Reactor Cores and 3D-shaped Motor Cores Manufactured by Powder Metallurgy

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1 Abstract

Powder Metallurgy has mainly been applied to structural parts in automobiles. We have developed and mass-produced magnetic parts manufactured by powder metallurgy. Recently, utilization of magnetic parts have been increasing due to the electrification of automobiles. In this report, we introduce reactor cores, which have low core-loss realized by our original lubricant, and 3D-shaped motor cores manufactured by powder metallurgy, which can downsize the volume of motors.

2 Characteristics

・Pure iron-based reactor core that suppresses core losses by applying Hitachi Chemical's original lubricant.
・3D net-shaped motor core that exploits the features of powder metallurgy.

3 Background of the Development

Many magnetic parts have been industrially produced using powder metallurgy to date. The investigation and application of soft magnetic materials and parts manufactured by powder metallurgy have expanded in recent years, not only for home appliances and general industries but also for automobile parts. **Figure 1** shows a schematic of the operation frequencies and processes for sintered cores and soft magnetic composites. In the DC region, sintered cores have been used as various electrical components, such as yokes and plungers. In the AC region however, in recent years there has been an increase in applications of soft magnetic composites for use in high-frequency regions such as in motors and reactors. This may be due to the significantly improved magnetic properties of soft magnetic materials created by powder metallurgy. Generally, to manufacture soft magnetic composites, insulated iron powder is filled into a mold, compression molded, and heat treated. Conventionally, the molding pressure was low and only low-density soft magnetic composites could be created, so that the magnetic properties tended to be lower than those of melted materials. However, advances in manufacturing methods in recent years, such as high compression molding technology, high purity powder, and fine powder technology permit the manufacture of high-density soft magnetic parts with equivalent magnetic properties to molten steel. In addition, insulation treatment technology for the base powder surface has also evolved and can now be applied to motor cores and reactor cores used in AC magnetic fields.

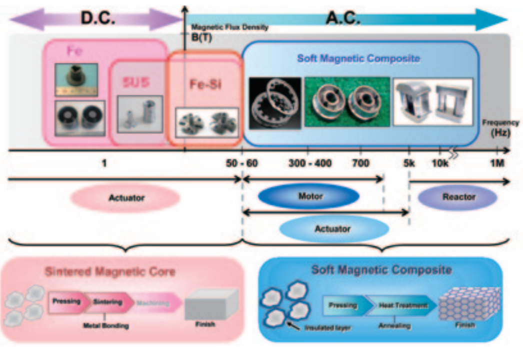

Figure 1　Schematic of the operation frequency and processes for sintered cores and soft magnetic composites

4 Technical Details

Pure iron-based reactor core that uses original chemical lubricant

While it is easy to increase the density of pure iron-based soft magnetic composites, the metal powder itself is soft so that plastic flow that destroys the insulating coating is likely to occur at the sliding surfaces of the mold. The corresponding significant increase in eddy currents in the surface layer prevents the properties of pure iron being realized. The increase in eddy currents is fatal for magnetic components, such as reactors, that are driven in the high frequency range and this issue presented a serious barrier to the entry and expansion of pure iron soft magnetic composites into the reactor market. Consequently, Hitachi Chemical started the development of an insulating lubricant that can suppress the plastic flow in the surface layer and improve the insulation of sliding parts, with an aim to commercialize net-shaped products.

Figure 2 shows the concept of the developed lubricant. The first aim was to suppress the plastic flow in the surface layer of soft magnetic composites at the time of mold extraction. It was thought that plastic flow could be suppressed by applying a solid lubricant that can exist as a strong lubricating layer even at large extraction forces and can actively fill and remain in the voids to suppress plastic flow at the time of extraction from the mold.

To meet the second aim of maintaining and improving insulation, insulating oxide particles were dispersed in the lubricant as an additive. The fine particles selectively bind to the surface of the iron powder coating during molding and serve to protect the coating. In this way, we developed a new insulating lubricant for soft magnetic composites that functions both to prevent plastic flow due to the lubricant itself and to improve the insulation of the coating.

We have also developed inverter reactors for photovoltaic generation system using our original chemical lubricant. **Figure 3** shows a photograph of the external appearance of these products. These are soft magnetic composites for reactors that exploit the high inductance of pure iron and maintain low iron losses through methods devised for mold lubrication and insulation during molding. In the future, we will promote the development of reactors for automobiles in anticipation of xEV. **Figure 4** shows a photograph of the external appearance of a reactor core for automobiles. Currently, reactors for automobiles are equipped with a cut core of silicon steel sheets or a composite reactor core using Fe-Si alloy powder. It is anticipated that soft magnetic composites will be adopted as reactor core in the future to meet demands for higher inductance and smaller size.

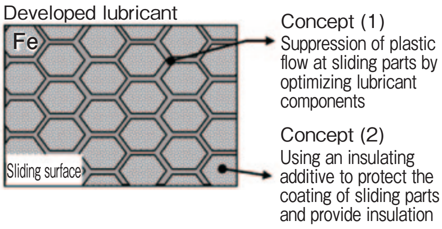

Figure 2 Concept of the developed lubricant

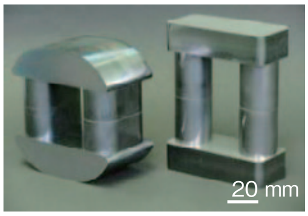

Figure 3 Inverter reactor cores for a photovoltaic generation system

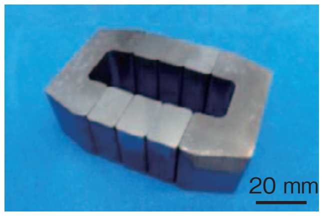

Figure 4 A reactor core for automobiles

3D net-shaped motor core

Soft magnetic materials currently used in the motor field are generally laminated electrical steel sheets. However, the laminates have a two-dimensional shape that makes it difficult to reduce the size of the motor when coil ends are included. On the other hand, a soft magnetic composite can be net shaped in three dimensions, and the motor core can be miniaturized by forming a three-dimensional magnetic circuit.

Hitachi Chemical has developed the EU-67 soft magnetic composite material with high magnetic flux density and low iron losses that exhibits excellent properties as a motor core. **Table 1** shows the magnetic properties of the EU-67 material. A comprehensive comparison of magnetic field analyses and actual machine evaluations indicated that claw pole motors that exploit the features of soft magnetic composites with a three-dimensional magnetic circuit, in particular, achieve the same improvement in output as 3-phase slotted motors of the same size using silicon steel plates. **Figure 5** shows the external appearance of claw-pole motor cores. When molding complicated shapes such as claw-pole motor core, multiple parts occur that have a small cross-sectional area in the press direction. This leads to concerns about problems such as failure of the mold when the necessary press force is applied. We were able to reduce the loads at positions of stress concentration and suppress damage to the mold by optimizing the mold shape by CAE analysis. The results of this investigation made it possible to perform molding with no damage to the mold even at a soft magnetic composite density of 7.5 Mg/m^3. **Figure 6** shows the results of CAE analysis.

In the case of axial gap motors too, it was possible to achieve the same improvement in output as a motor of the same size using silicon steel plates and the motor structure has a shape favorable for applying a soft magnetic composite core. **Figure 7** shows a photograph of a soft magnetic composite stator and the structure of an axial gap motor. As can be seen from the external appearance, the coil ends in a radial gap motor protrude outwards on both sides, whereas in an axial gap motor, a permanent magnet rotor is arranged opposing the end surfaces of the soft magnetic composite stators. As the coil ends do not protrude, the motor can be made more compact.

Table 1 Magnetic properties of EU-67

Item	Property
Density	7.5 Mg/m^3
Flux density : $B_{10000A/m}$	1.73 T
Iron loss : $W_{1T/400Hz}$	33 W/kg
Resistivity	5000 $\mu\Omega\cdot cm$


Figure 5 Claw-pole motor cores

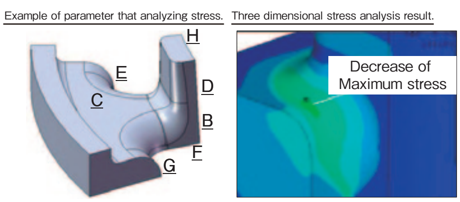

Figure 6 CAE analysis of a die

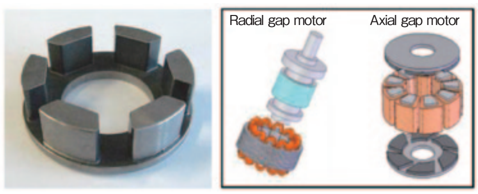

Figure 7 A soft magnetic composite stator core (left) and structure of an axial gap motor (right)

Thus, motors using a soft magnetic composite achieve the equivalent output to a conventional motor using silicon steel plates but with a significantly reduced motor volume. Due to their advantage of small size and thinness, these motors are expected to be adopted as xEV main motors and auxiliary motors in the future.

5 Future Business Development

- Development of pure iron-based reactor cores for automobiles
- Development of main and auxiliary narrow motors for automobiles