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Effects of Crystal Grain Size and Particle Size on Core Loss For Fe-Si Compressed Cores

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Abstract

Core loss of soft magnetic powder cores have been focused on to achieve high efficiency of power supplies. In this study the effects of crystal grain size on core loss were investigated by changing heat treatment conditions. It was found that core loss is influenced by crystal grain size because eddy current loss decreased and hysteresis loss increased by making crystal grain size smaller, and it is also influenced by particle size.

Keywords : powder core, atomized powder, hysteresis loss, eddy current loss, crystal grain size

1. Introduction

Soft magnetic powder cores are widely used for choke coils and reactors of switching regulators and DC-DC converters. Recently powder cores have been used replacing the conventional soft ferrite for smoothing and boost choke coils of these power supplies in high frequency 50kHz to 1MHz. There have been a lot of efforts to prepare Fe-3mass% Si powder cores with the large saturation magnetic flux density. The cores presented lower core loss than conventional lamination Si steels at high frequency, therefore they have a high potential of applying to magnetic cores like power supplies and high rotation motors.

In this study, the influence of heat treatment conditions on core loss was examined and effects of crystal grain size on eddy current loss were investigated.

2. Experimental and Results

Fe-3mass% Si alloy powders were prepared by modified water-atomizing method [1, 2]. The powders were sieved to make various particle distributions. These particles were seen almost round or spherical shape in every size distribution. The powders were heat treated at 948 to 1223K holding 3 hours under hydrogen gas atmosphere to change the crystal grain size, and then silicone resin binder was added by 0.5 mass%. Toroidal cores were prepared by press forming under 1960MPa at room temperature. Finally the cores were heat treated at 948 to 1023K holding 1 hour in Ar gas atmosphere.

Fg.1 shows the influence of powder heat treatment temperature on core loss. Core heat treatment temperature was 1023K. With increase of powder heat treatment temperature, eddy current loss increases and hysteresis loss decreases. Core loss indicates minimum value at specific heat treatment temperature, such as with 130μm powder at 948K. This figure deduces the existence of the parameters which have influence on eddy current loss as well as hysteresis loss contributed by heat treatment temperature differences, such as crystal grain size.

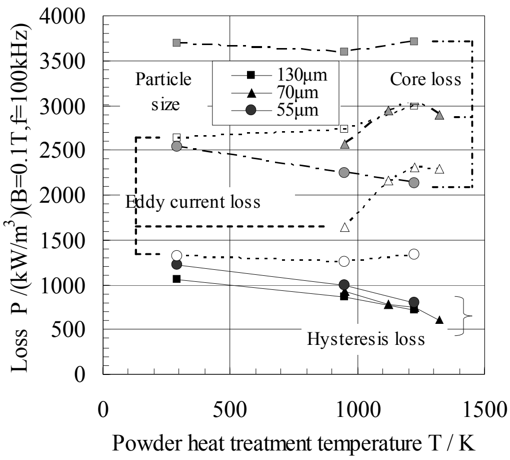

Fig. 1. Influence of powder heat treatment temperature on losses

To investigate the correlation between crystal grain size and hysteresis loss as well as crystal grain size and eddy current loss. As it is generally accepted that hysteresis loss reduces with increase of crystal grain size, the same tendency is identified with increase of heat treatment temperature and particle size.

On the other hand, it has been reported that eddy current loss increases with increase of particle size for Fe-Si and Fe-Si-Al powder cores under the condition that resistivity of them is so high that eddy current generates only inside electrically isolated particle [3, 4].

In this study it was found that eddy current loss depends on crystal grain size as well as particle size. Fig.2 shows crystal grain size dependency of eddy current loss. It indicates that eddy current loss increases as crystal grain size becomes larger as well as particle size becomes larger. These experimental results suggest that eddy current should generate based on the 2 modes. One is uniform magnetization in the particle, so called classical eddy current, and the other is localized magnetization involving crystal grain boundaries and domain wall motions etc. Classical eddy current loss is well known to be proportional to the square of particle size. So the measured eddy current loss data was analyzed separating into the contribution of classical eddy current loss and crystal grain by means of least square method.

$$Pe = \alpha D^2 + \beta d^m = 0.0967D^2 + 424d^{0.302} \quad (1)$$

(at 100kHz,0.1T)

Pe: eddy current loss [kW/m^3] D: particle size [μm]
d: crystal grain size [μm]

Moreover classical eddy current loss is expressed as equation (2) for spherical magnetic material.

$$Pe = (\pi BDf)^2/(20\rho) = 0.110D^2 \quad (2)$$

ρ: resistivity of particle (intrinsic resistivity)= 45×10^{-8} [Ωm]
B: excited maximum magnetic flux density = 0.1 [T]

The regression coefficient (0.0967) of equation (1) obtained by least square method and the one (0.110) of equation (2) derived from the classical electromagnetism shows good correspondence, and that means that eddy current loss is attributed to not only uniform magnetization but also localized magnetization such as crystal grain. The correlation between eddy current loss and domain structure through crystal grain can not be discussed in this study and now it is under investigation. Fig.2 also represents the calculated data using equation (1). Measured data are approximately consistent with the calculated data. Contributions of crystal grain are supposed fairly large, therefore fine particle size and at same time fine crystal grain should be effective to reduce eddy current loss according to equation (1). But hysteresis loss increases with finer crystal grain. It is necessary to choose the optimum particle size and crystal grain size for achieving minimum core loss.

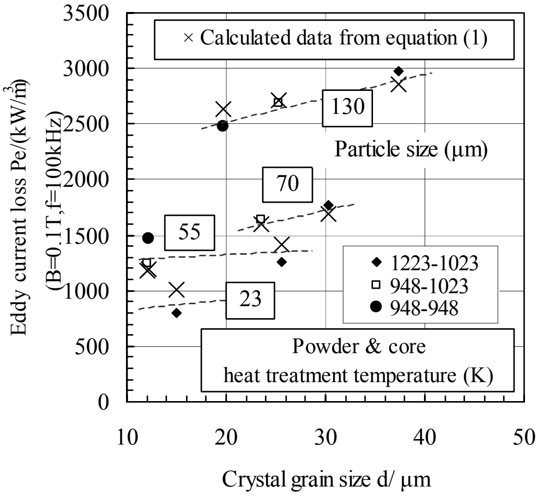

Fig. 2. Influence of crystal grain size on eddy current loss together with calculated data from equation (1)

3. Summary

We have studied influence of heat treatment conditions of atomized Fe-Si powder cores and investigated the correlation between crystal grain size and particle size, and losses. Higher powder and core heat treatment temperature make crystal grain size larger and make hysteresis loss decrease and eddy current loss increase. Both losses are influenced by particle size of powders as well as crystal grain size by heat treatment conditions at each frequency so that those parameters should be considered in terms of achieving low core loss.

4. References

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