Confocal Microscopy Imaging of Fe particle motion in Magnetorheological Elastomers

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Introduction

Magnetorheological elastomers (MREs), consisting of a polymeric matrix and embedded micro- or nano- magnetic particles, are a class of smart materials that have the unique capability to reversibly and instantaneously change their mechanical properties upon application of an external magnetic field. However, the underlying mechanisms behind these magnetic field dependent changes in the mechanical properties of MREs remains to be elucidated.

Our previous results from magnetometry characterization of MREs suggest that the magnetic particle motions may play an important role. In this summer project, we quantify the motion of the fluorescently labeled Iron particles in an MRE sample by confocal microcopy imaging and subsequent data analysis.

Confocal Microscopy Imaging and Image Analysis

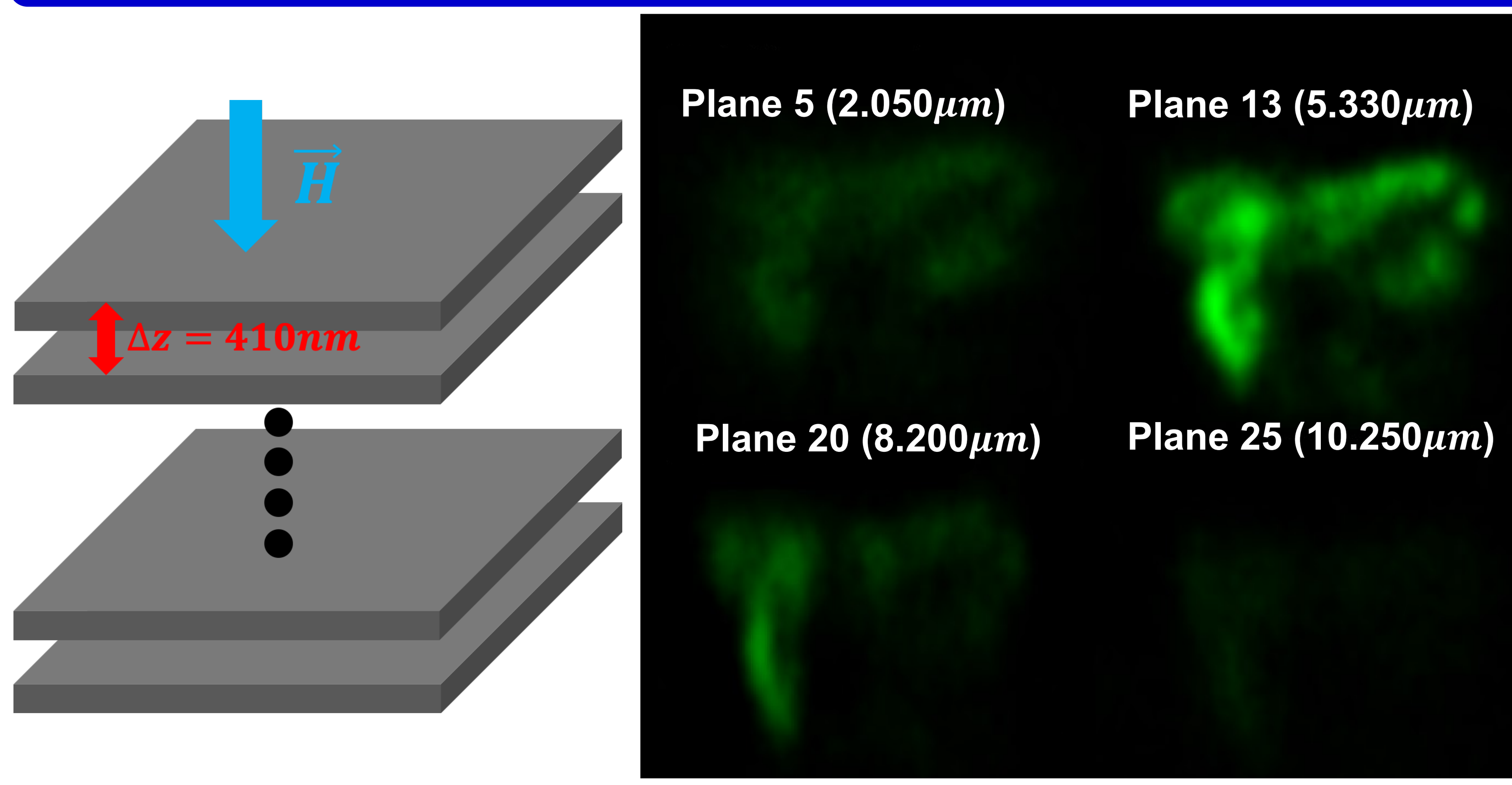

Fig 1: (Left) Illustration of confocal imaging set up. (Right) Representative confocal images of a conglomerate of fluorescently labeled Iron particles (S1) taken under a magnetic field of 70 mT.

A confocal microscope utilizes a laser and a spatial pinhole to reconstruct three-dimensional structures in a sample by taking two-dimensional optical images at different depths of the sample. Therefore, it is a powerful method for investigating Iron particle motion in MREs.

We performed confocal microscopy imaging with applied magnetic field along the optical axis (z-axis) with varied strength up to 130 mT. Under each magnetic field, a stack of images were taken at 28 different z-positions. The z-distance between adjacent focused planes is 410 nm, as shown in Fig. 1. Representative images of a specific conglomerate of particles (S1) taken at different z-positions under 70 mT are shown in Fig. 2.

An open source image processing program, ImageJ, were used for image analysis. The brightness value of S1 in each stack of images taken at a specific magnetic field are compared. The higher the brightness of S1 in an image, the more in-focus it is in the photo and thus the closer S1 is in position to the focus plane of that photo.

Iron particle motion in MREs

The brightness of a specific conglomerate of particles (S1) in the 28 focus planes imaged under each external field strength are plotted in Fig.2. The z-position of the brightness peak of each curve gives the z-position of S1 under that specific magnetic field, as the sample is most in focus at that focal plane. Fig. 3 shows the z-position of S1 as a function of magnetic field strength. The particle imaged in S1 is displaced along the applied magnetic field direction as the strength of the magnetic field increases. The motion of the iron particle is expected to be monotonic along the magnetic field direction, however an increase in z-position was observed between 60-70mT. We attribute this increase in z-position to external mechanical motion caused by switching the current direction in the electromagnetic coil, which was performed between the 60 and 70mT measurements.

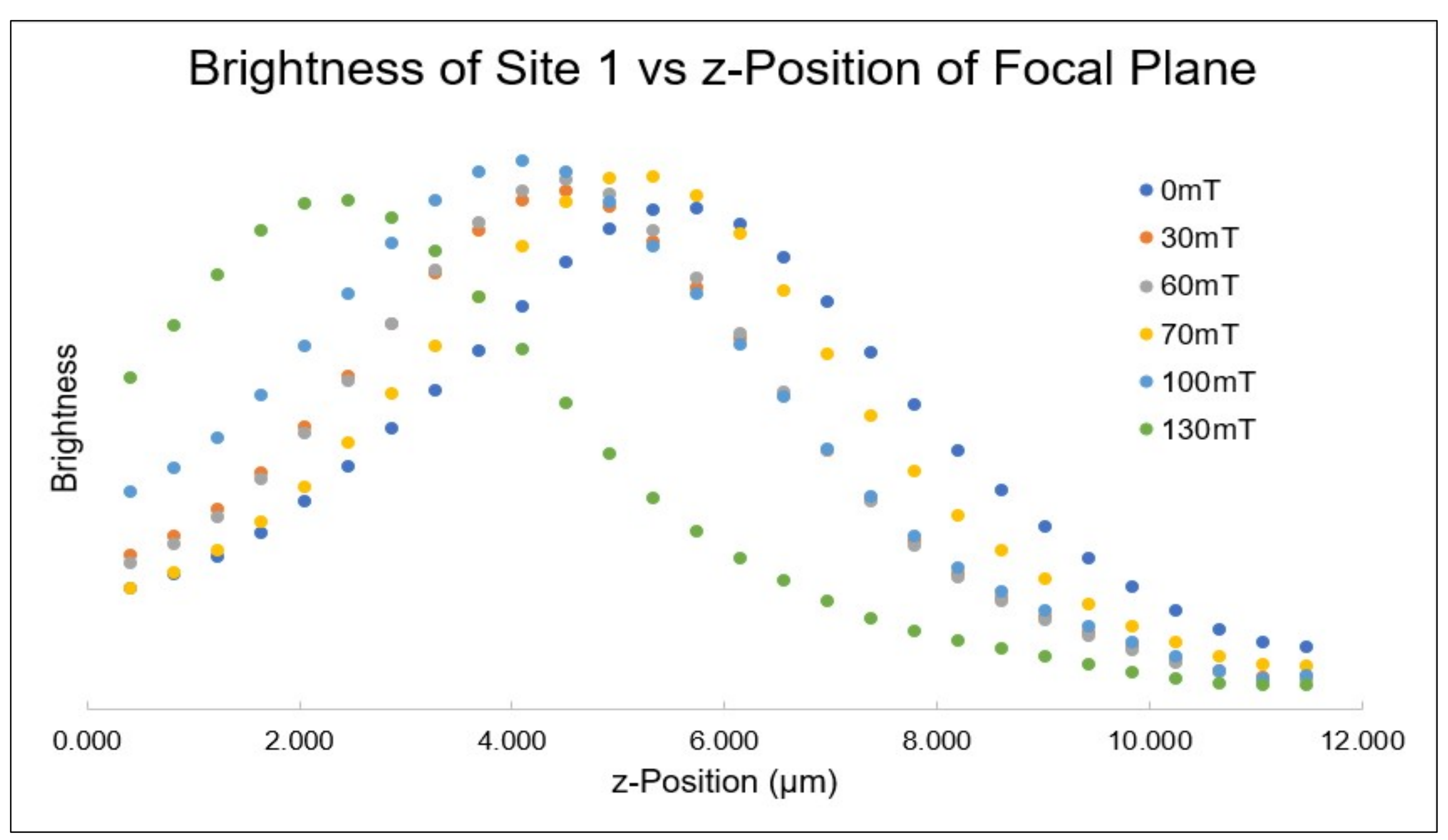

Fig 3: Comparative brightness of S1 images taken on 28 focus planes 410 nm apart in a range of 11.480 μm. Each curve constitutes data taken at the denoted magnetic field strength, from 0mT to 130mT. Points with higher brightness are more in focus.

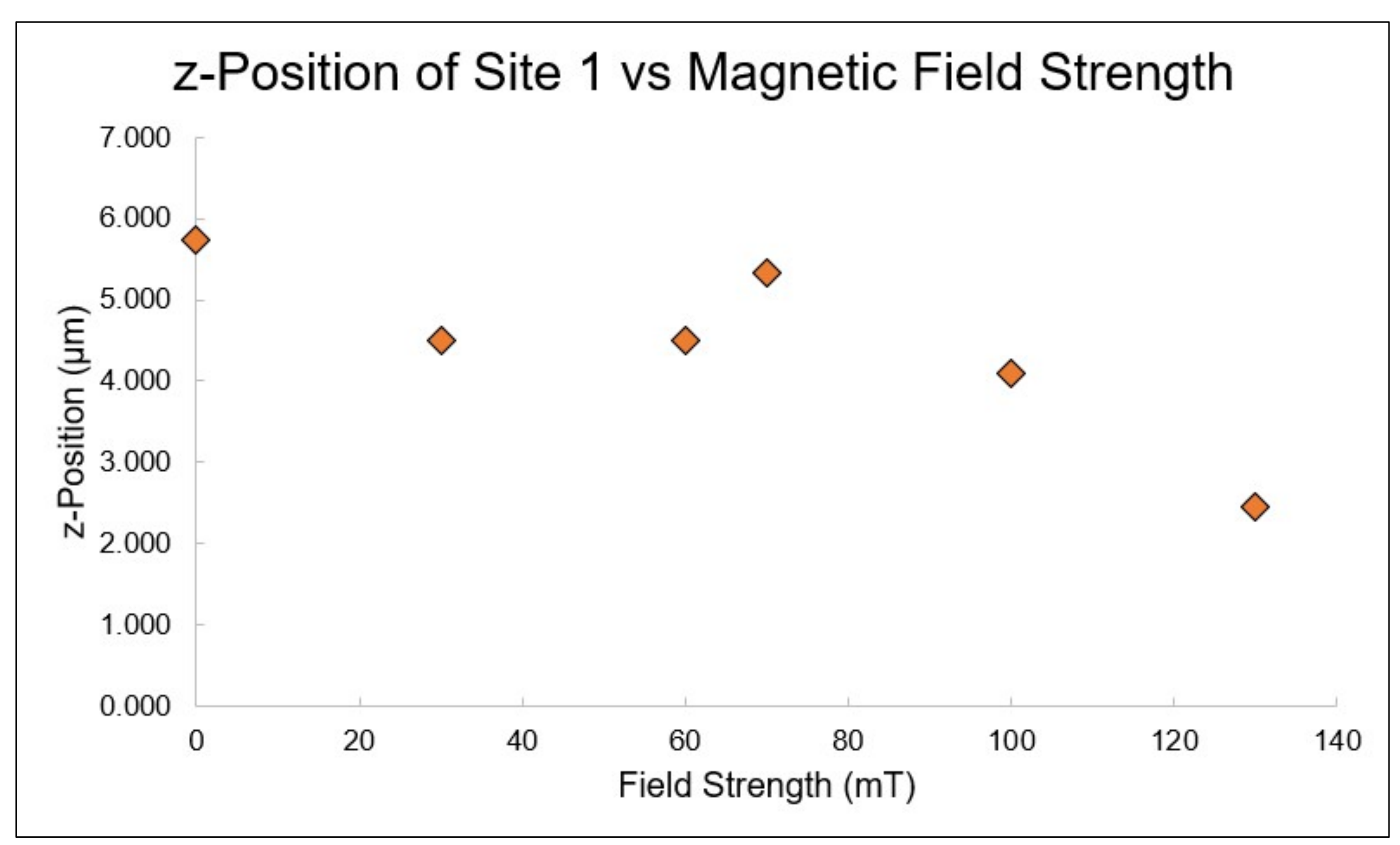

Fig 4: Z-axis position of S1 at varying magnetic field strengths, derived from the position of peak brightness in each curve of Figure 2.

Conclusions

- ❑ Confocal imaging enables three-dimensional imaging of Iron particles in the MRE sample to investigate the particle motion.
- ❑ The motion of Iron particles in the applied magnetic field direction has been confirmed by imaging analysis using ImageJ.
- ❑ In the future, theoretical modeling will be performed based on the information about the magnetic particle motion obtained by confocal microscopy imaging

References

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2. Clark, A., & Chen, X. (2020, July 2). Introduction to magnetorheological elastomers [Keynote address]. BMC Student Summer Research 2020, Bryn Mawr, PA, United States.
3. Confocal images courtesy of Andy Clark

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