Automobile Parts for the Environment

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Since global warming has become a serious problem, regulation of CO_2 emissions has been introduced globally as a main solution to the problem. CO_2 reduction programs of automotive manufacturers are becoming more active, since cars are one of the main CO_2 emission sources. As actual activities, weight reduction is an effective measure to improve fuel efficiency of cars, and automotive parts will take a great part in this solution. On the other hand, energy generation control to save automotive energy consumption, and the use of environmentally friendly materials to comply with regulations on hazardous substances are proceeding.

Our company has been manufacturing various kinds of automotive parts, and we are aggressively developing new products to achieve solutions to the environmental issues mentioned above. This report gives an overview of the R&D and manufacturing situation of automotive parts for weight reduction, thermal management and environmentally friendly materials.

1 Introduction

In recent years, amid heightened concerns about environmental degradation, auto companies are acting to improve fuel efficiency. We see this trend because of tighter fuel efficiency mandates worldwide, especially in Europe. Automobiles are a major source of CO_2 emissions, a major contributor of global warming. Each country has established a maximum allowable level of CO_2 emissions and it is especially stringent in Europe. The level of maximum allowable CO_2 emissions in Europe are scheduled to be tightened at the rate of 4% on average per year from 130 g/km in 2015 to 95 g/km around 2020. So, if Europe continues to tighten standards at the current pace, there is a possibility that it will be set to a very stringent level of 60 g/km around 2030.

Although environmentally friendly next generation vehicles such as hybrid electric vehicles (HEV) and electric vehicles (EV) are expected to increase soon, gasoline engine vehicles will still constitute 80% or more of new vehicles in 2020 and still high at 60-70% in 2030 according to the estimate by "The Next-Generation Automobile Strategy 2010" prepared by the Japanese government. Thus, our challenge should be: How much more can we reduce CO_2 emissions? If the prevalence rate of gasoline vehicles is assumed to be 70% and CO_2 emissions from HEV are assumed to be two-thirds (2/3) that of gasoline vehicles, then the level of maximum allowable CO_2 emissions will go down from 104 g/km in 2020, to 72 g/km in 2030, and if converted to fuel efficiency, it will be 18.0 km/L in 2015, 22.4 km/L in 2020, and 32.2 km/L in 2030. There are two approaches to overcome these challenges: one is to improve the power train and the other is to reduce vehicle body weight. If the contribution rate of weight reduction to fuel efficiency is assumed to be one fourth (1/4), and approx. 100 kg of weight reduction will be required to improve fuel efficiency by 1.0 km/L as shown in **Figure 1**. Thus, weight reductions of 110 kg and 356 kg are expected to be required in 2020 and 2030, respectively, according to the trial calculations[1]. If automotive weight increase for safety improvement and passenger comfort is additionally required in the future, the target of automotive weight reduction may be further raised.

Energy efficiency technologies that actively control energy produced in automobiles are being developed.

Meanwhile, regulations for hazardous substances used in automotive components are being phased in; ELV (The EU End-of-Life Directive [2000/53/EC]), RoHS (The Restriction of Hazardous Substances Directive 2011/65/EU), and REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) have already been issued in advance in Europe. In the U.S., the states of Washington and California decided to restrict the use of copper of levels not less than 5 wt% by January 1, 2021 and not less than 0.5 wt% by January 1, 2025 in friction materials for sale or

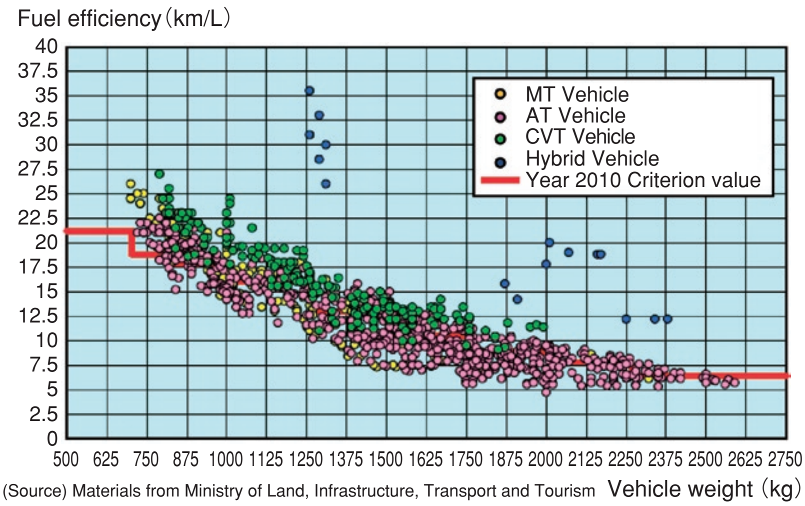


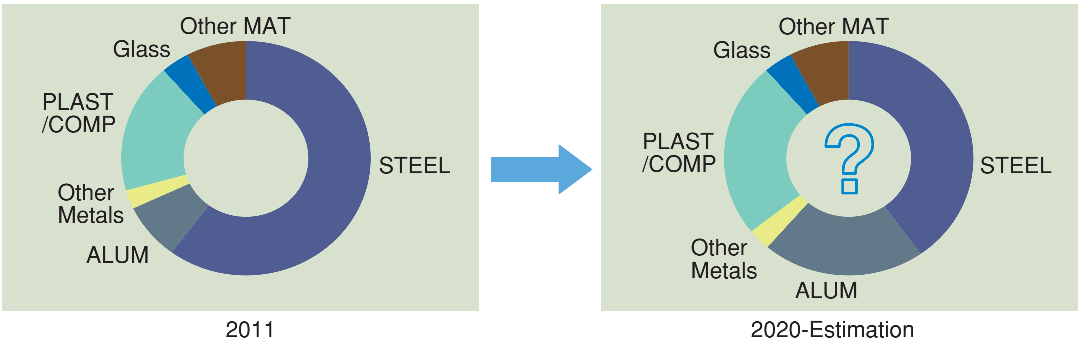
Figure 1 Relationship between 10·15 mode fuel consumption and automobile weight

installation in new motor vehicles. This regulatory movements has spread throughout the United States, leading to the agreement to the same restriction levels on January 1, 2015 by the Environmental Protection Agency (EPA), the Environmental Council of the States (ECOS) and the Motor & Equipment Manufacturers Association (MEMA).

Given the above background, actions by our company on automotive weight reduction such as resin molded automotive components and sintered material, thermal management products and our response to restricted hazardous substance in the case of friction material are introduced in this report.

2 Products developed for automotive weight reduction

Although iron based materials still make up a dominant share of materials for automotive applications according to a survey conducted by the Organisation Internationale des Constructeurs d'Automobiles (OICA), we predict the share of plastics and aluminum, etc. in automotive applications will increase through the replacement of iron based materials because of the weight saving (**Figure 2**).



(Source) Materials from OICA (Organisation Internationale des Constructeurs d'Automobiles): Steel Perspective for The Automotive Industry

Figure 2 Composition of materials of an average European automobile

What we call aluminum is actually an aluminum alloy including magnesium, copper and zinc, etc. for reinforcement. It has some unique properties such as low specific gravity: 2.7 (compared with 7.8 for iron), excellent corrosion resistance thanks to protection by oxidized surface film, good thermal conductivity and good casting performance. Aluminum alloy, however, has a drawback of poor formability due to its significantly smaller elongation after arriving at the maximum load compared to steel sheet[2) 3)], and its price per weight, almost 3 times that of steel sheet, is also a problem. Magnesium alloy is receiving attention, too, as it shows unique properties such as low specific gravity of 1.8, high thermal conductivity and high electromagnetic wave shielding effect. It also has a number of drawbacks including catching on fire when exposed to air, poor corrosion resistance, difficult magnesium alloy sheet forming and high cost. Therefore, we still have to overcome several hurdles before its commercial application[4)].

Plastics, which are generally considered as representing non-metallic materials, are called "synthetic resin" or simply "resin". In the automotive component field, fiber-reinforced plastic is also classified as "resin". Thanks to its light weight (specific gravity: 0.9-2.5) and excellent formability, resin is used in various applications including interior/exterior components, functional components in an engine room, the electronics system, fuel system, safety system and even some of the components for the chassis and powertrain.

At our company, resin has been used as a material for interior components (instrument panel, console box, etc.), exterior components (resin rear door, bumper, etc.), functional components in an engine room (resin gear), and electronics system components (housing to construct an electronic power supply circuit in an inverter unit)[5)].

On another front, there are number of ways other than replacing materials, including downsizing through the improvement of functional performance and/or wall thinning. At our company, powder metallurgy technology has contributed to downsizing of engine components in many ways, including turbocharger parts, axle bearing, bulb guide and bulb sheet.

In this report, we will explain the details of a resin rear door (interior component) and resin gear (functional component in an engine room) developed for automotive weight reduction, and downsizing by powder metallurgy technology in detail.

2.1 Interior/Exterior Component[6]

Our company has a long history of metal to resin conversions for interior/exterior components, and our products made of resins have been used by many domestic and international car manufacturers. Among them, especially rear doors, made of resin and have been adopted as a commercial product since 2001 as an assembled module comprising the rear door itself, door glass and other parts, have been improving performance characteristics. As a result, we found substantial benefits in resin-made rear doors compared to conventional steel doors, such as light weight, more freedom in forming and consolidation of parts. **Figure 3** shows comparison of number of compornents between steel rear door and resin rear door.

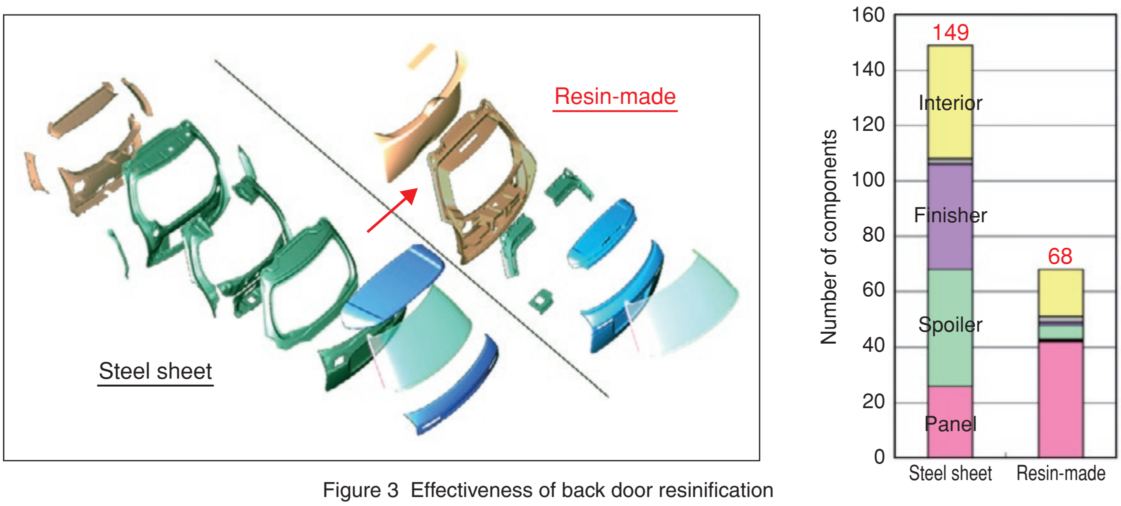


Figure 3 Effectiveness of back door resinification

Other than high strength and high stiffness, rear doors require multi-functional qualities such as vibration fatigue resistance, crash safety in the event of rear-end collision, dimensional stability after thermal (cooling/heating) cycling test, high creep resistance and high visual appearance quality. Conventional steel rear doors have met these quality requirements by hemming and welding inner and outer panels.

Required strength and stiffness for a resin-made rear door are basically provided by an inner panel. As shown in **Figure 4**[7], we use glass fiber reinforced injection molding grade polypropylene resin, which contains fiberglass with higher specific rigidity and higher specific strength than SMC (sheet molding compound) to make inner panels. (SMC is a compound for sheet molding method which requires a curing process under heat and pressure. The raw sheet consists of aligned short fiberglass bundles impregnated by resin paste which is a mixture of resin and fillers.) We use injection grade polypropylene resin, which offers superior heat resistance and visual appearance quality, to make outer panels.

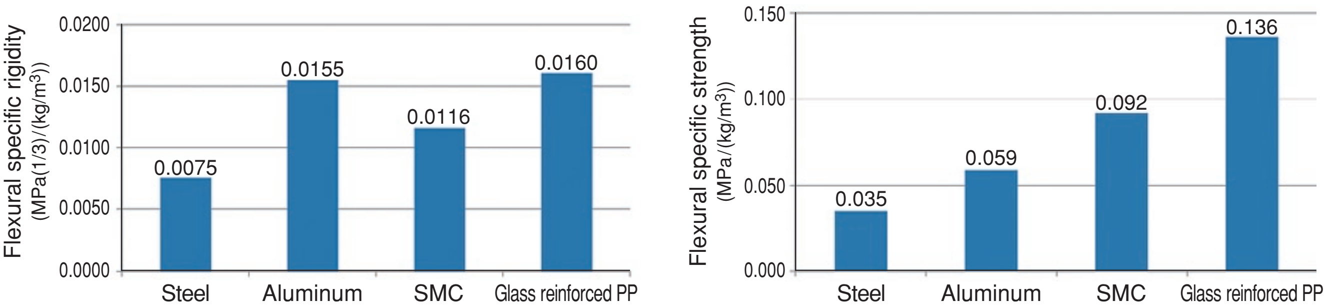


Figure 4 Selection of materials for inner panel

Designing plays a critical role to satisfy required functional performance for a resin-made rear door. At our company, we use CAE simulation technology for structural optimization. Case studies of warp phenomenon analysis of the inner panel are shown in **Figure 5**. Structural analysis results before and after implementation of warp countermeasures are coincident with actual measurement results of inner panels formed in the mold which was actually made for trial production. Adding ribs to the panel area proved effective as a countermeasure to prevent warping. Thanks to these technologies, our resin-made rear doors successfully achieved weight reduction by 30% compared to steel sheet rear doors.

For the future, we will further promote automotive weight reduction and improvements in product merchantability by panel thinning and re-examination of raw materials.

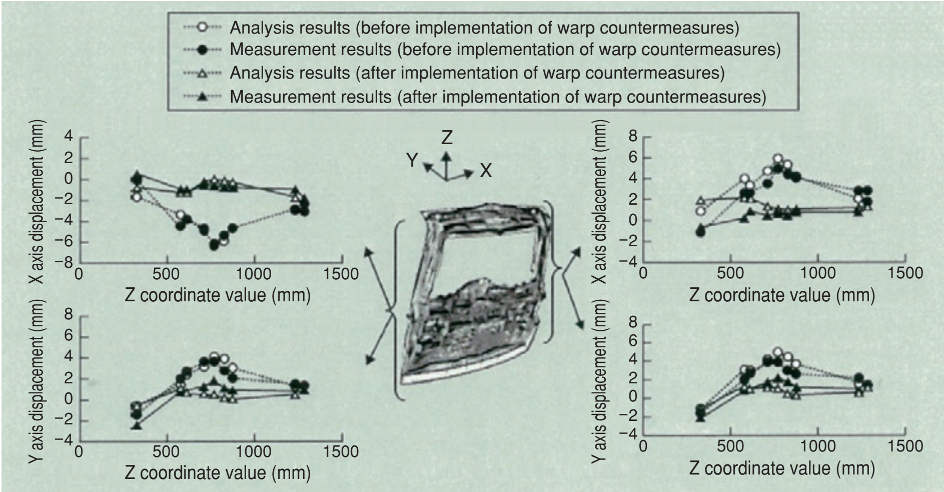


Figure 5 Warpage analysis of the inner panel made of glass fiber reinforced PP

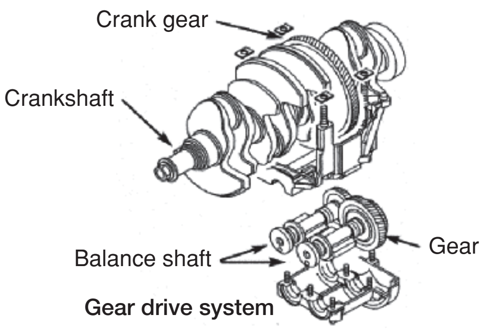
2.2 Resin gear[8,9]

We started commercial production of resin gears for balance shaft to help save the weight of functional components inside an engine room in 2000. As shown in **Figure 6**, balance shaft drive system is designed and fitted to help negate the secondary harmonic typical of four-cylinder engines, with a mechanism that a shaft with unbalanced mass is rotated at a speed twice as fast as engine revolution speed. Our challenges were how to control stresses generated on meshing gear teeth, life of gears and noise caused by gear mesh friction.

A picture of a resin gear itself is shown in **Figure 7**. In our development process to convert metal gears to resin, we selected polyamide resin, considering its high strength and resistance against high operating temperature. We successfully achieved increased resin strength under higher temperatures by selecting an appropriate curing agent. Since resin by itself could not maintain its strength level for long, it was reinforced with fibers. Polyamide resin gears reinforced with selected fibers were made and their functional performances were measured. As shown in **Table 1**, measured strength and modulus of elasticity of PBO (poly p-phenylene-2,6-benzoxazole) fiber composite material were lower than those of aramid fiber composite material. Carbon fiber composite material showed high strength and high modulus of elasticity but we found this material attacked the mating steel gear tooth surfaces and wore them away. Thus, we decided on aramid fiber as the best option to reinforce resin. Short fibers, not long fibers, were selected to increase material strength.

To reduce the noise level created by gear mesh friction, we re-examined the gear cutting process to improve the dimensional accuracy of finished products. We experimented the cutting process with conventional dry hobbing without cutting fluid, but found improving the accuracy of a hobbed gear difficult because of the discontinuous process to cut multiple teeth. Then, we decided to select a shaving process and shaving cutter because of its better performance, such as less loading and better productivity. We improved its processing accuracy by examining the processing conditions.

We will continue to work on further reinforcement of resin gears by re-examining fibers for reinforcement and composition of composite materials, and promote their expanded applications in other locations.



(Source) Tamio Hirota, *Engine Parts Kodawari Daihyakka (Encyclopedia Focused on Engine Parts)*; Grand Prix Book Publishing, (2004), p.75, p.78

Figure 6 Mechanism of balance shaft system

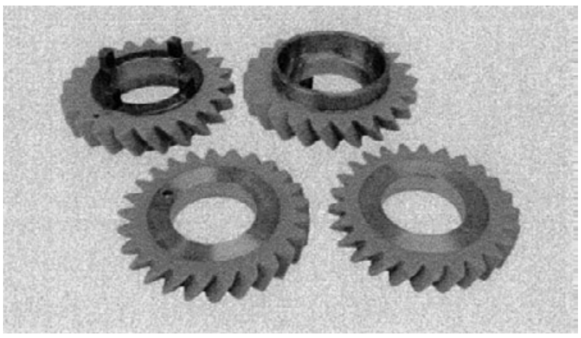


Figure 7 Resin balance shaft gears

Table 1 Mechanical properties of composite material

Test item	Unit	Carbon fiber composite material	BPO fiber composite material	Aramid fiber composite material
Flexural strength	MPa	580	190	220
Flexural modulus of elasticity	MPa	30,000	6,000	7,000
Compressive strength	MPa	400	150	270
Izod impact strength (without notch)	J/m	650	420	500

Resin: Polyaminoamide resin, Base material blending ratio: 50 vol%

2.3 Products of powder metallurgy[10)-12)]

Powder metallurgy is a material processing method to make raw material and/or parts by sintering metal powders and forming a metallurgical bond between them. The basic manufacturing process of powder metallurgy is shown in **Figure 8**. Powder metallurgy shows a number of unique characteristics including its ability to manufacture metals with a high melting point and alloyed metals, metal and non-metal composite materials, composite materials combining mutually insoluble metals, and to control porous materials, with good economic performance thanks to its simple process. Its products can also have unique properties that can't be obtained by regular steel because the finished product form or its approximate form can be obtained through the process of molding and sintering metals together with a degree of freedom in controlling alloy composition and metal structure.

High-strength sintered material has improved mechanical properties by adding alloying elements having a high harden ability and optimizing its method. On the other hand, there are many dispersed fine gas pockets called pores in powder metallurgy products as powder metallurgy uses metal powder as a raw material. Thus, a problem of impaired mechanical properties is caused by pores. We developed a densification technology to reduce pores and successfully developed a new material by combining this densification technology and material technology, and its mechanical strength was comparable to that of steel. As a result, thinning of component walls has become possible with this new material. An example of an automotive component made of high-strength sintered material is shown in **Figure 9**.

By taking advantage of the high degree of the freedom in material designing provided by powder metallurgy, we are developing various sintered materials with heat and wear resistance strong enough to meet specific operating conditions. We developed the technology to control the volume of the liquid phase formed during sintering process to have better material dispersion during the sintering process, and with it, we supply products having superior functional properties never before seen in conventional materials. As an example, high Cr material containing 20% chromium steel, in which about 30% carbide in the surface area is dispersed finely and uniformly, shows excellent wear resistance and oxidation resistance under 700°C or higher temperature conditions (**Figure 10**). This material is used in a downsized supercharged engine.

In the future, we will develop and release products that can contribute to automotive weight reduction and downsizing by applying the unique properties specific to powder metallurgy materials.

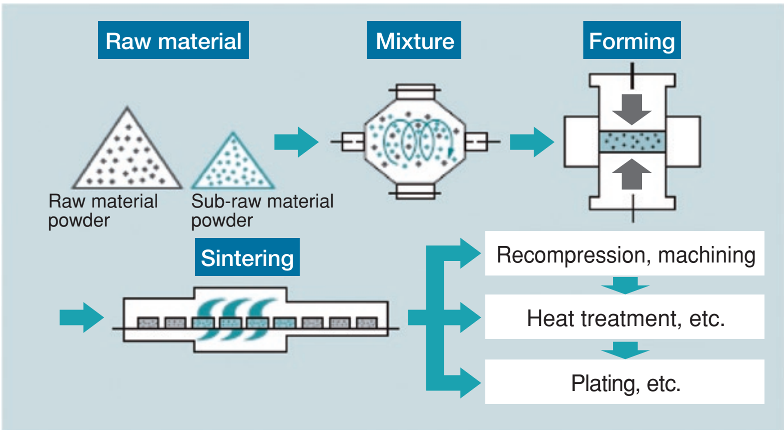


Figure 8 Manufacturing process of powder metallurgy

Figure 9 Products made from high strength sintered material

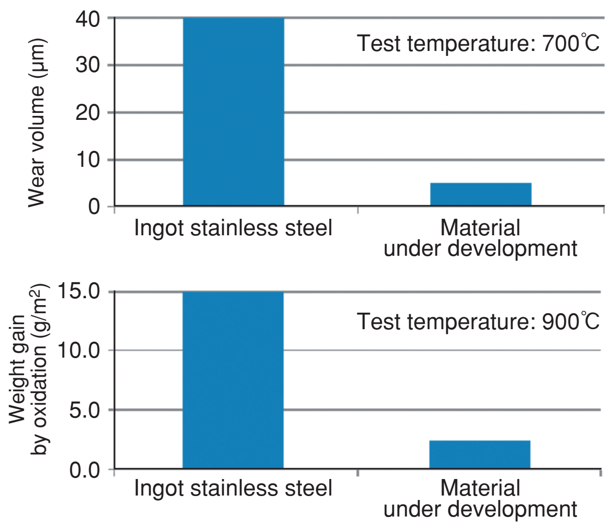


Figure 10 Anti-wear and anti-oxidation properties of developed material

3 Thermal management product

Technology to control heat received from the environment and generated inside an automobile is also important as an energy saving technology for automobiles. Our company is producing light-control films with the ability to control outdoor light transmission and room light transmission for light shielding, screening and heat insulation. We also developed thermoelectric materials that convert waste heat from automotive engines into electricity. We explain these subjects in detail below.

3.1 Light-control film [12) 13)]

Our company started commercial production of light-control emulsions and films using our proprietary functional material, polymer synthetic technology and film coating technology on the basis of SPD (Suspended Particle Device) technology licensed from RFI (Research Frontier Inc.) in the USA. The principle of the light-control film is shown in **Figure 11**. This is an active light-control film which changes its color from dark blue to transparent when light-control particles are aligned parallel to the electric field after alternative voltage is applied to the transparent electrodes placed opposite each other. This light-control film shows unique characteristics including little haziness (an indicator of the transparency of film to indicate the degree of cloudiness), ability to steplessly adjust visible light transmission, and even with benefits of low power consumption. The structure of the light-control glass is shown in **Figure 12**, in which light-control film is placed between two sheets of glass via an adhesive layer. The thermal management effect is shown in **Figure 13** when light-control film is applied to the sun roof of an automobile.

In a simple simulation experiment under irradiation of light with a spectral distribution approximately that of sunlight, the surface temperature of a paper with black hair image color was lower by 10°C than transparent glass when voltage was "ON" and was lower still when voltage was "OFF". So, both passenger comfort and energy saving can be provided when our light-control film is applied to an automobile sun roof.

We are developing achromatic black or gray color films which can easily coordinate with room designs for future use, as the color of the light-control material developed this time is dark blue when voltage is "OFF".

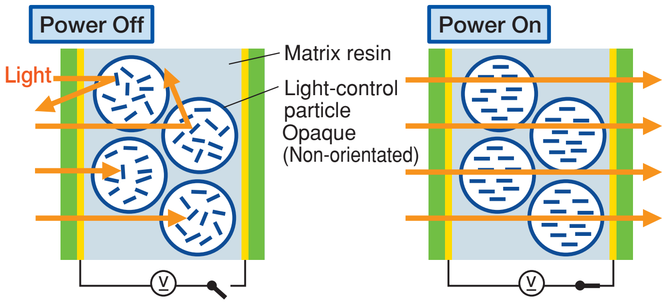


Figure 11 Fundamental driving mechanism of light control film

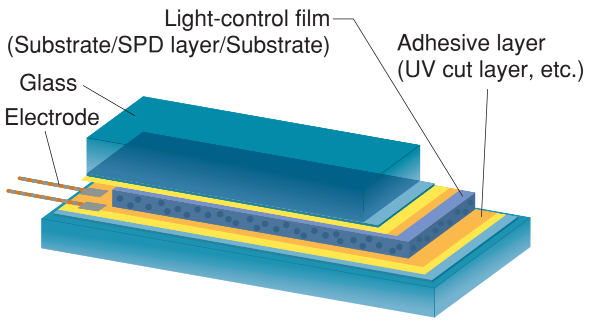


Figure 12 Structure of light control glazing

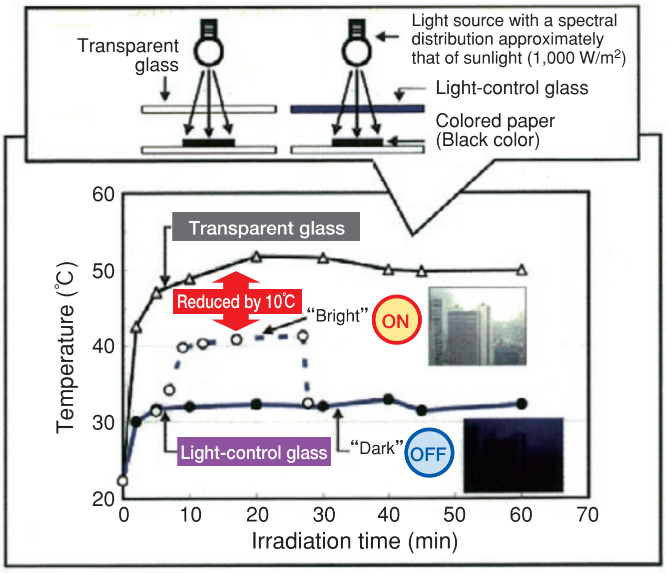


Figure 13 Surface temperature of black paper during the sunlight simulator test

3.2 Thermoelectric module [14)]

Thermoelectric conversion is an electricity generation method, in which heat (temperature difference) is converted directly into electrical energy through a phenomenon called the Seebeck effect. A thermoelectric module generally consists of two n- and p-type semiconductor elements connected via electrode in series. For practical applications at higher temperature, alleviating an effect of thermal stress distortion at the junction of a thermoelectric element and preventing performance deterioration due to diffusion of constituents of thermoelectric conversion members should be a key issue. So far, our company has developed a high-temperature module using an SiGe conversion element (**Figure 14**). This module was prepared by bonding an SiGe element produced by powder metallurgy technology with a molybdenum electrode using a special technique. We are continuing to develop new materials to achieve even higher performance and have obtained generation of a maximum output power of 1,000 mW/cm^2

under the 620°C temperature difference using a module consisting of SiGe and Mg_2Si elements. This output value was 1.7 times higher than that of a conventional SiGe module (**Figure 15**).

This thermoelectric module is considered as a very promising technology to recover waste heat from automobiles by converting it to electrical energy, thereby improving fuel efficiency. We will continue to develop thermoelectric elements with even higher performance and manufacturing technology of larger size modules, and aim at commercialization of these products.

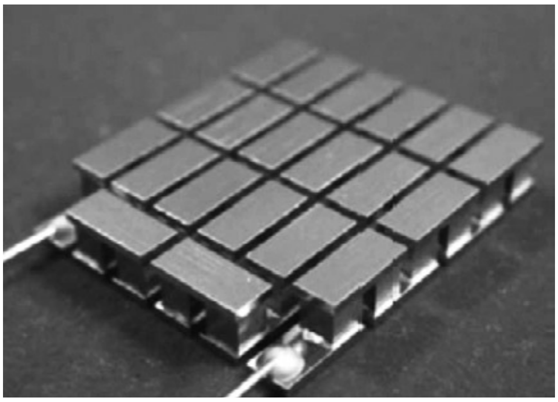


Figure 14 SiGe thermoelectric modules for high temperature

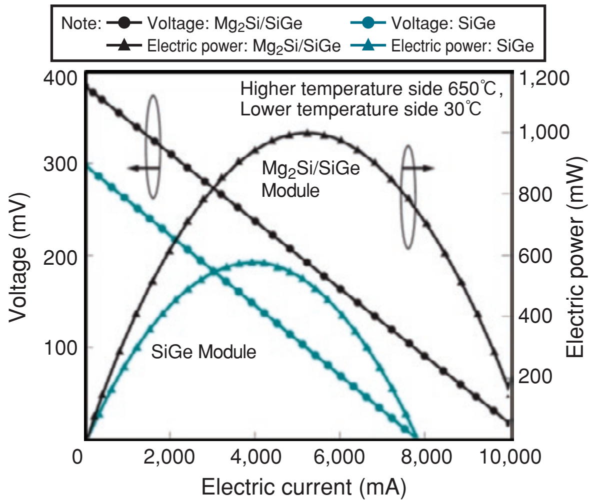


Figure 15 Electric current and voltage properties of two pairs of modules

4 Hazardous materials restraint product

4.1 Copper-free friction material

An automotive disc brake pad is an automotive component of a brake system. When the driver presses his foot against the brake pedal, two disc brake pads are clamped by pistons onto a cast iron rotor, which rotate together with an automotive wheel, and slow the automobile by the generated force of friction. A brake pad is prepared by attaching cured friction material cake, made from a resin compound reinforced with metal fibers, inorganic/organic fibers and more than 10 kinds of friction adjustment agents, to an iron plate[15]. Brake pads using copper metal fibers have been the main type for 20 years, thanks to their low noise when braking and well-balanced performance, and even in recent years, the overseas market for brake pads using copper metal fibers are expanding, especially in North America. However, due to the legislative trends to restrict the use of copper in brake pads, development of copper-free friction material has become an urgent task.

Each manufacturer is actively involved in the research and development of copper-free friction materials[16)-18)]. **Figure 16** shows the functional performance of copper and its influence on brake performances. Copper has high thermal conductivity, a high melting point and excels in strength retention if used in fiber form. Therefore, simple copper replacement hurts brake performance at higher temperature and/or performance related to material strength. Our company researched the effects of copper quantitatively and performance shortcomings of copper-free material were overcome with multiple metal and inorganic raw materials, eventually resulting in our successful introduction of copper-free brake pads. No performance problem was encountered with our copper-free brake pad, and neither friction coefficient nor wear resistance were inferior to those of conventional products, as shown in **Figure 17**. Shear strength was also at the same level as that of conventional products.

Each auto manufacturer has finally started to equip certain models with copper-free brake pads. We consider that the trend to use copper-free brake pads in new models will accelerate. We expect the braking performance of copper-free brake pads to be improved to an even higher level by re-examining friction material composition and modifying the manufacturing process in response to weight differences between light and heavy vehicles, different performance requirements in different categories such as speed-prioritized sport cars or different approaches by auto manufacturers.

Physical properties of copper		Functional performance of copper		Influence prediction to brake performance
・High thermal conductivity (386 W/m・K) ・Fiber form ・High melting point (1085℃) ・Low on the Mohs scale (2.5～3) ・Ductility	→	①Heat conduction (thermal diffusion) ②High temperature lubrication ③Cohesive force ④Skeletal strength	→	・High temperature judder (vibration) ・High temperature friction ・Braking force holding power (Heat fade [lower braking force]) ・Crack resistance

Figure 16 Estimate of influence of copper properties for brake performance

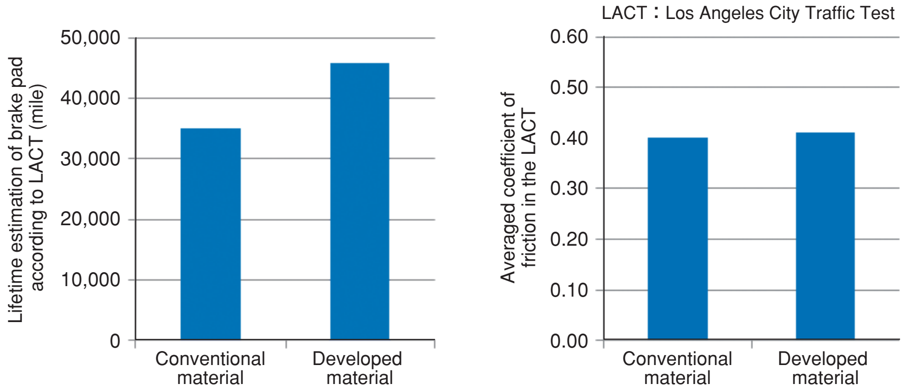


Figure 17 Friction properties of the new copper-free brake pad

5 Summary

We are living in an age in which we cannot talk about marketing without mentioning the environment. It is the same for the automobile industry, and we have to overcome difficult challenges in achieving both automotive performance improvements and environmental compliance simultaneously while rushing to comply with regulations imposed by each country. The current role of the automobile as a transportation system will not change in the future and automotive components making up an entire automobile will play a major role. Therefore, by means of superior automotive technologies and speeding up automotive R&D, we must contribute to better environmental compliance. We will do our best and contribute to society through the progress of the auto industry, in which environmental compliance can be realized through the aforementioned technologies and products incorporating future technical developments.

【References】

1) Daisuke Imanishi. (2015-9) *Developing lightweight vehicle bodies for 2030. (2030 Nen, Keiryouka no Shinario)*. Nikkei Automotive, pp.52-57
2) Yukio Kou. (March, 2006) *Vicissitude of Automotive Material. (Jidousha Sozai no Hensen)*. Japan Automobile Manufacturers Association, Inc. (JAMAGAZINE)
3) Takeo Sakurai. (2009) *Technical Trend of Aluminum Alloy Sheets for Automobiles. (Jidoushayou Arumi Goukinzai no Gijutsu Doukou)*. Kobe Steel Engineering Reports, 59, pp.121-127
4) Mitsui Global Strategic Studies Institute. (28 July, 2014) *Weight Reduction and Diversification of Automotive Structural Components. (Jidousha Kouzouzai no Keiryouka to Tayouka)*. Senryaku-Ken Report
5) Tetsuo Ito. (2013-1) *Automotive Parts for "Environment, Safety and Comfort Performance". (「Kankyo/Anzen/kaiteki Seinou」 o Jitsugensuru Jidousha Buzai)*. Hitachi Chemical Technical Report,55, pp.47-50
6) Teruhiko Iwata et al. (2005-1) *Plastic Back Door Module for Automotive. (Jidoushayou Bakkudoa Mojūru)*. Hitachi Chemical Technical Report, 44, pp.21-26
7) Shigeo Suzuki. (17 July, 2015) *The Japan Society of Polymer Processing Lecture Material. (Purasuchikku Seikei Kakou Gakkai Kouen Shiryou)*.
8) Yasuyuki Hashimoto et al. (2006-2) *High Strength Resin Gear Materials. (Kou Kyoudo Jushi Giyayou Zairyou no Kaihatsu)*. Shin-Kobe Technical Report, 16, pp.10-15
9) Masao Sugiyama et al. (2009-2) *Improvement of Accuracy for Aramid Fiber Reinforced Resin Gear. (Aramido Seni Kyouka Jushi Giya no Seido Koujou)*. Shin-Kobe Technical Report, 19, pp.35-42
10) Tadayuki Tsutsui. (2011-9) *Recent Technology of Powder Metallurgy and Applications. (Saikin no Funmatsu Yakin Gijutsu to Sono Ouyou Seihin)*. Hitachi Chemical Technical Report, 54, pp.13-21
11) Kei Ishii. (2013-1) *Trends in Environmental and Energy-saving Technology for Automobiles and Corresponding Developments in Powder Metallurgy. (Jidousha ni okeru Kankyo/Sho-Ene Gijutsu Doukou to Funnmatsu Yakin Gijutsu no Taiou)*. Hitachi Chemical Technical Report, 55, pp.51-54
12) Toshiaki Ishii et al. (2013-05) *Material Solutions for Clean Engines and Electric Vehicles. (Jidousha no Dendouka/Kurīnka ni taisuru Koukinou Zairyou)*. Hitachi Review, 95, pp.49-55
13) Osamu Higashida et al. (2007-7) *Active Light Control Film for Glass. (Akutibugata Choukou Garasuyou Firumu)*. Hitachi Chemical Technical Report, 49, pp.7-10
14) Kudo Makoto et al. (2013-05) *Innovative Materials for Renewable Energy. (Saisei Kanou Energi no Katsuyou o Sasaeru Kakushin Zairyou)*. Hitachi Review, 95, pp.24-29
15) Yasuhiro Hara et al. (2003-7) *High Friction Coefficient Disc Pads for Automotive Brakes. (Burēkiyou Kou Masatsu Keisuu Disukupaddo)*. Hitachi Chemical Technical Report, 41, pp.45-48
16) Poh Wah Lee, et al. (2012) *Development of Cu-Free Brake Materials*, SAE technical paper 2012-01-1787
17) Yasuki Hattori et al., Nisshinbo Brake Inc., *Friction Material*, Japanese Unexamined Patent Application Publication No. 2013-245338, 2013)
18) Eri Itami et al., Akebono Brake Industry Co., Ltd. *Friction Material*, Japanese Unexamined Patent Application Publication No. 2013-076058, 2013