The Effect of Various Binder Additions on the Magnetic Properties of Soft Magnetic Amorphous P/M Cores

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ABSTRACT

The effect of different binder addition on the soft magnetic properties of a $Fe_{78}Si_{13}B_9$ amorphous alloy powder core was studied. The powders were mixed with polyimide-based binder, or water glass of ~ 2 wt.% respectively, followed by cold compaction to form toroidal-shaped soft magnetic cores. Heat-treatment at 450℃ was performed to control the nano-grain structure. Among the P/M cores, the toroidal Fe-based core mixed with water glass binder diluted with DI water showed the best magnetic properties. Well-coated water glass binder on the powder surface improved the core loss and permeability. The excellent magnetic properties was obtained from the amorphous powder core mixed with 2wt% water glass diluted with DI water at 1:4 after annealing at 450°C for 11 minutes .
Key words: magnetic core, amorphous, binder, diluents

INTRODUCTION

Recently, as the size of electromagnetic devices such as Switch Moded Power Supply (SMPS), magnetic heads, transformers and electronic devices has been miniaturized, the demand for soft magnetic materials with high performance at a high frequency range is being increased. Most of the soft magnetic materials used in the field were iron, ferrite, permalloy (Ni-Fe) and sendust (Fe-Si-Al) powders because they have high saturation permeability and low core loss.[1] However, in a high frequency range, the magnetic properties of these materials were rapidly deteriorated due to the increased eddy current.

According to the previous studies [2], the core loss of Fe-Si-B amorphous powder compact was approximately ~90 W/kg at 0.1 tesla and ~ 50 kHz. On the contrary, the nanocrystalline Finemet powder compact mixed with diluted binders showed a remarkably decreased core loss after heat treatment for stress relief and crystallization. Based on the experimental results, the modified powder mixing process showed a good potential to develop the advanced amorphous powder core with excellent magnetic properties [3].

Therefore, in order to evaluate the effect of binder mixed with alloy powder on the magnetic properties, various binders diluted at the difference ratios were added to amorphous alloy power in this study [4-5]. The processed amorphous alloy powder cores have been studied mainly in terms of core loss and permeability at a high frequency.

EXPERIMENTAL PROCEDURE

The Fe-Si-B base amorphous ribbons were fabricated via melt spinning at the cooling rate of about 10^6℃/sec, and then the ribbons was heat treated at 370℃ for easy pulverization to make powder. Heat treated ribbons were jet-milled, and then ball-milled for 30 hrs to make homogeneous fine powders of ~53 ㎛ in size. To study effect of the binder in core, the pulverized powers was mixed with different binders. One group of the amorphous alloy powders were mixed with 2wt% of water glass and DI water at the ratio of 1:2 and 1:4, respectively. The other group of alloy powders were mixed with polyimide and NMP(N-Methyl-pyrrolidone) at the ratio of 1:4. Cold compaction was performed at 650MPa to form toroidal-shaped soft magnetic cores, which were heat treated at 450℃ for up to 11 minutes under a nitrogen atmosphere.

The magnetic properties such as the permeability and core loss of each core were investigated using a B-H analyzer and a flux meter at the high frequency range of 5 ~ 50 kHz. The microstructure of amorphous alloy power was analyzed with scanning electron microscope (SEM).

RESULTS & DISCUSSION

Figure 1 shows the SEM image of Fe-Si-B amorphous powder. Since amorphous ribbons was prepared by melt-spinning and then pulverized, the power was observed as flake-shaped.

Figure 2 showed the frequency dependence of core loss for Fe-Si-B amorphous powder core mixed with water glass. The core loss of amorphous powder core, mixed with the 2 wt% water glass diluted by DI water at the radio of 1: 4, was dramatically decreased. The lower core loss or amorphous power core was considered to be mainly caused by interaction between the amorphous power and the diluted water glass.

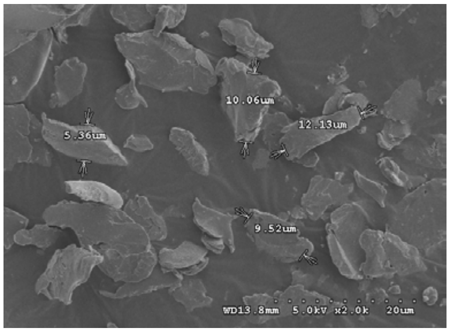

Figure 1: SEM image of Fe-Si-B (amorphous powder)

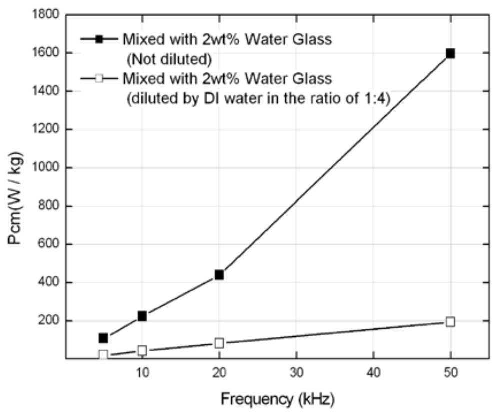

Figure 2: The dependence of core loss for Fe-Si-B amorphous powder core mixed with 2 wt% water glass and the diluted 2 wt% water glass at 1:4

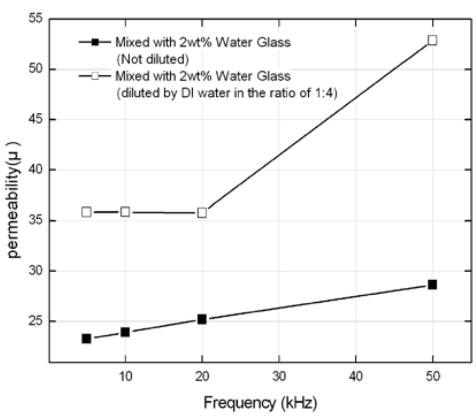

Figure 3: The dependence of permeability for Fe-Si-B amorphous powder core with 2 wt% water glass and the diluted water glass at the radio of 1:4.

The core lose showed the very low value of ~ 200 W/kg when the amorphous powder core was mixed with water glass diluted by DI water at the ratio of 1:4..

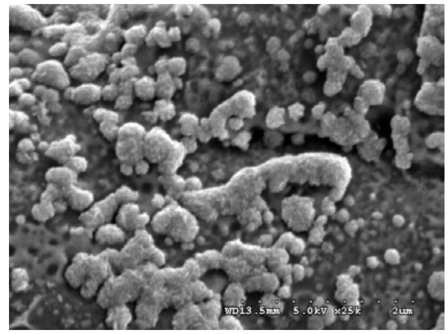

Figure 4: SEM image of Fe-Si-B amorphous powder surface mixed with 2 wt% water glass (without diluents).

Figure 3 shows the frequency dependence of permeability of Fe-based amorphous powder core mixed with the diluted water glass. The permeability of amorphous powder core mixed with diluted binder at 1:4 is gradually increased with frequency, and reached to a value of ~ 53 at 50 kHz. The reason of the relatively low permeability of core mixed without DI water was caused by the inhomogeneous distribution of the water glass with a high viscosity, as shown in Figure 4.

As a result, it can be concluded that the properly diluted binder affect the magnetic properties pronouncely by the effective insulation of magnetic powders.

Figure 5 shows the core loss variations of amorphous cores mixed with various binders (water glass and Polymide) and diluents (DI water and NMP) after heat treatment from 11 to 19 minutes, measured at 50 kHz under an applied magnetic field of 0.1 T. The powder core mixed with water glass diluted by DI water at 1:4 showed the lowest value among the specimens, which was attributed by well –distributed binder beyween the alloy powders. The diluted Polymide was not effective to reduce the core loss, indicating the flowability of binder is one of important factors for powder core process.

Figure 6 shows the permeability variations of amorphous cores mixed with various binder as a function of annealing time. (f = 50 kHz, Bm = 0.1 T)

The permeability of amorphous core mixed with polyimide and NMP is almost constant at around 25 after annealing at 450℃, regardless of heat treatment time. The low permeability seemed to be caused by the easy vaporization of polyimide, resulting in the formation of voids in the matrix, at high temperature.

On the contray, the permeability was remarkably increased by the use of water glass diluted with DI water because of effective insulation of the alloy powders. However, with the increase of annealing time more than 11 minutes, the permeability was decreased rapidly. This implies that the stress relief treatment less than 11 minutes was sufficient for the powder cores.

As a result, the core mixed with water glass and DI water at the 1:4 ratio showed the best magnetic properties of amorphous powder core. The results revealed that to fabricate the core with superior magnetic properties, the water glass diluted by DI water is strongly recommended as insulator for soft magnetic powder cores.

The ideal combination ratio of water glass and DI water was not decided yet, however the dilution and evaporation method showed a good potentials to develop the high performance soft magnetic cores.

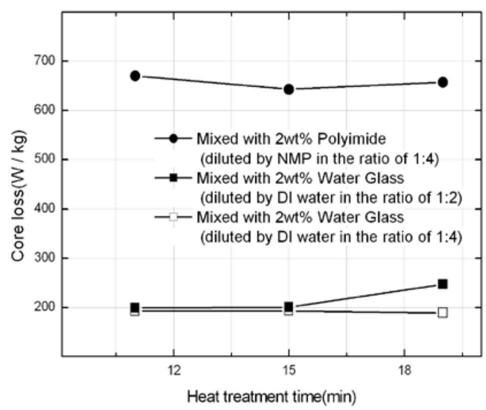

Figure 5: The Core loss variations of amorphous cores mixed with various binder and dilluent and with heat treatment time. (measure at f = 50 kHz, Bm = 0.1 T)

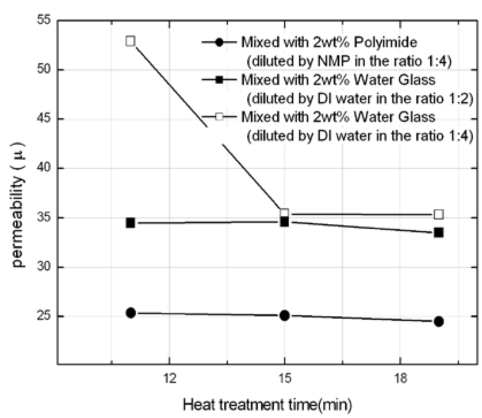

Figure 6: The permeability variations of amorphous cores mixed with various binder as a function of heat treatment time. (measured at f = 50 kHz, and Bm = 0.1 T)

CONCLUSIONS

The $Fe_{78}Si_{13}B_9$ amorphous powders were mixed with 2 wt% binders to analyze the effect of various binder additions on the magnetic properties such as core loss and permeability.

1. Magnetic properties were strongly affected by the kind of binders and diluents. The core mixed with water glass showed better magnetic properties than that with polyimide.
2. The amorphous powder cores mixed with water glass diluted using DI water possessed the improved soft magnetic properties in core loss and permeability.
3. Water glass diluted with DI water at the ratio of 1:4 improved the magnetic properties of powder cores effectively. Therefore, the dilution process of binders is high recommended to produce the amorphous powder cores

REFERENCES

[1] Y. Yoshizawa, S. Oguma, K. Yamauchi, New Fe-based soft magnetic alloys composed of ultrafine grain structure, J. Appl. Phys. (1988)64, 6044.

[2] R. Hasegawa, R. E. Hathaway, and C. F. Chang, J. Appl. Phys. 57(1), 3566 (1985).

[3] (1997–2005) The Latest Development in Soft Magnetic Composite Technology. SMC Update, Reports of Höganäs AB, Sweden.

[4] L. Pennander and A.G. Jack, "Soft Magnetic Iron Powder Materials AC Properties and their Application in Electrical Machines", paper presented at EURO Powder Metallurgy (EURO PM) 2003, Valencia, Spain October 2003.

[5] L. Hultman and Z. Ye, "Soft Magnetic Composites – Properties and Applications", paper presented at Powder Metallurgy and Particulate Materials (PM2TEC) 2002, Orlando, USA June 2002.