High Performance Magnetic Core for Induction Hardening Devices

1. Introduction

Machine structural parts, such as bearings and gears, are strengthened by the thermal process for improving reliability. The drive parts for automobiles are required to have strength in certain areas of complex shapes; therefore, the best thermal process is applied to the required area with induction hardening.

Magnetic material called "core" is attached to the heating coil of induction hardening equipment ("magnetic core"). In this paper, we are presenting a high performance magnetic core that exhibits superior magnetic characteristics as well as mechanical strength developed for induction hardening.

2. Magnetic core for induction hardening heating coils

One of the induction hardening parts for automobiles is a drive shaft. Fig. 1 shows some examples of its application.

A magnetic core installed on the back of the heating coil of induction hardening equipment can accelerate induction heating by concentrating magnetic flux on the work.

On the other hand, if it is installed on the front of the heating coil, it can block the magnetic flux to prevent heating where hardening is not needed. Therefore, it is an essential component for heating coil of induction hardening equipment.

When the target work has a complex shape and the depth of hardening area needs to be adjusted, induction heating can be completed by adjusting the shape, size,

Fig. 1 Example of induction hardened parts (Drive shaft)

*Nihon Kagaku Yakin Co., Ltd. of the NTN group develops various magnetic materials satisfying demand properties. In this report, it is attached to the heating coil part of the induction hardening device and introduces about a high-performance magnetic core in a magnetism characteristic and a mechanical characteristic to be used for control of the quenching depth.

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number, direction and position of the installed magnetic cores. This controls the hardening depth of the work.

Nihon Kagaku Yakin Co., Ltd. developed high performance magnetic core by combining iron powder and thermosetting resin as shown in Fig. 2.

3. Development of high performance magnetic core

3.1 Background of the development

Commonly used ferrite based magnetic core has relatively small iron loss even in the high frequency range. However, a larger size may be required to maintain hardening performance due to its low saturation magnetic flux density. Magnetic steel sheet cannot be used, even if it has high magnetic flux density, because the iron loss becomes larger in the higher frequency range.

Commercially available cores or base material of powder compact based cores manufactured by powder metallurgy are frequently used as magnetic cores installed on heating coils of induction hardening equipment. They are expensive, exhibit low material strength, and are challenging to machine and handle.

Therefore, our task was to develop magnetic cores that have better characteristics than the conventional material, can be produced with a simple manufacturing process, and are suitable for volume production.

3.2 Development concept

Since the magnetic cores for heating coils of induction hardening equipment are used in the high frequency range (several kHz to 100 kHz), the following characteristics are required:

(1) High saturation magnetic flux density
(2) High relative permeability
(3) Good frequency response (small variation of inductance against variation of frequencies)
(4) Low iron loss
(5) Superior mechanical strength

3.3 Features and performance of developed magnetic cores

3.3.1 Structure and features

Fig. 3 shows the structure of the developed high performance magnetic cores.

We used iron powder for powder metallurgy as the magnetic powder, added a small amount of thermosetting resin with high adhesive effect, and applied insulating layer on the iron powder surface by granulation process. This is a composite material which reduces the damage to the insulation layer by applying compaction molding at low pressure and thermal hardening.

This process brought a magnetic material that is strong yet has low contacts among magnetic powders. It has low iron loss, even in the high frequency range, so that the material can be used in a broad frequency range.

The features of the developed high performance magnetic cores are as follows:

- Saturation magnetic flux density: 1300 mT
- Relative permeability: 54
- Iron loss [10KHz/200mT]: 1480 kW/m³
- Radial crushing strength: 150 MPa
3.3.2 Performance
(1) Magnetic characteristics
   (i) Saturation magnetic flux density, relative permeability

Table 1 shows a comparison of the saturation magnetic flux density and relative permeability of the developed and conventional products. Fig. 4 shows the graph indicating the relation between the magnetic flux density B and magnetic field strength H (B-H curve).

The developed product improved approximately 10% in saturation magnetic flux density and approximately 30% in relative permeability over the conventional product. In addition, the rise of the magnetic flux density B is faster over the magnetic field strength H indicating its high efficiency. When the developed magnetic core is installed on the back of the heating coil of the induction hardening equipment introduced at the beginning of this paper, it can accelerate induction heating by concentrating magnetic flux on the work.

Table 1 Saturation magnetic flux density and relative permeability

<table>
<thead>
<tr>
<th>Material</th>
<th>Saturation magnetic flux density mT</th>
<th>Relative permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed material</td>
<td>1300</td>
<td>54</td>
</tr>
<tr>
<td>Conventional material</td>
<td>1200</td>
<td>40</td>
</tr>
</tbody>
</table>

(ii) Variation of inductance

Fig. 5 shows the rate of inductance variation, which serves as a measure of the magnetic field generation capability in the high frequency range, among the frequency characteristics of the magnetic material. The rate of inductance variation of the developed material is equivalent to the conventional material in all ranges, including the high frequency range, with both materials showing small inductance variation up to about 100 kHz.

As a result, it was revealed that this characteristic is stable up to the high frequency range.

(iii) Iron loss

Fig. 6 shows iron loss of the developed and conventional materials in the high frequency range (10 kHz) equivalent to the induction hardening condition. The iron loss of the developed product at 200 mT was approximately 15% smaller than the conventional material indicating less energy loss; a favorable result.
(2) Mechanical strength

The developed magnetic core is a strong material, where iron powders are adhered with thermosetting resin and hardened, as mentioned above. The mechanical strengths of the developed and conventional materials were compared by obtaining radial crushing strength (Fig. 7), applying compressive stress on the annular test piece, and using the following equation:

\[
K = \frac{F (D - e)}{L \cdot e^2}
\]

- \(K\) : Radial crushing strength (MPa)
- \(F\) : Maximum load at break (N)
- \(L\) : Length of hollow cylinder (mm)
- \(D\) : Outer diameter of hollow cylinder (mm)
- \(e\) : Wall thickness of hollow cylinder (mm)

The result is shown in Table 2. The radial crushing strength of the developed material is approximately 5 times stronger than the conventional material.

![Fig. 7 Method for radial crushing strength measurement](image)

### Table 2 Mechanical strength

<table>
<thead>
<tr>
<th>Material</th>
<th>Density g/cm³</th>
<th>Radial crushing strength MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developed material</td>
<td>6.1</td>
<td>150</td>
</tr>
<tr>
<td>Conventional material</td>
<td>6.4</td>
<td>30</td>
</tr>
</tbody>
</table>

4. Conclusion

In this paper, we presented the high performance magnetic core with superior magnetic and mechanical characteristics to be installed on the heating coil of inductance hardening equipment.

The developed magnetic core showed superior magnetic characteristics compared to the conventional product and significantly improved mechanical strength. By applying this high performance magnetic core to inductance hardening equipment, we believe we can achieve not only stable quality and improved reliability of inductance hardened components but also reduced size of these materials through enhanced strength and hardness of the structural components. This will contribute to manufacturing lighter vehicles.

References

1) Takayuki Oda, Shinji Miyazaki, Eiichiro Shimazu: The Reactor Core for HEV Boost Converter, NTN TECHNICAL REVIEW No. 81 (2013) 46-51
4) Japan Electronics and Information Technology Industries Association: Soft Magnetic Metal Materials