization increases.

In addition, rising corporate awareness of global environmental issues means that the use of recyclable and plant-derived plastics is also increasing as an environmentally friendly measure.

Development is also actively focusing on carbon fiber as an extremely promising future lightweight material.

4. 2. 1. Exterior parts

Since plastics have excellent design properties and mass reduction potential, these materials are widely used for bumpers. Recently, polypropylene (PP), which provides excellent stiffness, impact resistance, and cost performance, has become the mainstream plastic. The excellent design properties and chipping resistance of PP means that this material is also widely used for rocker moldings, over fenders, back door panels, and the like (29).

Although there are fewer examples of plastics used for exterior panels in Japan than in the U.S. or Europe, development is continuing with the aim of achieving the same quality as steel sheets. This includes decreasing the coefficient of linear thermal expansion, as well as improving stiffness, heat resistance, and surface quality.

Polycarbonate (PC) is being used to manufacture plastic sun roofs and quarter glass. The use of this material is likely to expand in the future as manufacturers make progress in enhancing properties such as damage and weather resistance.

Some models have started to use carbon fiber reinforced plastic (CFRP) for flat surfaces such as the hood and roof. There are also many cases of CFRP developed for structural members. To widen the application of CFRP to mass-production vehicles, future technical development will have to achieve breakthroughs in material cost reduction and shortening forming lead-times (30).

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4. 2. 2. Engine parts

The development of polyamide (PA) materials with excellent heat resistance has enabled the application of plastics to engine parts such as the intake manifold, cylinder head cover, and radiator tank. In addition, recent developments have seen greater application to intake and cooling system parts to reduce cost and weight. In the fuel system, more vehicles are using blow-formed polyethylene (PE) fuel tanks, polyoxymethylene (POM) fuel pump modules, and the like for improved corrosion resistance and lower weight. Research is also under way to develop functional parts using super engineering plastics such as aromatic PA and polyphenylene sulfide (PPS), which are capable of withstanding even harsher use environments.

4. 3. Interior materials

The development of interior plastics is actively aiming to improve external appearance as a means of enhancing material textures. Low-gloss plastics with greater scratch resistance that can improve the appearance of the interior without applying a coating have been developed. Weight reduction measures are also making progress to help improve fuel economy. For plastics, this means adopting materials suitable for injection foam molding and developing stiff materials that can help to reduce product thicknesses.

Other recent trends include the development of artificial urethane leather as an alternative to real leather for seat coverings. This artificial leather is more durable and lighter than real leather. In addition, there are also moves to replace specific halogen flame retardants that are defined as a substance of concern (SOC). The development of carbon-neutral materials such as plant-derived biomaterial is also making progress (31). However, biomaterials are still more expensive than conventional petroleum-derived materials and full-scale adoption has not yet started. Accordingly, new ecological materials that combine economic and environmental performance, such as Bio-PET (polyethylene terephthalate) and the like have been developed and are starting to find applications as fiber covering materials for interior parts (32).

4. 4. Rubber

Rubber has unique viscoelastic properties and is an irreplaceable material for functional parts. For example, vibration isolating rubber is used for tires, hoses, weather strips, mounts, bushings and the like, and rubber is also for sealing parts such as o-rings and gaskets. Fuel economy is increasingly being included as a requirement for tires.

The adoption of rubber with low rolling resistance to tires is spreading due to the development of material mixture designs that substantially lower hysteresis loss through the addition of silica compounds and terminal-modified polymers.

In the case of vibration isolating rubbers for mounts, bushings, and the like, increasing demands for size and weight reduction are promoting the use of rubbers with greater durability and the optimization of adjoining metallic parts. Furthermore, heat resistance and other durability requirements are becoming more demanding due to the harsh heat environment in many markets such as those close to the equator. Consequently, rubber materials with superior thermal properties are also being developed.

Solid weather strips are being replaced by lightweight foamed materials with greater expansion ratios. Technology has been developed and incorporated into parts in practical use to resolve the trade-off relationship between expension rations and compression set or material strength.

For boots, dust covers, and similar parts, the use of thermoplastic polyester elastomers (TPEE) and other ester-based elastomers with excellent resistance against bending fatigue is growing as a replacement material for conventional chloroprene rubber (CR).

Conventionally, the inner tubes of fuel system hoses frequently used nitrile rubber (NBR). However, fluorocarbon rubber (FKM) or plastic tubes are now in general use to improve hose durability as fuels diversify and vehicle lifetimes increase.

4. 5. Glass

The basic performance requirements of automotive glass include safety and visibility. In addition, the development of glass parts must also consider style design and interior comfort. Reinforced glass with a similar ultra-violet and infra-red ray blocking performance (approximately 99%) as the laminated glass used for windshields has been developed and adopted for front door glass (33).

Large plastic panorama roofs and quarter panels have also started to enter use as a means of reducing weight. However, since these materials still have issues in terms of weather, damage, and wear resistance, low-cost coatings are also being developed as a countermeasure.

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4.6. Paint

Recent years have seen the adoption of a larger variety of exterior colors to enhance the product appeal of vehicles. This trend was particularly noticeable in Japan in 2012 with a major promotion of pink as a color for luxury vehicles and the growth of two-tone color options for mini-vehicles. Technologically, studies have examined how to create multi-layer paints to enhance vehicle style. Functional distribution of the first and second base layers has achieved unprecedented levels of both distinctiveness and depth (34) and a powerful metallic appearance (35). As these stylish colors enter the market in greater number, more optional colors are becoming available in addition to the traditional pearl white. In the last few years, stylish expressions such as matte finishes and colored clear coats, which were previously adopted on luxury vehicles, have begun to be used in compact cars, particularly in Europe.

Trends in paint materials and processes continued from 2011. These included the introduction of waterborne primers and topcoats and the recovery of thinners to reduce volatile organic compound (VOC) emissions. In addition, three-layer wet paint processes and shorter preheating processes entered more widespread use to reduce CO_2 emissions. Waterborne three-layer paints were also introduced in emerging markets such as China and Brazil (36).

Trends that began several years ago also continued in the field of chemical conversion and electrodeposition coating. For example, zirconium oxide conversion coatings with a zero phosphorous and nickel content were introduced as a replacement for conventional zinc phosphate conversion coatings to reduce environmental load. In addition, high throwing power e-coats were adopted to reduce costs by optimizing exterior panel paint film thickness and reducing the amount of paint required for each vehicle.

References
(1) Kuriyama, et al. : Future Steel Vehicle (1)-(4), 2011 JSAE Annual Spring Congress Forum Text, 20114326-20114329, p. 7-30 (2011)
(2) Nikkei Automotive Technology, No. 26, September, p. 66-73 (2011)
(3) Kaiso, et al. : Steel Products Contributing for the Weight Reduction of Automobile, Journal of the Japan Society of Mechanical Engineers, Vol. 112, No. 1088, p. 556-559 (2009)
(4) Mazda Websit, http://www.mazda.co.jp/corporate/publicity/release/2011/201110/111004b.html
(5) Senuma, et al. : Microstructural Control in Hot Stamping Processes for Producing Ultra-high Strength Automotive Steel Components, Ferrum, Vol. 17, No. 11, p. 751-757 (2012)
(6) e.g. Material from BMW and EURO CAR BODY2012
(7) Matsugasako: Low Alloy Steel for Fracture Splitting Connecting Rod, R&D Kobe Steel Engineering Reports, Vol. 61, No. 1, p. 75-78 (2011)
(8) Kishigami, et al. : Hitachi Metals Technical Review, Vol. 28 (2012)
(9) Maruo, et al. : High Strength Wire Rod with Low Nickel and Vanadium-free for Suspension Spring ACROS1950, R&D Kobe Steel Engineering Reports, Vol. 61, No. 1, p. 43-46 (2011)
(10) Hatano, et al. : Development of Sn-added Low Interstitial Ferritic Stainless Steel Sheet with High Corrosion Resistance and Low Cr Content, Bulletin of the Japan Institute of Metals Materia Japan, Vol. 51, No. 1, p. 25-26 (2012)
(11) Kawauchi, et al. : Microstructure of High Silicon Ductile Cast Iron and SUS304 Lap Jointed by Friction Stir Weldingm Journal of Japan Foundry Engineering Society, Vol. 83, No. 6, p. 336-342 (2011)
(12) Development of Thrust Plate for VariableTiming System, Journal of the Japan Society of Powder and Powder Metallurgy, Vol. 59, No. 4, p. 214 (2012)
(13) Development of Corrosion-resistant Bearing Material for Fuel Pump in the Global Market, Journal of the Japan Society of Powder and Powder Metallurgy, Vol. 59, No. 4, p. 217 (2012)
(14) Nissan Website, http://www.nissan-global.com/JP/NEWS/2012/10_12.html
(15) Yasuhara: Weight Reduction of Vehicle by Applying Aluminum Alloy Die Casting Sub-frame, Journal of Society of Automotive Engineers of Japan, Vol. 64, No. 11, p. 41-56 (2010)
(16) Bekki: The Current State of Aluminum Alloys for Car Bodies and the Trend of the Future, Journal of Society of Automotive Engineers of Japan, Vol. 65, No. 6, p. 29-34 (2011)
(17) Ohno, et. Al. : Development of high corrosion resistance aluminum clad material for cooler, JSAE Autumn Annual Congress Proceedings, Paper No.20125526, p. 9-13 (2012)
(18) Yotsuya, et al., : Development of Aluminum Hollow-Extrusions Rear Lower Arm, Journal of Society of Automotive Engineers of Japan, Vol. 65, No. 6, p. 91-95 (2011)
(19) Nakamura, et al. : Development of Aluminum Space-Frame Body with New Structure in Front, Journal of Society of Automotive Engineers of Japan, Vol. 65, No. 6, p. 86-90 (2011)
(20) Fujimoto: Introduction of Friction Spot Joining (FSJ) and its Application to Automobile Industries, Journal of Society of Automotive Engineers of Japan, Vol. 65, No. 6, p. 76-80 (2011)
(21) Kawabata: Bonding Technology for Light Weight Materials Suitable to Vehicle Weight Reduction, Journal of Society of Automotive Engineers of Japan, Vol. 65, No. 6, p. 76-80 (2011)
(22) Saikawa: Development Trend of Magnesium Alloy Castings for Automotive Lightening, Journal of Japan Institute of Light Metals, Vol. 60, No. 11, p. 571-577 (2010)
(23) Itakura: Application of Magnesium for Automobile, The Journal of Japan Institute of Light Metals, Vol. 60, p. 305-311 (2010.6)
(24) Semcon Lightweight Seminar Sweden Future Challenges in Lightweight : Semcon website, http://www.semcon.com/en/About-Semcon/NewsList/Report-from-Lightweight-Technology-seminar/
(25) Japan Magnesium Association, Magnesium, Vol. 41, No. 11, p. 13 (2012)
(26) The National Institute of Advanced Industrial Science and Technology: Development of New Rolling Process for Improving Room-Temperature Formability of Damping Magnesium Alloy Sheets, http://www.aist.go.jp/aist_j/press_release/pr2013/pr20130124/pr20130124.html
(27) Murakami, et al.: Corrosion Protection of AZ91 D Magnesium Alloy by Anodization using Phosphate Electrolyte, Journal of Japan Institute of Light Metals, Vol. 58, No. 8, p. 381-387 (2008)
(28) NGK INSULATORS website, http://www.ngk.co.jp/news/2008/0611.html

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(29) Fujita, et al.：Polypropylene Materials for Automotive Application, POLYMERS,　Vol. 60, No. 8, p.504−506 (2011)

(30) Ozawa, et al.：Development of CFRP Body for LFA, Journal of Society of Automotive Engineers of Japan, Vol. 64, No. 7, p. 52－57 (2010)

(31) Takayama, et al.：Development of Bio-based Plastics for Injection Molding, Journal of Society of Automotive Engineers of Japan, Vol. 65, No. 6, p. 47−51 (2011)

(32) Miyake, et al.：New Ecological Plastic「Bio-PET」, Journal of Society of Automotive Engineers of Japan, Vol. 65, No. 6, p. 29－34 (2011)

(33) Mazaki, et al.: High performance UV cut tempered automotive glass "UV verre Premium", Research Reports Asahi Glass Co., Ltd., Vol. 61 (2011)

(34) Nakano, et al.：Development of “SOUL RED”, Mazda Technical Review, No. 30, p. 83−87 (2012)

(35) Nishimura, et al.：Development of Silver Color Like Real Metallic, 2012 JSAE Annual Spring Congresss Proceedings, No. 54-12, p. 13−14 (2012)

(36) Umetani; Toyota’s Coating Strategy in Developing Nations-Activities in Asia and Latin America, Japan Coating Technology Association, 2013 3rd Lecture Meeting Proceedings, p. 43－50 (2013)

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