Observation of Magnetization Processes in Soft Magnetic Composites

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A magneto-optical imaging technique has been employed to visualize magnetization processes of soft magnetic composite material. The profiles of reflecting light intensity of magneto-optical images at the sample surface were plotted. The results demonstrate that magneto-optical imaging is a sensitive tool to visualize magnetization process. The flux profiles obtained under conditions of perpendicular and tangential magnetizations indicate that the sample behaves as a collection of individual magnetized particles rather than as a uniform and continuous magnetic substance.

1. Introduction

In optimum design of modern electromagnetic devices using advanced magnetic materials, accurate models of the magnetic properties, such as magnetic hysteresis and power losses, are required. To derive reliable magnetic property models based on the physical magnetization mechanisms, the local magnetic characteristic is essential information since the study on local magnetization processes can reveal intrinsic magnetic characteristics of the material and help understand the influence of various microstructures on microscopic and macroscopic properties.

The conventional magnetic measurements can only deliver the average magnetic properties over the whole volume of a sample, rather than the local magnetization in micrometer scale.[1] The averaged information is insufficient to interpret the mechanisms of magnetization. Modern equipments, such as magnetic force microscopy (MFM), scanning electron microscopy with polarization analysis (SEMPA), magnetic near-field scanning optical microscopy (NSOM), magneto-optical Kerr effect (MOKE),[2,3] scanning Lorentz force microscopy[4] and SQUID can study the magnetism in nanometer or micrometer scale from different aspects,[5-7] but most papers focus on the observation of magnetic domain. This paper shows the local magnetization processes by means of the magneto-optical imaging (MOI) technique.

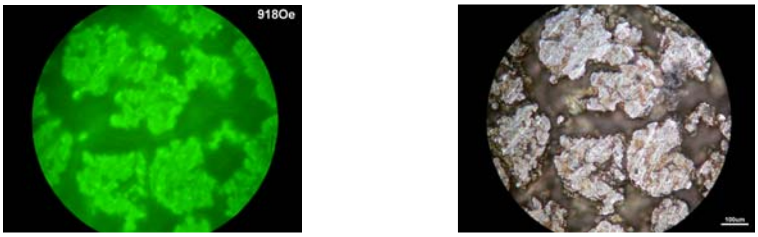
2. Sample preparation

The MOI equipment was built[8] based on the Faraday rotation, that is, the rotation of the polarization plane of a beam of light in an indicator film induced by a magnetic field. In order to study the magnetic flux profile at the surface of opaque samples, the reflecting model of the Faraday rotation is employed. As a result of rotation, the magneto-optical image captured by a CCD camera mounted on a microscope with crossed polarizers is a grey scale image. In this study, a green filter was employed to improve the contrast of the image. The MOI indicator film was immediately placed on the sample surface with slight mechanical pressure in order to improve spatial resolution.

The sample in this study was a soft magnetic composite (SMC), which is made of iron powder coated with an organic isolating layer. The major advantages of such material include magnetic isotropy, much higher electrical resistivity compared with SiFe sheets, and easy and cost-effective compression into the complicated and practical net-shapes required in various electromagnetic devices. The sample surface was carefully polished to improve the magneto-optical image quality. The toroidal-shape SMC sample studied in this work were compressed from iron powder with 450 MPa, followed by a heat treatment in a steam/N2 atmosphere for 30 minutes. The density of the sample is 6.54 g/cm^3. The dimensions of the sample are inner diameter of 28.29 mm, outer diameter of 53.46 mm, and thickness of 5.05 mm.

3. Results

A series of magneto-optical images was taken at the compression surface while the applied magnetic field perpendicular to the surface was increased. Figure 1 shows the image taken at the field of 918 Oe and in-situ optical microstructure. All images in this paper are 2272 pixel in width and 1704 pixel in height. The shapes of the iron particles are irregular and interstices exist between the particles. In addition, intra-particle overlaps are found. With an increasing applied field, the light intensity upon the particle regions increases much quicker than that upon the interstices. This means that the flux density at the particle surface is much stronger than that at the interstices and the flux lines propagate mainly from one particle to another. The indicator film is so sensitive to the flux density that an unexpected non-uniformity of the light intensity within one particle was visualized. It is believed that this non-uniformity results from the overlaps of the particles and intra-particle pores.



(a) (b)

Fig. 1. Magneto-optical images at field of 918 Oe (left) and *in-situ* microstructure at the compression surface (right).

The compression surface was then ground off and carefully polished. The microstructural topography is shown in figure 2(a). It is noted that the particles are much closer than that at the compression surface. Some particles are so tightly compact that part of the boundary becomes invisible. Due to the limitation of the optical microscope, it is difficult to identify the cross-section of the isolating coating of the particle. A series of in-situ magneto-optical images were captured, shown in figure 2(b-d), when the sample was subjected to external DC magnetic fields up to 3155 Oe perpendicular to the polished surface. In general, the light intensity, that is, the flux density within an individual particle is uniform in contrast with the compress surface. However, the intensity varies from each particle, and boundary between the particles is clearly found. The particles were magnetized to different extents though they were subjected to the same magnetization field. It is believed that the different magnetizations are caused by the shape anisotropy of the particles. The flux density is high over the particles and low at the boundaries and pores. At high fields, the low-density lines disappear due to the bending of the magnetic flux lines just above the sample surface. Figure 3 plots the profiles of the light intensity along the black bar shown in figure 2(b). It is noted that the light intensity profiles have a low peak at the boundary and a sharp peak at the edge of the particle. The intensity is stable within the particles. It reaches the maximum value at the field of 1420 Oe. After that, the intensity decreases when the external magnetic field increases due to the rotation angle is over $\pi/2$.

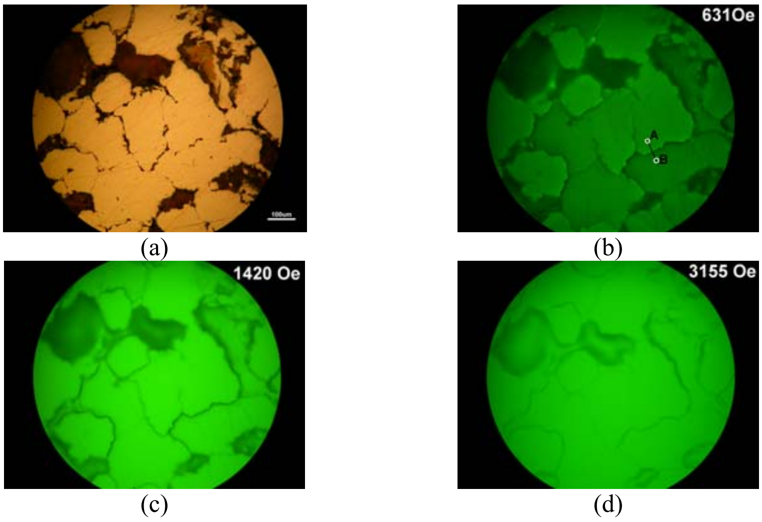


Fig. 2. Optical morphology and magneto-optical images at the polished surface of the sample magnetized in perpendicular external magnetic field.

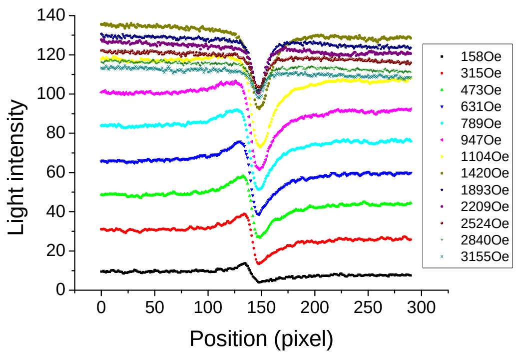
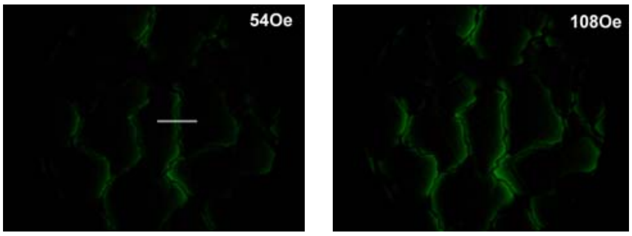


Fig. 3. Profiles of light intensities along the black bar shown in figure 2 when the sample was subjected to the perpendicular magnetic fields.

Figure 4 shows the magneto-optical images when the sample was magnetized by circumferential magnetic fields generated by a coil wound around the toroidal sample. Figure 5 shows the intensity profiles along the white line shown in figure 4(a). The normal component of the stray field changes sharply at the boundary of the particles. There is a low peak in the gap and two high peaks on the side. It is found that the polarizations of the normal component of the stray field at both sides were opposite by rotating the reflective analyser. The field changes dramatically at the boundaries which are perpendicular to the applied magnetic field. The alternation gradually becomes smooth if the boundaries tend to be parallel to the magnetization field. There is no field change observed at the boundaries parallel to the applied field.

4. Conclusion

In summary, a high resolution magneto-optical system has been employed to visualize the magnetization processes in individual iron particles of the soft magnetic composite material. The results indicate that the flux lines are concentrated inside the particle. They propagate mainly from one particle to the next. Each particle exhibits its own magnetization behaviour and the whole sample behaves as a collection of individually magnetized particles rather than a uniform and continuous magnetic substance.



(a) (b)

Fig. 4. Magneto-optical images when the sample was magnetized by circumferential magnetic fields.

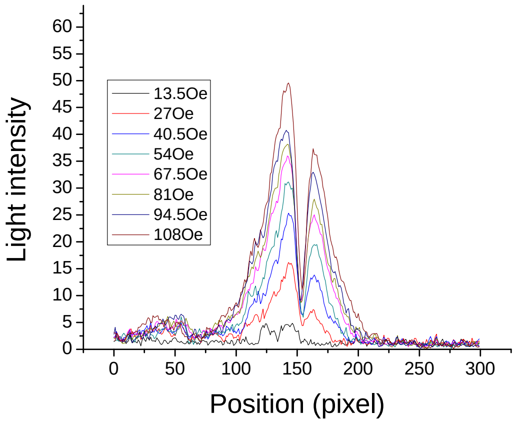


Fig. 5. Profiles of light intensities along the white line shown in figure 4 when sample was magnetized by circumferential magnetic fields.

Acknowledgments

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