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Trends in Environmental and Energy-saving Technology for Automobiles and Corresponding Developments in Powder Metallurgy

Kei Ishii
Automotive Products Business Headquarters
Powder Metal Products Business Sector
Powder Metal Development Department

The motorization of society in China, India, Southeast Asia, and other emerging nations is driving a global increase in demand for primary energy. In 2030, this demand is predicted to be 40% greater than at present, with 60% of petroleum consumption predicted to be for automobiles. To decrease the environmental burden and minimize fossil fuel consumption, automobile makers are accelerating the development of environmentally friendly and fuel-saving automobiles. In response, more and more of our powder metallurgy products are supporting our customers' development of environmentally friendly automobiles. This report briefly reviews overall trends in the automobile industry and efforts by automobile makers to create environmentally friendly automobiles, while in the second half outlines examples of Hitachi Chemical powder metallurgy products that support these efforts.

1 Introduction

The popularization and development of automobiles have provided us with a means of transportation and delivery and made our lives more convenient and affluent. Conversely, automobiles consume vast amounts of fossil fuels, are a major source of carbon dioxide causing air pollution in urban areas and a greenhouse gas, and significantly impact on the global environment. In Japan, efforts to reduce atmospheric carbon dioxide as a countermeasure to global warming started in 2008, targeting a 6% reduction compared to the 1990 level pursuant to The Kyoto Protocol. Moreover, each country is mandated to establish a reduction target toward 2020 from 2013 onward.

17% of the total atmospheric carbon dioxide in our country comes from vehicle emissions, meaning measures to counter carbon dioxide from automobiles become more important than ever.

According to the "World Energy Outlook 2010"[1)] report prepared by an international energy organization, global primary energy demand will increase 40% by 2030 if appropriate energy-saving actions are not undertaken, mainly propelled by increased petroleum consumptions in emerging countries, especially China, India and Southeast Asia, where motorization is rapidly expanding. In this case, petroleum consumption by automobiles is estimated to account for 60% of the total.

Under such circumstances, auto manufacturers are accelerating efforts to develop a technology for environmentally friendly automobiles to ensure their own survival in the international market.

2 Changes in the Automobile Market

2.1 Polarization of Automobile Markets and Accelerating Growth

Trends of the global automotive market show that 13.79 million automobiles were sold in China in 2009, where the automobile market surpassed that of North America. Automobile sales in Japan at the time went under than 8 million. Although little increase in vehicle sales is forecast in Europe, Japan and North America henceforth, sales are set to soar in China, India and other emerging markets alongside the growing polarization in automobile sales between developed and developing countries. In terms of passenger car sales, figures of 58 million cars in 2010, 72 million in 2020 and more than 100 million in 2030 are forecast thanks to increased sales in emerging countries[2)].

2.2 Changes in Power Source for Automobile Propulsion

Japan targeted a 25% greenhouse gas reduction by 2030 compared to the 1990 level pursuant to the recently agreed Copenhagen Accord (COP15). The price of fossil fuel also soared after the Lehman Shock in 2008, while the subsequent breakdown of atomic power plants during the earthquake on March 11, 2011 further intensified Japan's energy dependence on thermal power generation, explaining the continuing high price of automobile fuel. Concerned by such situations, automobile manufacturers have accelerated the development of hybrid cars (HV, HPV), fuel cell cars (FCV) and electric cars (EV); conversely, renewed efforts to lower the fuel consumption of fossil fuel engines are still attracting attention, more than before. It is amazing to see that there is still room left to improve fuel efficiency given the long history of automobile development; 130 years for the gasoline engine and 90 years for diesel.

3 Trend of Environmental and Energy-Saving Automobile Technologies

In recent years, developments in energy-saving automobile technologies have been focused and simultaneously promoted in the following areas: (1) Enhancing the fuel efficiency of the traditional combustion engine, (2) Developing next-generation powered vehicle such as EV, HV (including PHV) and FCV for compatible energy-saving and environmental protection. **Table 1** shows the trend toward technological improvements in fuel efficiency and corresponding powder metallurgy products[3]. The key technology includes weight-saving, low-friction, heat-/wear-resistant, thermally insulated and magnetic parts with low loss/high efficiency; corresponding powder metallurgy products contribute to the development of environmentally friendly automobiles.

Table 1 Technology Trend of Fuel Economy Improvement in the Automotive Industry

Relevance ◎Strong ○Weak

Automotive System	Technology to improve the environment and fuel consumption	Targeted Automobile				Main targeted powder metallurgy product
		Gasoline	Diesel	HPV (including PHV)	EV	
Engine System	Reducing friction	○	○	○		Full range of structural parts
	Multi-valve (4 valves)	◎	◎	○		Valve guide, valve seat
	Variable valve train	◎		◎		Parts of the variable valve train
	Solenoid valve train	○				Wear-resistant parts, Sintered magnetic parts
	Direct fuel injection	◎				High-efficiency injector parts
	Multi-stage fuel injection		◎			High-efficiency injector parts
	Mirror cycle system	○				
	Exhaust gas recycling (EGR)		◎			Heat-resistant material (bush)
	Thermal management (reducing cooling loss)	◎	◎	◎		Porous heat insulation metal parts
	Thermal management (thermoelectric waste heat regeneration)	○	○	◎		Thermoelectric conversion module (system)
	Downsized-turbo	◎	○			Heat-/wear-resistant material
	Lightweight parts	◎	◎	◎		High strength thin-walled parts, metal-resin composite parts
Auxiliary Engine System	Electric power steering	◎	◎	◎	◎	Motor/core soft magnetic composite (powder core)
	Charge control	○	○	○	○	
Drive System	Idling neutral control	○	○	○		
	Automatic transmission (AT) multi-step	◎	◎	○		Internal gear, Planetary gear mechanism parts
	Automatic transmission (AT) lock-up	◎	◎	◎		
	Continuously Variable Transmission (CVT)	◎	○	◎		Internal gear, Planetary gear mechanism parts
	Automated Manual Transmission (AMT)	◎	◎	○		Synchronized mechanism parts
	Dual Clutch Transmission (DCT)	◎	◎	○		Friction material, Clutch material
Fuel System	Alternate fuel (biomass fuel)	◎	○			Anti-wear material (valve seat), Fuel pump bearing
	Idle stop	◎	○	○		Long life low-friction bearing, High fatigue strength gear
EV, HV Motor	Low-friction, High efficient motor			○	◎	Low loss motor rotor
EV, HV Power Source Control System	High efficient inverter, Low loss magnetic parts			◎	◎	Low loss magnetic parts (reactor)

4 Responses by Powder Metallurgy Technology to Environmentally Friendly Automobiles

4.1 Improvement in Fuel Efficiency of Traditional Internal-Combustion Engine for Automobile (Fossil Fuel)

• Parts for Turbocharger (Downsizing Turbo)

Downsized engines are increasingly popular thanks to applications of the turbocharger (hereinafter referred to as T/C) as an optional piece of automobile technology in response to environmental challenges. T/C parts require wear resistance under high temperature operating conditions, so the main materials used are steel-based with high Cr content, such as stainless steel. It is also possible to further enhance performance with sintered materials thanks to its higher scope of design freedom. A new high-Cr content material was developed anticipating use in an even hotter environment. **Figure 1** shows the metallographic microstructure of high-Cr-sintered material EW-50. EW-50 is a steel-based material with 20% chromium content, which is finely and uniformly dispersed with Cr carbide (30% area ratio), and shows remarkable wear and oxidation resistance, even at temperatures of 700 ˚C or more. We are now promoting EW-50 for T/C parts[4].

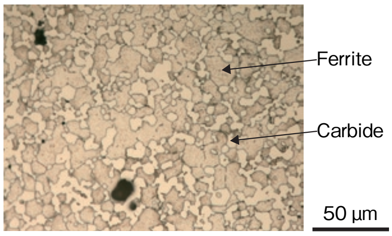

Figure 1 Microstructure of High Cr Content Sintered Material “EW-50” with High Heat and Wear Resistance

• Compact/Lightweight Parts

It has become possible to manufacture thinner-walled products thanks to the improved strength of sintered material, which can also contribute to miniaturization and weight-saving. We enhanced the mechanical property by adding alloys with high sintering performance and optimizing the addition method for the alloy. Developing a new additive element requires sufficient considerations of safety, recycling efficiency and cost. Accordingly, we are promoting the development of a new and more economical Cr-based material which replaces the current Ni-based materials. Also, sintered material with strength equivalent to conventional wrought steel was practically applied. **Figure 2** shows automobile parts using high strength material[5].

Figure 2 Sintered Products Applied High Strength Material for Automobiles

• Low-Friction Sintered Bearing (ISS starter bearings)

The number of automobiles mounted with idling stop systems (ISS) is expanding. The idling stop is a system stopping the engine when the driving speed declines to a certain level and then restarting it when the accelerator pedal is pressed. Accordingly, starter motors must be more durable than those currently used and the noise when restarting has to be suppressed. To improve these starter motor qualities, we developed a Cu-based

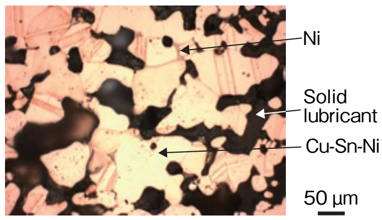

Figure 3 Microstructure of Low Friction Bearing Material “KCR-1”

sintered bearing, the material of which was dispersed with solid lubricants, whereupon the friction coefficient and squeals generated from sliding surfaces were reduced. The metallographic microstructure of the sintered oil-impregnated bearing (KCR-1) in the starter motor is shown in **Figure 3**. This material contributes to reliability and noise reduction[6].

• Magnetic Parts for Diesel Engine Injector (Clean Diesel)

To clean exhaust gas from a diesel engine, a high-precision and high-speed mechanism to open and close fuel injection valves is required, for which we use a soft magnetic composite (powder core) (hereinafter referred to as SMC) for solenoid magnetic parts (stator core). The SMC core is prepared by compacting magnetic powder of about 100 μm in diameter, the surface of which is electrically insulated. It is used without sintering and can reduce iron loss (thermal loss) in the AC magnetic field. **Figure 4** shows the structure of the SMC. Although iron loss of widely used magnetic material (soft ferrite) is small in the high frequency range, its magnetic flux density is low, hence the size of the magnetic parts increases. The magnetic flux density of the magnetic steel sheet is also high, but since its iron loss is also high in the high frequency range, it is not applicable to magnetic parts. The SMC can compensate for defects in both magnetic materials. **Figure 5** shows a stator core, which is made from the SMC of a solenoid valve for the injector of a common rail system for diesel engines[7].

• Valve Train Parts for FFVs

FFV (Flexible Fuel Vehicle) engines use bio-ethanol, which is a replacement for gasoline, and natural gas and offers clean combustion. However, it has a tendency to adhere and wear due to the high frequency of metal contacts between the valve seat and valve, meaning the valve seat requires high wear resistance. **Figure 6** shows the microstructure of the valve seat material EH-51H developed for FFV, for which the anti-adhesion property was improved thanks to optimization of dispersion hard particles in substrate and added amount, also by the dispersion of solid lubricants. It also shows superior wear resistance[8].

• Porous Metal Parts for Engine Heat Insulation

In recent years, various thermal management materials have come into focus to enhance automobile fuel efficiency. We developed a porous metal with ultra-high porosity, exceeding all levels achieved by traditional powder metallurgy to date. **Figure 7** shows an example of the SUS 316L (austenitic stainless steel) porous metal. It is characterized by a fine porous binary structure and a maximum porosity level of 95% can be set. The open-pore type with continuous coarse-scale pores and the closed-pore type with independent closed pores can be used as materials for heat exchangers and insulation respectively. The latter closed-pore type can help retain heat inside a combustion engine, leading to highly efficient combustion.

4.2 Response to Next-Generation Powered Vehicles

• Magnetic Parts for HV and EV (motor core)

Since magnetic parts prepared by powder metallurgy method include a unique feature to facilitate the construction of 3D magnetic circuits, they are optimally suited to meet needs in response to vehicle electrification. The direct current magnetic property of sintered material is mainly defined by the material composition, the density of the sintered material and crystal particle size. Sintered pure iron shows a high magnetic flux density strongly related to the purity and density of iron, while high density sintered material using high purity iron powder can obtain high magnetic flux density. **Figure 8** shows the motor rotor core of HV with a sintered magnetic core of pure iron formed along the outer peripheral section. Since the inner peripheral section requires high strength to deliver motor torque to the shaft directly, an Fe-Ni-Cu-C based material is used and unified via a method of sintered diffusion bonding[9].

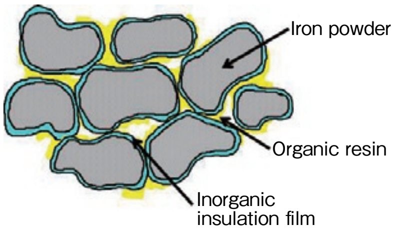

Figure 4 Schematic Structure of Soft Magnetic Composite (SMC)

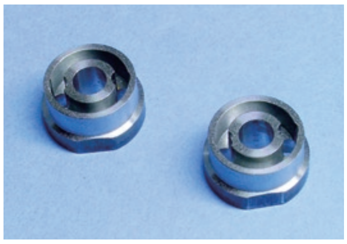

Figure 5 Fuel Injector Stator Core of Diesel Engine

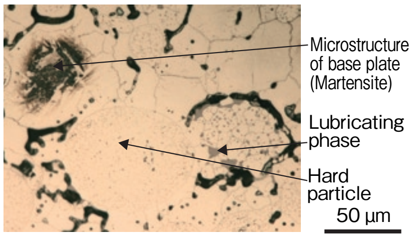

Figure 6 Microstructure of Valve Seat Material "EH-51H" for FFV

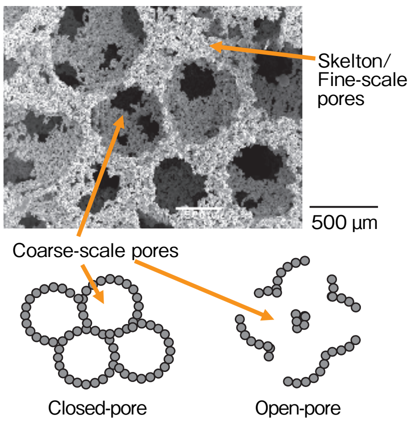

Figure 7 Dual Porous Structure Containing Coarse and Fine Pores of Porous Metal

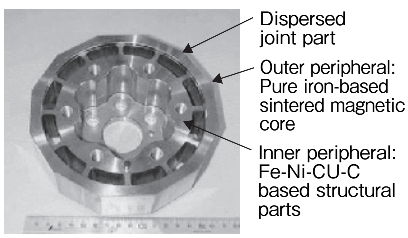

Figure 8 Motor Rotor Core for HV

• Magnetic Parts for HV and EV (power source reactor)

The reactor core for inverters in HV/EV with a voltage-increasing function must be made of material with low hysteresis loss. Eliminating residual stress inner raw material by heat treatment under high temperature is an effective solution, and the heat-resistant resin for the coating of the surface of the raw material requires stability at high temperature. **Figure 9** shows the exterior appearance of a reactor core used in HV. This core, combining both high magnetic flux density and low hysteresis loss, can be mounted in power inverters of not only HV/EV but also solar power, hot-water supply system using heat pump and wind power generation. Accordingly, a wider applicable scope covering more automotive and non-automotive fields is expected.

Figure 9 Reactor Core for In-car Inverter System Using Heat-resistant Film

• Thermoelectric Conversion Module for a Waste Heat Regeneration System

Thermoelectric conversion technology capable of directly converting thermal energy to electric energy is anticipated as a promising form of waste heat regeneration technology for automobiles and industrial furnaces due to its structural simplicity and ease of installation. By using a powder metallurgy method to manufacture this module, reduced thermal conductivity (phonon scattering) is enabled via micronization of crystals, helping improve the performance of thermoelectric materials. We are trying to make a thermoelectric conversion module with environmentally friendly materials such as SiGe, Mg_2Si and $Mn_{1.8}Si$ and develop a thermoelectric element of ZT=1.0 or higher, which is a performance index criterion suitable for actual use. **Figure 10** shows an encapsulated thermoelectric conversion module. By decompression-sealing the encapsulated module, the thermal contact resistance between the module and contacting case can be reduced to an extent that underlines the potential for use within high-temperature and corrosive environments. It is therefore expected to be a technology capable of regenerating electricity from waste heat from automobiles and improving fuel efficiency[10)-11)].

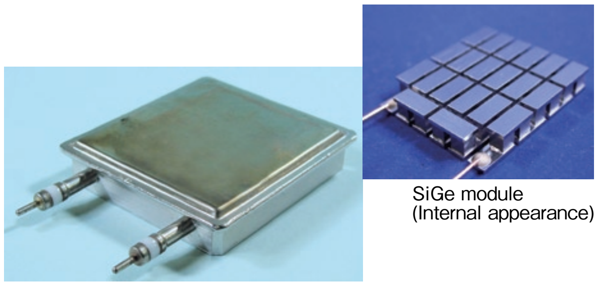

Figure 10 SiGe Thermoelectric and Encapsulated Modules

5 Summary

The market for automobile has expanded, weathering multiple challenges throughout its long history. We envision the future path of automobile over the next 20 years as follows:

The automobile market will continue alongside growth in emerging markets while manufacturing sites and manufacturing processes change. Improved fuel-efficient technology for fossil fuel automobiles will be pushed to the limits, and the era of a switch to next generation powered vehicles is upon us. We intend to develop new products as an automotive parts supplier, remembering the keywords: “comfort and rapidity”, “safe and at will” and “earth-friendly”, swiftly responding to “the needs for automobile technology development”.

【References】

1) IEA material, http://www.iea.org/weo/2010.asp.2010
2) Ministry of Economy, Trade and Industry (METI) “Strategy for Next Generation Automobile 2011”, published April, H22
3) Standard of fuel consumption for passenger cars, etc. in 2010, METI, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), 2010
4) Hideaki Kawada, Kunio Maki: “Recent Trend of Heat-Resistant, Wear-Resistant Sintered Alloy”, Hitachi Powdered Metals Technical Report 6, pp. 2-8 (2008)
5) Tadayuki Tsutsui: “Future Prospect and Development Trend of Structural Material”, Hitachi Powdered Metals Technical Report 7, pp. 2-6 (2008)
6) Takeshi Yanase: “Development of Bronze-Based Bearing Applicable under High-Load Condition”, Hitachi Powdered Metals Technical Report 6, pp. 22-26 (2007)
7) Chio Ishihara, Rei Hamano, Hirotake Hamamatsu, Takeshi Akao: “Development of Injector Solenoid Valve Parts for Diesel Engine”, Powder and Powder Metallurgy 59, pp. 249-253 (2012)
8) H. Kawata, K. Maki: “Development of High Performance Valve Seat Insert Materials for Heavy Duty Engines”, SAE Technical Paper 2006-01-0394
9) Kazuo Asaka, Chio Ishihara: “Soft Magnetic Parts- Trend of Material Technology”, Hitachi Powdered Metals Technical Report 4, pp. 5-9 (2005)
10) Jinushi, Okahara, Ishijima, Shikata, Kambe, Progress in Powder Metallurgy (2-Volume set): Proceedings of the PM2006 Powder Metallurgy World Congress, “DEVELOPMENT OF THE HIGH PERFORMANCE THERMOELECTRIC MODULES FOR HIGH TEMPERATURE HEAT SOURCES”
11) Itoh, Chinushi, Ishijima: 9th Science Lecture Meeting of Thermo-electric Society of Japan (TSJ2012), Collection of Lecture Summaries: “Simulation of Power Generation Using Thermo-electric Module Based on Finite Element Method and Effect of p-n Element Geometry on Power Generation Efficiency”