Improved Magnetic Properties of Silicon-Iron Alloy Powder Core

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Abstract

Eventhough Fe-6.5 wt.% Si alloy shows excellent magnetic properties, magnetic components made of the alloy are not totally because of its extremely low ductility. In order to overcome this demerit of alloy, 6.7 wt.% Si alloy powders were produced by gas atomization and then post-processed to form magnetic cores. By doing so, the total core loss could be minimized by reducing both hysteresis and eddy current loss. From our experiments, we were able to achive a core loss of 390 mW/cm^3 at 0.1 T and 50 kHz through proper processes and a permeability μ_{eff} of 68 at low frequency.

Keywords : Fe-6.5Si, powder core, core loss, grain size, particle size, atomization

1. Introduction

Silicon steels containing about 3 wt.% Si are widely used as core materials in transformers, magnetic amplifiers and many other electronic devices. Also, it is widely known that the soft magnetic properties of the silicon steel sheets can be improved by increasing the silicon content. At about 6.5 wt.% Si, magnetostriction(λ) and crystalline anisotropy(K) can be optimized to have lower core loss because of higher permeability and lower coercivity(H_c) at the composition. However, addition of silicon deteriorates ductility of iron-base alloy so that the alloys with Si content higher than ~ 4 wt.% become too brittle to be processed by conventional rolling process at room temperature [1-5]. Some authors have reported that this can be overcome by using silicon-iron alloy powder cores [6]. However, there have not been enough studies to show that they fully satisfy modern electronics requirements such as lower core loss and high permeability. In this paper, we investigated the magnetic properties of Fe-6.5 wt.% Si powder cores, by utilizing PM techniques and to achieve a value lower than 450 mW/cm^3 at an induction of 0.1 T and 50 kHz.

2. Experimental and Results

Fe-6.7 wt.% Si alloy powders with sperial shape were prepared by gas atomization process, and then sieved to classify four groups of powders with different particle sizes. These powders were annealed at 800~1170℃ in H_2 gas atmosphere for 2 hours and then subjected to wet coating process to form ceramics insulating layers. Toroidal core (ϕ_{in} = 14.6, ϕ_{out} =26.8, and H= 11.1 mm) were produced under a high pressure of 18 ton/㎠ and then heat treated at 730℃ for 1 hour in nitrogen atmosphere to reduce the press-induced internal stress. Effective permeability μ_{eff} and core losses of the powder cores were evaluated by impeadance analyzer(HP4294A) and B-H analyzer(Iwatsu SY-8232), respectively.

Figure 1 shows the optical microscopy of Fe-6.7 wt.% Si alloy powders annealed at a) 880 ℃ and b) 1170 ℃. As the annealing temperature increases, the grain size increases from about 20 to 100 ㎛. Figure 2 shows the core loss (hysteresis loss (P_{hv}), eddy current loss (P_{ev}) and tatal loss (P_{tot}=P_{hv}+P_{cv})) and grain size of the core, the powders of which were annealed at varous temperatures.

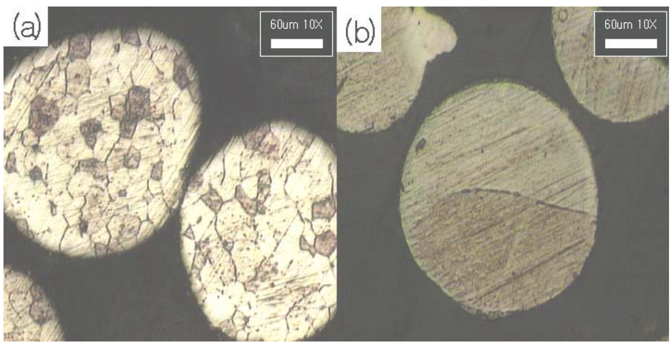

Fig. 1. Optical microscopy of Fe-6.7 wt.% Si alloy powders annealed at a) 880 ℃ and b) 1170 ℃.

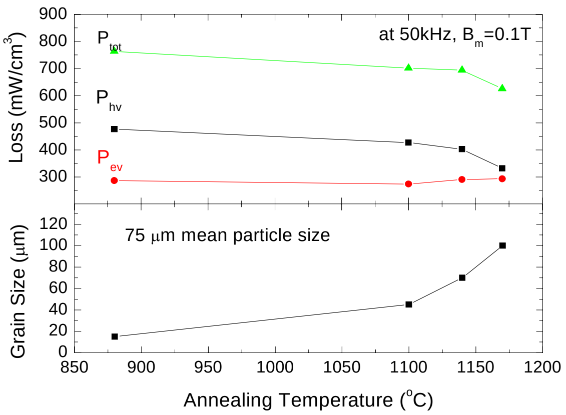

Fig. 2. Core loss and grain size of Fe-6.7 wt.% Si alloys annealed at various temperatures.

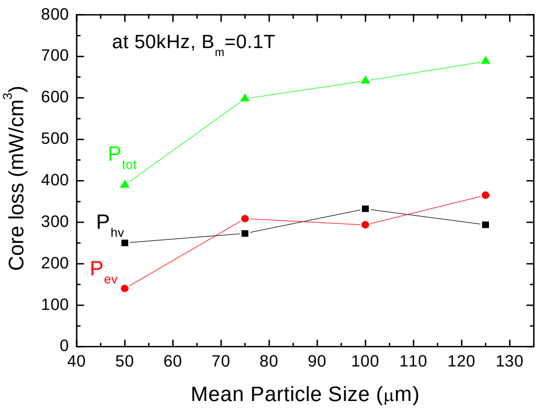

Fig. 3. Core loss of Fe-6.7 wt.% Si powder cores as a function of particle size.

As the annealing temperature increased from 880 to 1170℃, total core loss (P_{tot}) and hysteresis loss (P_{hv}) decreased from 750 to 610 mW/cm^3 and from 470 to 330 mW/cm^3, respcetively. However, there was no noticeable change in eddy loss (P_{ev}). This result is due to larger gain size of the powder annealed at higher temperature. The coercivity H_c of soft magnetic materials is inversely proportional to particle or grain diameter [7].

Figure 3 shows the dependancy of core loss on the particle sizes. The smaller particle diameter is, the lower the core loss is. The behavior of P_{ev} corresponds with that of P_{tot} while there is relatively small change in P_{hv}. The powder core with a mean particle size of 45 ㎛ shows the lowest P_{tot} value of 390 mW/ cm^3. The results in Figure 3 corresponds with A.J. Moses's results [8] based on which we can conclude that large grain and high green density is required for small hysteresis loss while small particle size and high reisitivity is required for small eddy current loss.

3. Summary

Fe-6.7 wt.% Si alloy powder cores were succefully manufactured using gas atomization, annealing and coating process in this work. The total core loss could be minimized by reducing both hysteresis and and eddy current loss, which were attributed to both grain size adjustment and particle size control. An excellent core loss of 390 mW/cm^3 was achieved at an induction of 0.1 T and 50 kHz with proper processes and a permeability μ_{eff} of 68 of the core at low frequency was kept up to 700 kHz. These properties are comparable with the properties of well-known soft magnetic materials such as Fe-Si-Al and Ni-Fe alloys. From the above results, it could be concluded that Fe-Si alloy powders with high Si content have a high potential for commercialization.

4. References

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