An Elemental Operator for Simulating Hysteresis of Soft Magnetic Composite Materials

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This paper introduces an elemental operator based on the physical mechanisms to simulate the scalar hysteresis phenomenon of the soft magnetic composite materials. To directly describe the relationship between magnetic applied field and magnetization for one single elemental operator, an analytical expression is deduced by the partial approximate substitutions. Moreover, the magnetic hysteresis of a kind of soft magnetic composite materials under alternating excitations was measured by the magnetic property measurement system and calculated by this elemental operator, respectively. The comparison suggest that this elemental operator is effective and can be a useful tool to simulate the scalar magnetic properties of magnetic material.

***Index Terms*—Vectorial elemental operator, hysteresis model, soft magnetic composite materials.**

I. Introduction

THE SOFT Magnetic Composites (SMC) material is made of pure iron powder particles coated with an electrically insulated layer [1]. Due to its unique properties such as low eddy current and magnetic isotropy, the SMC material can be regards as an ideal candidate to develop high-performance but low-cost electromagnetic devices with three-dimension magnetic fields [2]. With the SMC materials are increasing widely used, the magnetic properties of the SMC material, especially the magnetic hysteresis, should be comprehensive understood before development can go forward [3].

In this study, an elemental operator is presented to simulate the magnetic properties of SMC material based on the physical mechanism. Meanwhile, an improved analytical expression is presented to directly describe the relationship of magnetic field H and magnetization M on each elemental operator. This approach utilizes the concept of distribution function density in order to consider the interaction field and the coercive force of each elemental operator.

The elemental operator is derived in the form of two dimensions, and adopted to model the scalar magnetic hysteresis by restricting the applied magnetic field to vary along one dimension and ignoring the transverse hysteresis component.

II. Elemental Operator

In the SMC material, each magnetic dipole in the iron crystal particle is regarded as an elemental operator with biaxial anisotropy on arbitrary crystal plane.

Then, it can be assumed that the magnetic material is composed by lots of interacting elemental operators. Similar to the conventional Stoner-Wohlfarth (S-W) model, the magnetization orientation of each biaxial anisotropy elemental operator can be obtained by the energy minimization. The total energy of this elemental operator is

$$E = K\sin^2\theta\cos^2\theta - \mu_0 HM\cos(\theta_H - \theta) \quad (1)$$

where K is the anisotropy coefficient, θ and θ_H are the angles of the magnetization and applied field with respect to the particle's easy axis, respectively. M is the saturation magnetization. The first term represents the biaxial anisotropic energy, and the second the interaction energy associated with the external magnetic field and the particle magnetization.

With the help of the asteroid method in S-W model, graphical interpretation can also be employed to explain the magnetization process on the elemental operator, as shown in Fig. 1.

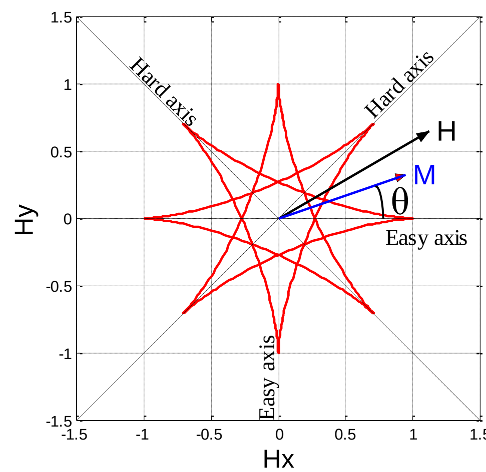
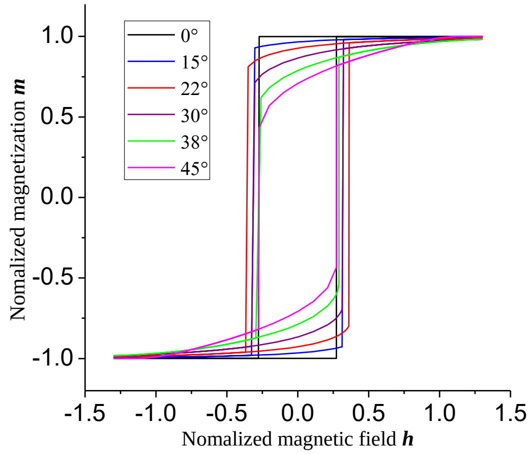
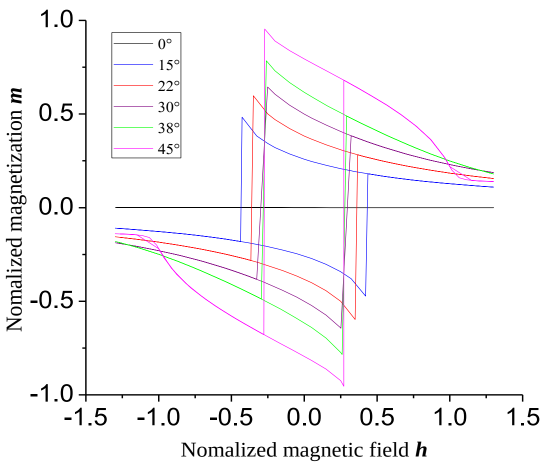


Fig. 1 Flower-shape of the elemental operator with two easy axes and two hard axes.

If the alternating magnetic field applying on one elemental operator with different fixed orientation, a series of hysteresis loops will be produced. The longitudinal and transverse magnetization components for different orientations of the applied field are illustrated in Fig. 2(a) and Fig. 2(b), respectively.



(a)



(b)

Fig. 2. (a) Longitudinal hysteresis loops and (b) transverse hysteresis loops of one elemental operator for different external field orientation determined by the graphical interpretation.

After the magnetic properties of one single elemental operator has been fully studied, the bulk magnetization **M** of a SMC material sample can be determined by integrating the effects of all the elemental operators in the sample with a two-dimensional distribution function. In this model the distribution can be described by a Gaussian-Gaussian distribution.

With the employment of Preisach diagram, the magnetization **M**, which varying on the downward trajectory or upward trajectory of hysteresis loop under an alternating field **H**, can be easily determined by the following integrals, respectively [4].

$$M_d(H) = M(H_n) - 2T(H_n, H) \quad (2)$$

$$M_u(H) = -M(H_n) + 2T(H, H_n) \quad (3)$$

where the subscript d and u denote the downward trajectory and upward trajectory of the hysteresis loop, respectively. H_n is the magnetic field strength of the n-th (last) reversal point on the Preisach diagram, T(α,β) is the area integration over the right triangle of vertex (α,β) on the Preisach diagram.

III. Experimental Verification

To verify the accuracy and the feasibility of the proposed elemental operator, the hysteresis loops of a classical type of SMC material, SOMALOY™ 500, were measured under alternating magnetic field [5]. For better readability and the symmetry of the hysteresis loop, only the upper-half hysteresis loops ,which under different alternating magnetic fields with flux densities up to 0.39 T, 0.78 T, 1.14 T, 1.39 T, were illustrated in Fig. 3.

As shown, the simulated results agree well with the experiment results in both major hysteresis loops and minor hysteresis loops.

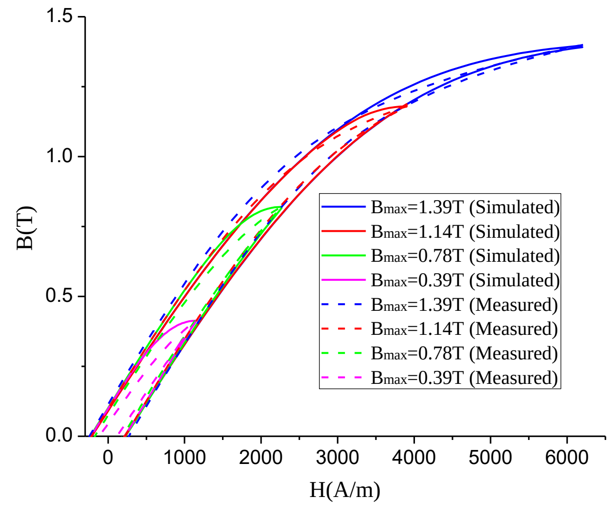


Fig. 3. Comparison of measured and simulated B-H loops in a SMC sample magnetized with different alternating magnetic fields.

IV. Conclusion

In this paper, an elemental operator with biaxial anisotropy has been introduced based on the magnetization mechanism. In the frame of distribution function on the Preisach diagram, the scalar magnetic hysteresis of SMC material is simulated and compared with the measured result. It can be proved that the results predicted by this model are acceptable. Additionally, the vectorial elemental operator is a feasible method to simulate the scalar magnetic hysteresis of SMC material.

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