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The percolation effect and optimization of soft magnetic properties of FeSiAl magnetic powder cores

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ABSTRACT

In this paper, a new magnetic percolation phenomenon between the green compact density ρ and effective permeability μe in $FeSi_{9.6}Al_{6.5}$ magnetic powder cores, was discovered. The Magnetic Percolation Area of ρ is the range of 5.6 g/cm^3 ~ 5.78 g/cm^3, and the percolation threshold is 5.78 g/cm^3. As a result of the guidance of the percolation theory, the best comprehensive magnetic properties have been optimized through adjusting the distribution of powders. The special distribution of the magnetic powder cores with the best comprehensive magnetic properties was as follows: the content 60% with the particle size distribution of 100–200 mesh, the content 20% with the particle size distribution of 200–325 mesh and the content 20% with the particle size distribution of ≥400 mesh. When the green compact density ρ of cores was 5.79 g/cm^3, and the frequency was in the range of 1 kHz ~ 100 kHz, the best comprehensive magnetic properties were as follows: μe = 91, Δμ = 0.61%, μe(H80 Oe) = 43, μe(H100 Oe) = 33, μe(H120 Oe) = 26, Pc(50 mT/20 kHz) = 30.58 kW/m^3, Pc(50 mT/50 kHz) = 76.85 kW/m^3, Pc(50 mT/100 kHz) = 178 kW/m^3. Not only have those cores the excellent constant magnetic properties with frequency, the excellent DC superposition characteristic and the lower loss at high frequency, but also the effective permeability outstandingly goes up, which has important significance for the miniaturization of inductance components.

1. Introduction

Metal magnetic powder cores (MMPCs) are made up of metal powders with excellent soft magnetic properties and after the surface insulated treatment, which used to be directly compacted under high pressures. MMPCs can't be sintered at high temperature, but must be relief annealed, which are different from the metal powders metallurgy materials. Those powders of MMPCs are separated by the thin insulation so that the particles size will not grow with the diffusion of atoms. The internal microstructures of MMPCs are composed of powders and a great deal of three-dimensional mesh gaps. When MMPCs are applied, in order to improve the strength and wear-resistance, the epoxy resin used to be dipped into the gaps of cores, at last, which makes cores form metal powders/epoxy resin composite materials [1–4].

MMPCs are mainly used in AC circuits of medium-frequency that the frequency is usually above 500 Hz, and electrical signals circuits, as the inductance components or transformer cores, and so MMPC is one of three elemental components (such as, inductance, capacitor, resistors) for electrical and electronic products [1–3]. At present, electronics miniaturization and energy conservation are the main development direction of MMPCs. MMPCs have the advantage of soft magnetic properties in the frequency band of 0.5 kHz ~ 100 kHz, which are the indispensable materials because of electronics miniaturization and energy conservation. Electronics miniaturization requires constantly improving the effective permeability of MMPCs, on the other hand, loss of electronics at high frequency requires to be dropped for energy conservation demands.

FeSiAl alloy magnetic powder core (FeSiAl core) is very typical kind of MMPCs, which is made up of $FeSi_{9.6}Al_{6.5}$ alloy powders coated with insulation material. The maximum flux density of FeSiAl cores is 1.05 T and the effective permeability μe, is in the range of 26 ~ 70. FeSiAl cores can be used in the frequency band above 8 kHz, and even produce no noise because the magnetostriction, λs, is close to zero. The DC superposition characteristic of FeSiAl cores is better than that of MPP, and cost-effective of them is the best. FeSiAl cores are mainly used in AC inductance, output

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inductance, line filters and circuits for rectifying the power factors, etc [1–9].

The effective permeability μe, the frequency characteristic(μe-f), the DC superposition characteristic and the loss at high frequency Pc, are four important indicators interacted each other, respectively corresponding to device miniaturization, application frequency band, application circuit power and energy conservation. Therefore the four indicators must be integrated and coordinated. At present, the best soft magnetic properties of FeSiAl cores that μe is about 70, Pc(50 mT/100 kHz) is about 200 kW/m^3, and the frequency characteristics (μe-f) that Δμ is less than 2% can be achieved[1–11].

How to further improve the comprehensive soft magnetic performances of $FeSi_{9.6}Al_{6.5}$ cores plays a very important role in electric device miniaturization, energy conservation and reducing consumption. Especially, under the condition that the frequency characteristics will not be reduced and the loss level at high-frequency will not be increased, further improvement of μe is significant. So far, to improve the soft magnetic properties of FeSi alloy series magnetic powder cores, some literatures have recorded a few means, such as, surface processing or coating [6,10,11], heat treatment [12,13], changing the particle size [14,15], selecting the amorphous or nanocrystalline powders [16–18], further alloying powders [7,19,20], and adopting new compact process [8,21]and so on. However, the comprehensive soft magnetic properties haven't still made a significant breakthrough.

According to a large number of productions and experiments, it can be speculated that there may exist the percolation effect between the density and soft magnetic properties of the magnetic powder cores. The percolation effect is that when the system component or an index reaches a certain value (called the percolation threshold), some long-range associability will suddenly appear or disappear among the range of percolation threshold, which makes the physical properties change sharply. Studying the percolation characteristics of the magnetic powder cores and finding out the percolation threshold play a key role in controlling the soft magnetic properties of powder cores. Based on the percolation characteristics, changing the size and contents of the powders, reasonably matching the powders size and finding out the best size match, can improve the soft magnetic properties of powder cores significantly, which have great guidance significance for industrial productions. By the density experiments of magnetic powder cores, this article studies the associability between the density and magnetic permeability of the green compact, finds out the percolation effect and optimizes the soft magnetic properties of powder cores according to the percolation effect.

Fig. 1. Samples of FeSiAl magnetic powder cores.

2. Preparation and analysis of FeSiAl MPCs

At first, $FeSi_{9.6}Al_{6.5}$ powders were selected. The distribution of particles size was 42% for 200 ~ 400 mesh powders, 37.6% for 400 ~ 500 mesh powders, 20% for more than 500 mesh powders and 0.4% for less than 100 mesh powders. This powders type was signed as No. A0.

The powders coated with silicone, were molded into green compacts with the size of Φ27-Φ17-10 mm under various pressures, then annealed for 750 °C × 60 min and impregnated with epoxy glue. Finally $FeSi_{9.6}Al_{6.5}$ magnetic powder cores (MPCs) have been prepared (Fig.1).

The samples of MPCs were analyzed to observe the microstructural aspects by JSM-6701F cold field emission scanning electron microscope (SEM), and to clear its composition by EDS. The microstructures of MPCs were observed by metallographic microscope.

Cores were winded turns of 33 with copper wires of Φ0.6 mm. Soft magnetic properties of the cores were measured by TH2816B digital electric bridge, such as effective permeability μe, the frequency characteristics (μe-f) Δμ(%) when the frequency being the ranger of 20 kHz ~ 100 kHz, the DC superposition characteristic, and the loss at high frequency Pc when the magnetic flux density H was 50 mT and 100 mT respectively.

3. Results and discussion

3.1. Microstructure of MPC

According to EDS analysis (Fig.2), the actual component of the designed $FeSi_{9.6}Al_{6.5}$ powders is about Fe-10.4 wt%Si–7.0 wt% Al. There is a little difference between the designed component and

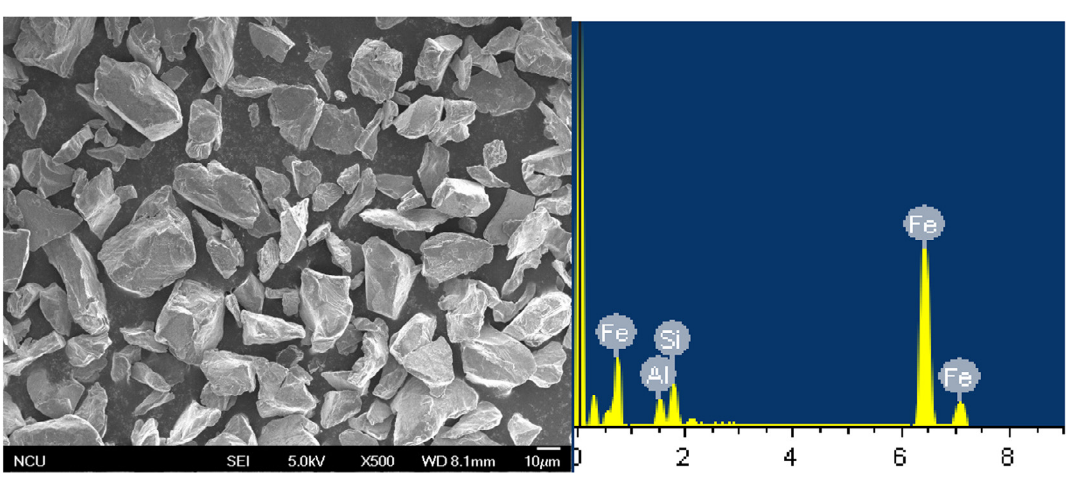

Fig. 2. SEM and EDS of $FeSi_{9.6}Al_{6.5}$ powders.