Magnetic properties of soft magnetic composite using external flux impression method

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In this paper, fabrication method with flux impressing to improve the efficiency of motor using soft magnetic composite is proposed and examined. The authors attempted to minimize the iron-loss by impressing the flux during the compaction process of iron powders to have arranged powders. By impressing magnetic flux, iron-loss of SMC was decreased by 6.25% because of decreased hysteresis loss by increased permeability. Proposed method, so called EFIM (External Flux Impression Method), would be helpful for high efficiency, high output and miniaturization of motor core and actuator core hereafter.

1. Introduction

Recently, a lot of efforts to apply a soft magnetic composite for a light-weight actuator have been actively attempted. Using the soft magnetic composite is more beneficial than conventional silicon steel for an actuator because 3-dimensional magnetic flux can be utilized by soft magnetic composition. Therefore, the actuator can be lighter and smaller. However, no surpassing properties in magnetic property against to silicon steel have ever been obtained yet. Therefore, it becomes important to investigate on the reduction of iron-loss of soft magnet composite for the high efficiency applications such as vehicle [1].

In this paper, External Flux Impression Method (EFIM) is proposed. In this method, external flux is impressed from the outside of compaction mold during the compaction of iron powders in order to have magnetically stable powder structure. The presence of external magnetic flux allows forming arranged particles (or powders) to have minimized reluctance [2]. The EFIM allows for the SMC to have high permeability due to the reduction of magnetic resistance by applied external magnetic force. This ordered configuration makes energy conversion easier and results in minimization of energy loss during energy conversion [3].

Therefore, using the soft magnetic composite core that is fabricated in magnetically stabilized method shows much lower iron-loss than the core with conventional method. To impress an external magnetic flux, compaction molds were designed and fabricated based upon the FEM analysis to have optimum magnetic circuit and performance. Especially in design of the mold, not only optimization of thickness of the mold but also selection of adequate material was inevitably considered to deliver magnetic flux to the compacted composite powder sufficiently [4]. In other words, both structural analysis and electro-magnetic analysis were considered to have structural stability as well as optimum magnetic circuit for the design of the molds.

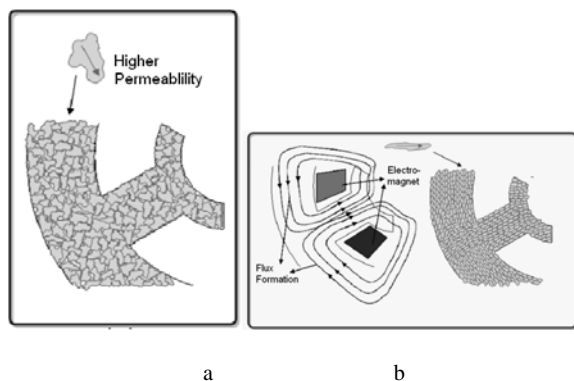## 2. External Flux Impression Method (EFIM)

The actuator core using soft magnetic composite was manufactured through compaction process as shown in Fig. 1. At this time, the soft magnetic composite powders were arranged in disordered condition. Proposed EFIM is designed to arrange the particles in order magnetically during compaction process by impressing flux. Before considering the complex magnetic property of motor core, a tetragonal test sample mold was also prepared and examined the magnetic property. Fig. 2 described the main concept of proposed EFIM.

There were some important considerations during the design of the mold. The external flux has to affect the powders inside of the mold magnetically and also the mold must have enough mechanical strength to withstand the high pressure compaction.
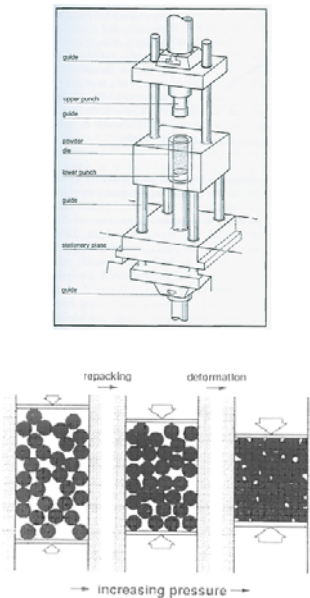
Fig. 1. Schematic diagram of compaction process;) Press(b) Compaction process

In this research, among the different methods to impress the flux to powder in the design of mold, the permanent magnet was used. As shown in Fig. 3, three different forms of mold designs were considered to have one direction of the magnetic flux vectors inside of the compaction and maximum flux in order to have high coherence among the powders inside of the mold as the external flux was impressed. The results showed that Fig. 3(b) exhibited the highest magnetic flux density; therefore, the molds were manufactured with that design.


Fig. 2. Proposed external magnetic flux impression method, a) Conventional method, b)EFIM

As mentioned earlier, the mold needs to have suitable mechanical strength to withstand high pressure during compaction process, and also it should be designed to fabricate the compaction without defects such as crack and distortion. By using structure analysis, mold was designed and produced with easy to impress the flux inside and
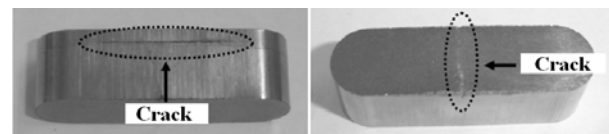
suitable mechanical strength, as shown in Fig. 4(a). Very little deformation may result in the defects, as shown in Fig. 5, it is important to consider the mold's mechanical properties.
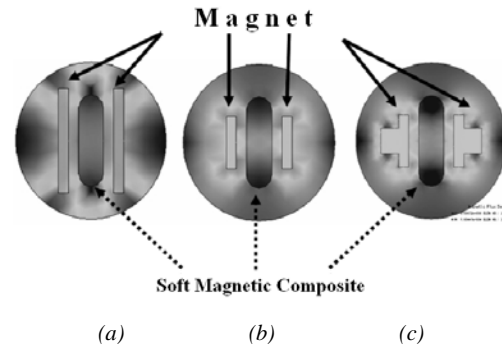
Fig. 3. Designs of mold with consideration of magnetic properties
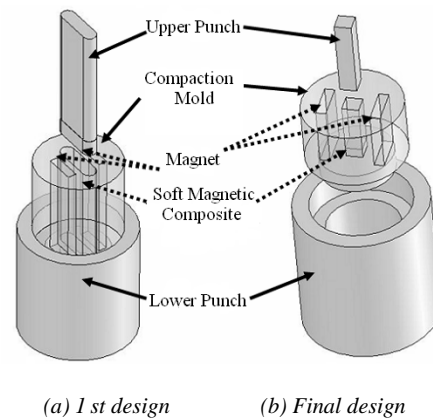
Fig. 4. Designs of mold with consideration of mechanical properties

Fig. 5. Crack defects after ejection of SMC from the 1st design mold

3. Experimental

In compaction, SMC500 and SMC550 powders from Hoganas and KE lubricant was used in 700MPa of pressure. After compaction, the SMC was heat-treated at the temperature of 500　for an hour. Then magnetic properties were analyzed. Also, properties before and after

the magnetic impression were investigated and compared. To analyze the magnetic properties of SMC, a special magnetic probe and search coil, Fig. 6, were prepared to minimize the air effect that could be different by the wind way. And we measured magnetic properties by using the Brockhaous MPG measuring equipment.
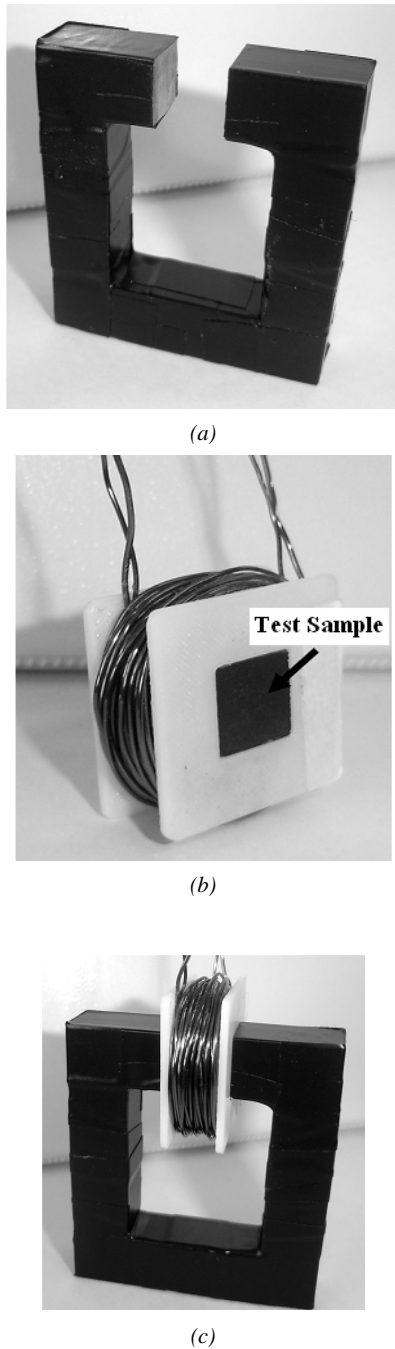

(a)

(b)

(c)

Fig. 6. The probe to analyze the magnetic properties of SMC

4. Results and discussion

Fig. 7 shows the powders before and after flux impressing. As shown in Fig. 7, by impressing the flux, the powders were arranged. Fig. 8 shows the iron-loss measured according to the frequency before and after flux impressing. As shown, iron-loss at 500mT, 900Hz before flux impressing was 272W/kg; however, it was decreased to 255W/kg after flux impressing. Generally, iron-loss can be calculated by using Equation1 that contains Eddy current loss, hysteresis loss and anomalous loss. Fig. 9 shows measurement results of Eddy current loss and hysteresis loss in various frequencies; Pw and Ph means Eddy current loss and hysteresis loss. As shown in Fig 10, the values of hysteresis loss are more than Eddy current loss in total iron-loss when we increased the frequency. So we compared resistivity and permeability of the materials to search the reasons. The loss was reduced because the eddy current loss is inverse proportional to the resistivity, and hysteresis loss is proportional to the permeability, Equation2, 3. There was no difference in resistivity before and after flux impressing, while permeability was increased relatively, Fig. 11. It means that the reluctance value is decreased by flux impressing. Moreover, Fig.12 shows results in comparison with B-H properties before and after flux impressing. As shown, hysteresis curve shapes were much smaller after flux impressing which means it was more magnetically stabilized than before.
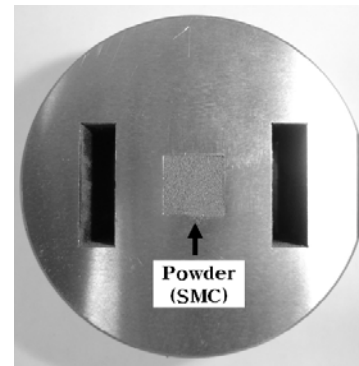
(a) Arrangement of SMC before magnetic impression
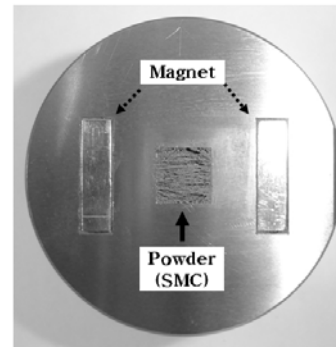
(b) Arrangement of SMC after magnetic impression
Fig. 7. Arrangement of SMC before and after magnetic impression
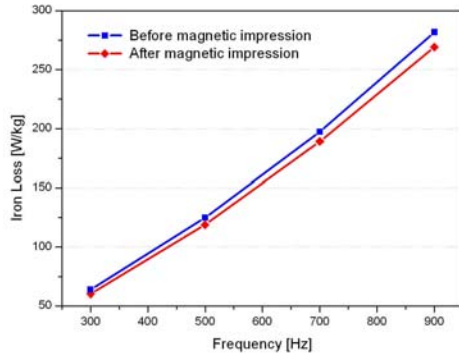
Fig. 8. Iron-loss of SMC before and after magnetic impression

Proposed "EFIM" allows the molds to have high magnetic properties effectively without damages, but for high speed compaction that researched previously, the pressure being applied during compaction is so high that can damage the molds [5]. So it is hard to be applied in actuality, while EFIM would be more advantageous for mass production. In the process of the motor core production with EFIM, decrease of iron-loss should also give high efficiency to the motor, and therefore, proposed EFIM could contribute to the protection of environment and the economy of sources.

$$\frac{P_c}{f} = k_h \hat{B}^n + k_{ec} 2\pi^2 \hat{B}^2 \cdot f + k_a 8.76 \hat{B}^{3/2} \cdot \sqrt{f} \qquad (1)$$

k_{ec} : Coefficient of eddy current
k_a : Coefficient of anomalous
B : Magnetic flux density
H : Magnetic field intensity

The equation for the hysteresis loss (P_h) can be written as

$$P_h = f \int H dB = k_h f \hat{B}^n \qquad (2)$$

k_h : Coefficient of hysteresis
n : Coefficient of material (1.5 ~ 2.5)
and the Eddy current loss (P_{ec}) can be written as

$$P_{ec}(t) = \rho i^2 = \frac{E^2}{\rho} \qquad (3)$$

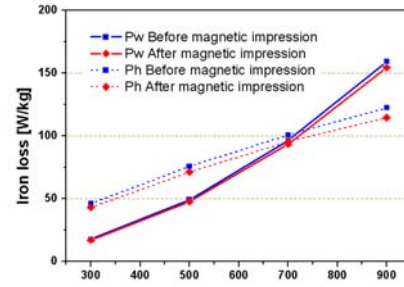ρ : Resistivity of the material
E : Electric field
i : Eddy current

Fig. 9. Eddy current loss and hysteresis loss before and after
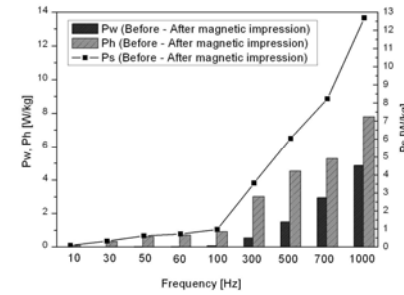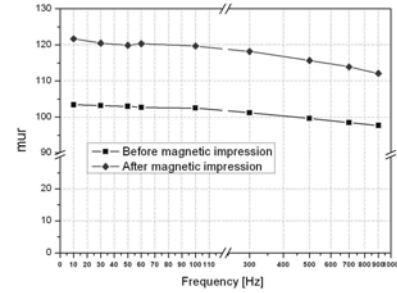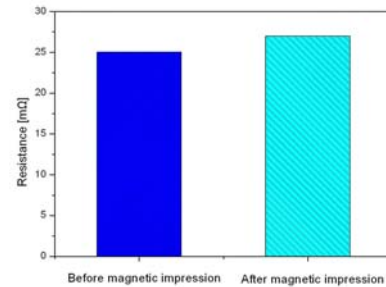
magnetic impression

Fig. 10. Comparison of eddy current loss and hysteresis loss,

iron loss

a

b

Fig. 11. Permeability and resistance of specimen before and after magnetic impression a. Permeability before and after magnetic impression b. Resistance of specimen before and after magnetic impression
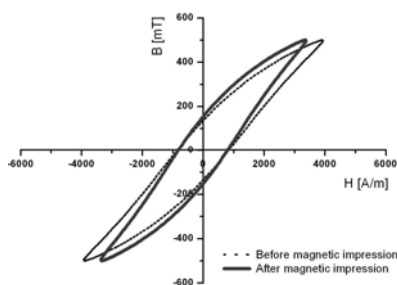
Fig. 12. B-H characteristics before and after magnetic impression(300Hz)

5. Conclusion

In this paper, EFIM (External Flux Impression Method) is proposed that is able to impress the external magnetic flux during compaction process. As a result, after flux impressing, iron-loss is decreased by 6.25%, that is caused by decrease of hysteresis loss by increased permeability. Proposed method would be helpful for high efficiency, high output and miniaturization of motor core and actuator core hereafter.

References

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