Further Research Into High Strain Magnetostriction in a Ferromagnet-Polymer Composite

Thomas I. Richardson & E. Dan Dahlberg, Department of Physics, University of Minnesota

University of Minnesota
Driven to Discover®

University of Minnesota
Driven to Discover®

Background

Magnetostriction is a property of some materials that exhibit strain (stretch/compression) by the application of a magnetic field.

Magnetostriction is typically small, with maximum strains of approximately 2000ppm for the alloy Terfenol-D in fields on the order of 100 kOe. [1]

Magnetostrictive materials have applications as magnetically-induced linear motion actuators.[2]

We previously developed a metal-polymer composite material that exhibits high-strain magnetostriction, with strain on the order of 10% (100,000ppm).[3] [4]

The material is composed of short steel wire suspended in soft polymer, with wires acting as magnetic dipoles and thus inducing visible macroscopic strain (see Fig. 1).

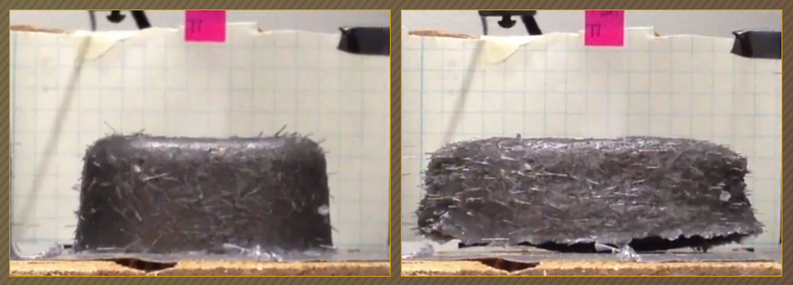

Figure 1. Composite in zero applied field, and in 7.50 kOe applied field.

Introduction

We have further improved the high-strain magnetostrictive composite, both increasing the strain (order of 20%) in weak magnetic fields (order of 5 kOe) and improving the cycle lifetime (no degradation over repeated stretching).

We find the strain increases with wire loading up to a maximum value, and then further loading reduces strain. The loading associated with maximum strain is higher for shorter wire lengths.

The measured maximum strain of 38.8% in a 3.0 kOe field, using 0.50 cm wire and 0.100 wire volume fraction, is the maximum observed in any system to date.

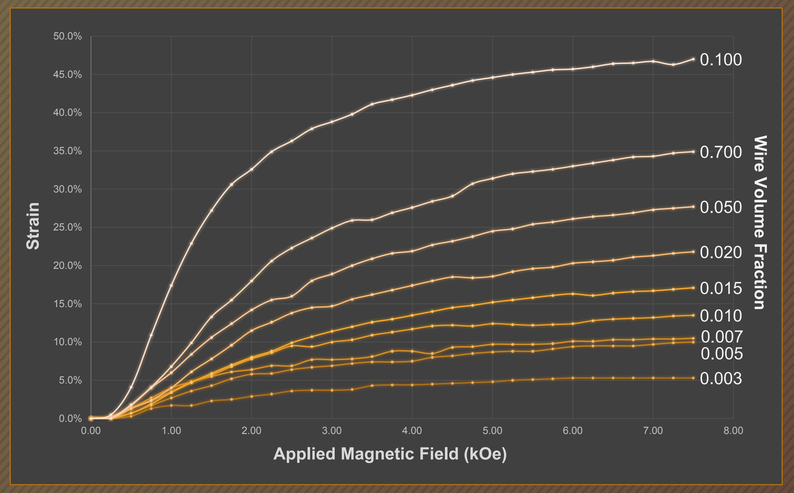

Figure 2. Graph of Strain vs. Magnetic Field for 0.50 cm wire, varying wire loadings.

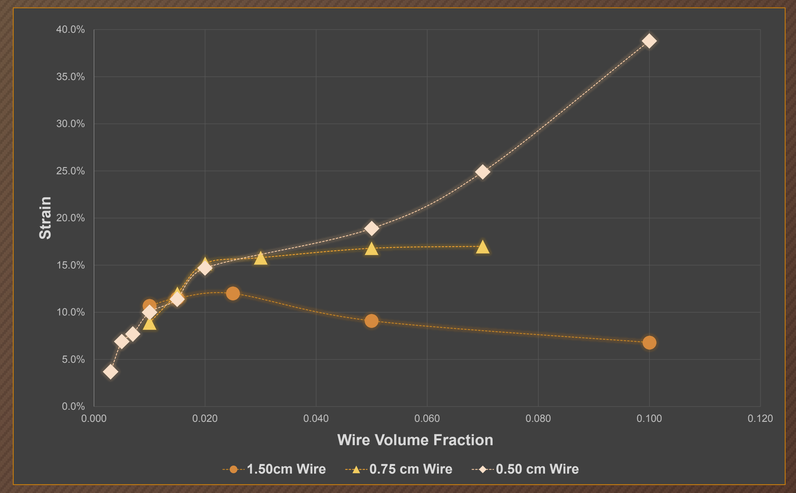

Figure 3: Graph of 3.0 kOe Strain vs. Wire Volume Fraction. The dashed lines are guides to the eye.

Method

Wires were cut from 0.010” diameter high-carbon steel piano wire, to lengths of 1.50 cm, 0.75 cm, and 0.50 cm. To cut large quantities of wire at once, wire bundles were coated in nail polish and later cleansed in acetone.

The polymer base was made from 50.0g Ecoflex 00-10 silicone rubber mixed with 12.5g silicone thinner additive. Wire loadings up to 0.100 wire volume fraction were suspended in the polymer as it set for 24 hours.

Composites were tested in magnetic fields up to 7.50 kOe. Strain was measured by video analysis in three trials, and averaged for each 0.25 kOe increment.

Fig. 2 shows a comparison of 0.50 cm wire loadings.

Results

Fig. 3 shows how wire length and loading affect strain.

With 1.50 cm wire, strain increased with wire loading up to a maximum 12.0% strain, at approximately 0.025 wire volume. Strain actually decreased with higher wire loading.

Shorter wires exhibit higher maximum strain at higher wire loadings. Composites with 0.75 cm wire have a maximum 17.0% strain at approximately 0.060 wire volume.

Composites with 0.50 cm wire show 38.8% strain at 0.100 wire volume, though the maximum strain may occur at an even higher wire loading.

Conclusions

As shown by 1.50 cm wires, strain increases with wire loading up to a maximum point, after which higher wire loading will decrease strain.

We believe this is caused by excess wires interfering with each other’s rotation. This can be avoided by using shorter wires, as seen with the 0.75 cm and 0.50 cm samples.

The improved magnetostriction material uses higher wire loading and shorter wire lengths. The new maximum strain at 3.0 kOe is 38.8%, using 0.50 cm wire and 0.100 wire volume.

This strain is the greatest observed in any system to date. It is almost 200x greater than the maximum strain of Terfenol-D, in much weaker magnetic fields.

Future Research

Further research could test wire volumes of 0.150, 0.200, and above to find the maximum strain with 0.50 cm wire.

Additionally, even shorter wire lengths could be tested to find the optimal wire length and wire loading combination.

This would contribute to our eventual goal to apply our magnetostriction material in technological applications.

Contact

Thomas I. Richardson
Department of Physics, University of Minnesota
Undergraduate
rich1348@umn.edu

References

1. P. Halkyard, Ph.D. thesis, University of Salford (2011). Terfenol-D Magnetostrictive Linear Motor.
2. A.G. Olabi, A. Grunwald, Mater. Des. **29** (2), 469 (2008). Design and application of magnetostrictive materials.
3. A. Hamann, D. E. Dahlberg, Appl. Phys. Lett. **110** (9), 091906 (2017). High strain magnetostriction in a ferromagnet-polymer composite.
4. Schleusner, Austin; Hamann, Aaron; Dahlberg, E. Dan. (2018). Development of a Robust Magnetostrictive Polymer. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/196281.