Soft Magnetic Insulated Iron Powder in Electromagnetic Applications

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Abstract

Soft magnetic material using powder metallurgical techniques are gaining wide spread use in motors, compressors and other rotating devices. Sintered soft magnetic materials are used extensively in automotive and non-automotive applications. To further grow the PM industry number of materials have been developed in the past several years. More recently a high-density soft magnetic material (AncorLam®) was developed. A range of variations is possible with this material system with excellent induction and coercive force. Green densities of 7.45 to 7.6 g/cm3 at 800 MPa compaction force, coercivity of 240 to 300 A/m, resistivity of 5000 micro-ohm cm (50 micro-ohm-meter), to 130000 micro-Ohm-cm, and a green strength of 40 to 90 MPa are achieved.

Introduction

Powder metallurgy offers excellent choice for lower cost solutions for designers of automotive structural and electronic components. (1)

It has been the desire of powder metallurgists to replace lamination steel with powder metal components. Lamination steels are punched to shape and are stacked and welded. Powder metal components can be made directly to shape in one single operation. The development of the powder metal process for replacing lamination steel was inspired by the fact that eddy current core loss can be confined to an individual particle in a compact as long as a coating electrically isolates these particles. Major application of these types of materials is in devices, such as motors, induction coil cores, actuators etc.

Work at Hoeganaes on a technology such as this resulted in the development in iron polymer coated powders. [2-4] These powders required heating of the powder to 150C and the die at 250C to achieve plastic softening and achieve densities as high as 7.45g/cm3

A new coating process has been developed to individually coat iron powder particles with a oxide coating, this new powder does not require heating of the powder for producing parts and also use moderate (93C) die temperatures. This powder is referred to as AncorLam. This newly developed insulated iron powder is compacted with heated dies at 93°C. Densities as high as 7.5 g/cm³ can be achieved at compaction pressures of 800 MPa with resistivity exceeding 5,000 micro-Ohm cm. The green strength of these compacts after curing at 450C for one hour in nitrogen atmosphere is dependent on compaction pressure, at 800 MPa a green strength of as high as 90 MPa is achieved.
**Experimental**

Insulated iron powder was premixed with lubricants and compacted at 800 MPa to produce green torroids. The ratio of inner diameter to outer diameter is 0.67. The torroids produced are cured at 450°C for one hour in a nitrogen atmosphere. The core properties were measured using a commercial magnetic Hysteresisgraph. The DC portion complies with ASTM A773/773-M1 and AC portion to ASTM A927/927-M99.

**Results and Discussion**

Figure 1 shows the hysteresis curve measured using DC applied field. In Figure 2, a comparison is made of the hysteresis curves measured at various AC fields. The near complete superposition of the loops suggests very little contribution from the eddy current loss indicating good insulation of individual particles.

![Figure 1: D.C Hysteresis of Insulated iron powder pressed to a density of 7.5 g/cm³. (Applied field in Oe)](image1)

![Figure 2: Hysteresis Curves measured at various AC frequencies superposed on a DC hysteresis curve. (Applied Field in Oe)](image2)

A comparison of core loss for AncorLam with 0.35mm commercial lamination steel is shown in Figure 3 below. AncorLam was pressed to a density of 7.45 g/cm³. Core loss data was collected at 1Tesla induction. It is interesting to see the superior performance of AncorLam at higher frequencies. Lamination steels coating resistivity breaks down at higher frequencies. Resistivity is a key component in eddy current losses and varies as square of the frequency.
We developed additional materials with varying levels of permeability and core loss to address specific application needs. These variations were achieved by varying the coating thickness and particle size distribution. AncorLam and AncorLam HR uses particle size distribution of 20 to 200 microns. Coarser particle distribution in AncorLam 2 type of grades improves coercive force and Induction. Table 1 shows the properties of various developed materials.

Table 1: Properties of various AncorLam materials developed

AncorLam 2HR* uses proprietary high-density process. Note: all the data above (except Hall flow and apparent density) are measured after curing the torroid at 450C for one hour in nitrogen atmosphere.

<table>
<thead>
<tr>
<th>Property</th>
<th>Ancorlam</th>
<th>Ancorlam HR</th>
<th>Ancorlam 2</th>
<th>Ancorlam 2HR</th>
<th>Ancorlam 2HR *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induction at 40 kA/m, Tesla</td>
<td>1.9</td>
<td>1.902</td>
<td>1.954</td>
<td>1.931</td>
<td>2.02</td>
</tr>
<tr>
<td>Induction at 10 kA/m, Tesla</td>
<td>1.47</td>
<td>1.52</td>
<td>1.6</td>
<td>1.58</td>
<td>1.64</td>
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<tr>
<td>Maximum Permeability</td>
<td>470</td>
<td>370</td>
<td>550</td>
<td>490</td>
<td>610</td>
</tr>
<tr>
<td>Coercive force A/m</td>
<td>300</td>
<td>270</td>
<td>245</td>
<td>240</td>
<td>246</td>
</tr>
<tr>
<td>Coreloss at 400Hz,1T, W/kg</td>
<td>67</td>
<td>53</td>
<td>67</td>
<td>54</td>
<td>52</td>
</tr>
<tr>
<td>Coreloss 1kHz,1T, W/kg</td>
<td></td>
<td>147</td>
<td>245</td>
<td>163</td>
<td>172</td>
</tr>
<tr>
<td>Green density g/cm3</td>
<td>7.47</td>
<td>7.45</td>
<td>7.49</td>
<td>7.45</td>
<td>7.6</td>
</tr>
<tr>
<td>cured strength,MPa</td>
<td>90</td>
<td>60</td>
<td>40</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>resistivity micro-Ohm-meter</td>
<td>&gt;50</td>
<td>&gt;1300</td>
<td>&gt;50</td>
<td>&gt;400</td>
<td>&gt;475</td>
</tr>
<tr>
<td>Apparent density g/cm3</td>
<td>2.85-3.1</td>
<td>2.85-3.1</td>
<td>2.85-3.1</td>
<td>2.85-3.1</td>
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<tr>
<td>Hall flow seconds max</td>
<td>32max</td>
<td>32max</td>
<td>32max</td>
<td>32max</td>
<td>32 max</td>
</tr>
</tbody>
</table>

Figure 3. Variation of total losses as a function of frequency measured at 1 Tesla induction.
Applications

Major application includes the use of AncorLam as cores in induction coils for automotive applications. Use of this type of product for fuel injector applications in diesel engines is very promising. The higher induction with insulated iron powder compacts allows the possibility to replace soft ferrites in electronic applications using high frequency devices. The insulated iron will be effective up to 20 KHz by controlling the thickness of insulated coating. The use of insulated iron to replace lamination in electric motors requires redesign of the motor to take advantage of the three dimensional magnetic flux achievable with insulated iron compared to preferred flux in the sheet rolling direction of lamination steels. Other possible applications for this material include stators for brushless DC motors [5], brushed DC motors, stepper motors, claw pole motors, switch reluctance motors, etc. Insulated iron compacts are particularly effective for devices operating at frequencies greater than 400Hz [6-14].

Conclusion

A new insulated iron powder (AncorLam) was developed that can be compacted to high densities, excellent green strength, and resistivity. Core loss data reflect eddy current losses dominating at frequencies greater than 1000 Hz. Further advancements are in progress to improve the core losses.

References


