# Giant Magnetostriction of Field-Structured Composites

*by James E. Martin, Robert A. Anderson and Gerald Gulley*

**Motivation**—There is a need for soft actuators that have a much larger strain response than piezoelectrics and that can respond in microseconds. Applications include artificial muscles for robots, and strain sensors based on permeability changes (an inverse effect). To meet these needs we have begun to investigate Magnetostrictive Elastomers, polymer/particle composites that contract in a uniform magnetic field. This experimental research is motivated by a recent theoretical paper [J. E. Martin and R. A. Anderson, J. Chem. Phys. 111, 4273 (1999)] that shows that using magnetic fields to structure magnetic particles into chains should significantly enhance the observed contraction, due to the strong dependence of the magnetic permeability of such field-structured composites (FSCs) on tensile strain.

**Accomplishment**—We have built an optical cantilever apparatus, Fig. 1, capable of measuring field-induced sample strains as small as 1 ppm. With this apparatus it is possible to apply a preload (a tensile stress) to the sample, and the sample geometry is designed to minimize the opposing effect of the demagnetization field. In accord with theory, structuring particles into chains greatly increases magnetostriction, Fig. 1, the observed increase being even larger than the factor of three predicted. In a saturating magnetic field the FSCs we have developed are capable of magnetic strains of 10,000 ppm, five times larger than Terfenol D at room temperature, the highest-performing homogeneous material. But these materials also show a puzzling increase of the magnetic strain with sample preload, Fig. 2, in contrast to the monotonic decrease expected. To understand this effect, we have completed an analysis of a single chain of particles embedded in an elastic gel that shows that a hierarchy of structural phase transitions occurs, Fig. 2, that reduce magnetostriction from that expected with strictly affine deformation of the composite. The critical field at which this clustering transition occurs depends strongly on the sample preload and gel modulus. A full scale simulation of this transition is now in progress for physically reasonable models of FSCs, and we hope that this might explain the anomalous dependence of magnetostriction on sample preload.

**Significance**—We have demonstrated that giant magnetostriction, far exceeding that possible with Terfenol D, is indeed possible in particle/polymer composites structured by magnetic fields. These investigations have led to the discovery that this effect is enhanced by preloading the sample, which has led us to postulate that a novel structural phase transition occurs in these materials. This transition reduces the dependence of the permeability on strain, which decreases magnetostriction. The effect is largest at small preload, in accord with the experimental data, but whether this transition is the primary cause of the preload effect is the object of current theoretical and simulation studies.

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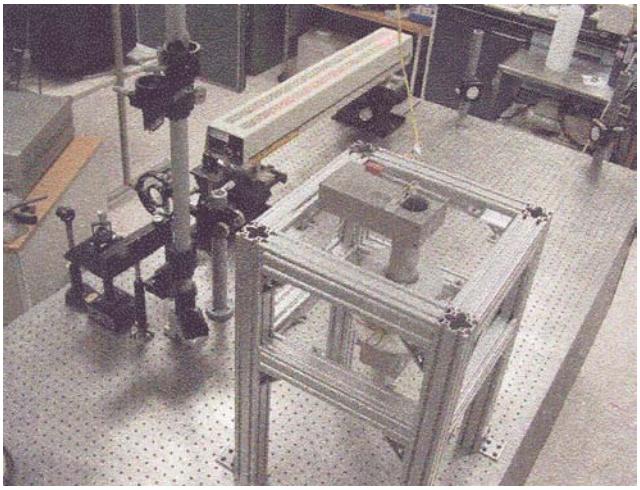


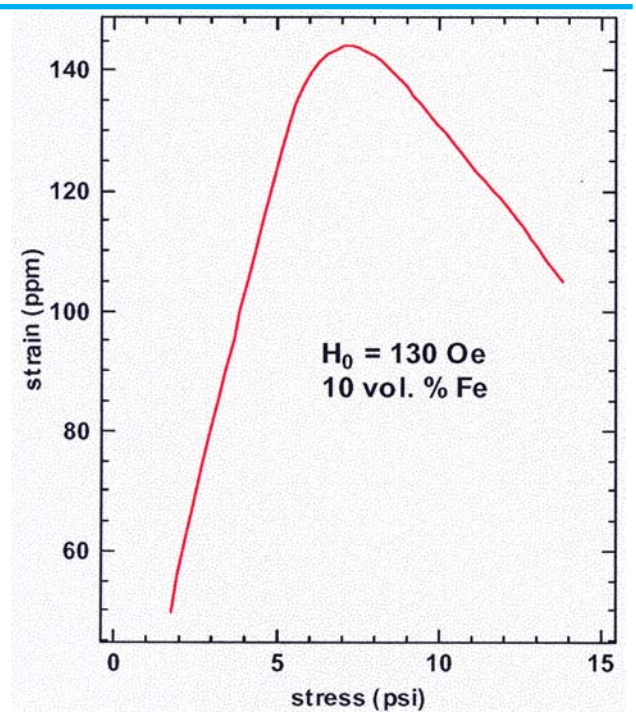
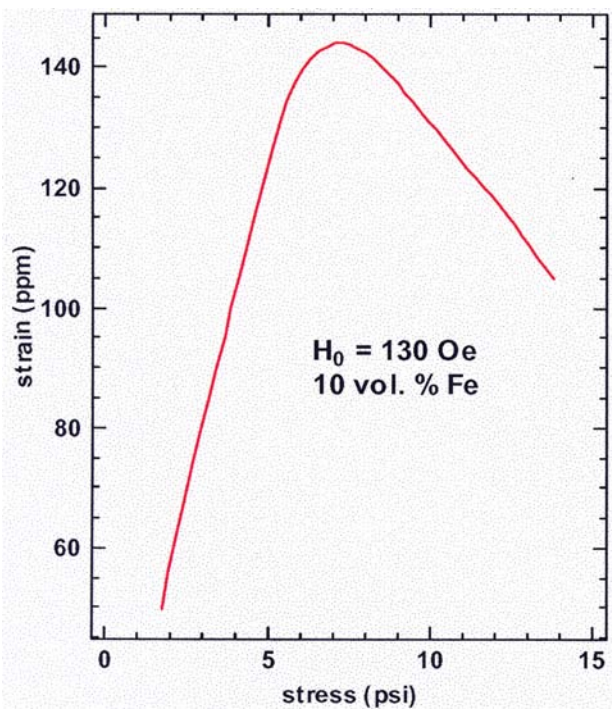



**Figure 1**. (left) Optical cantilever apparatus. (right) Magnetostriction is larger in FSCs than in random composites. Composites were 10 vol.% Fe in a silicone elastomer, and had a 11.6 psi preload.



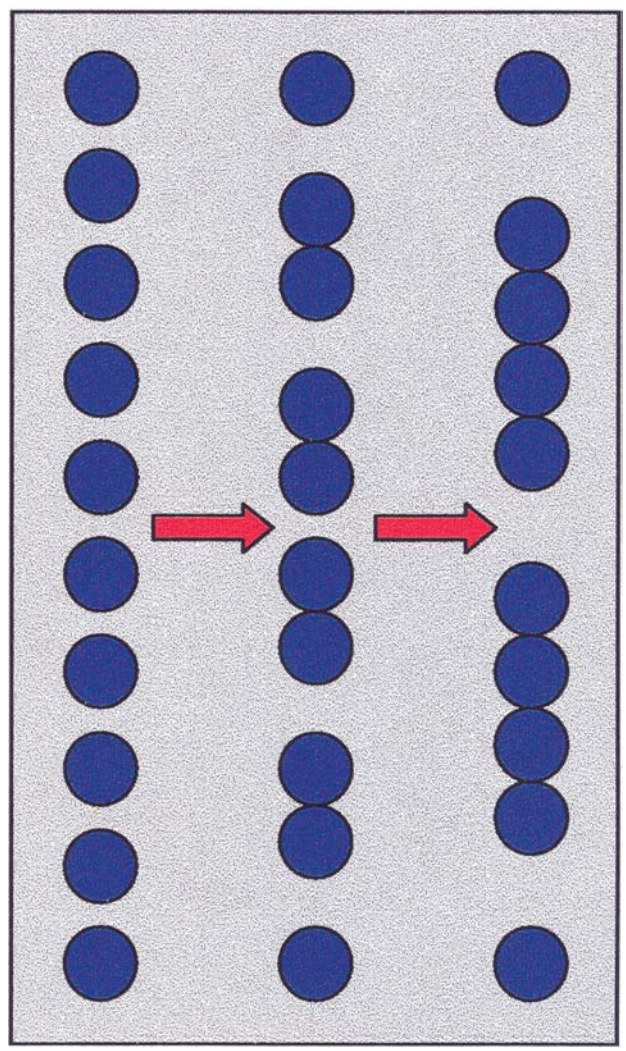



**Figure 2**. (left) Magnetostriction depends strongly on the sample prestress, actually increasing initially. (right) A chain of particles shows a hierarchy of phase transitions with increasing field.