Study of non-linear magnetomechanical constitutive relations of ferromagnetic materials

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ABSTRACT

Ferromagnetic materials have been widely used in modern science and technology since they become the important functional materials. A robust constitutive relation is desirable in order to guide the processing and development of ferromagnetism and for use in the design of ferromagnetic devices. In this paper, both experimental and theoretical work performed on developing nonlinear magnetomechanical constitutive relations of ferromagnetic materials are presented.

1. A novel magnetomechanical testing setup and the measurement techniques, which were developed for the measurement of the nonlinear magnetomechanical response of both magnetostrictive and soft ferromagnetic materials subjected to coupled magnetomechanical loading, are introduced (see Figure 1). In experiments, there were three kinds of ferromagnetic materials used to investigate the magneto-mechanical coupling behavior, such as the soft-ferromagnetic metal of Ni6 and electrolytic nickel, the giant-magnetostrictive material (Terfenol-D), and Manganese-Zinc ferrite ceramics. The characteristic curves of ferromagnetic materials were measured, including the hysteresis loops, piezomagnetic curves, magnetization curves and the magnetostriction curves under different compressive stress and stress-strain curves under different external magnetic fields.

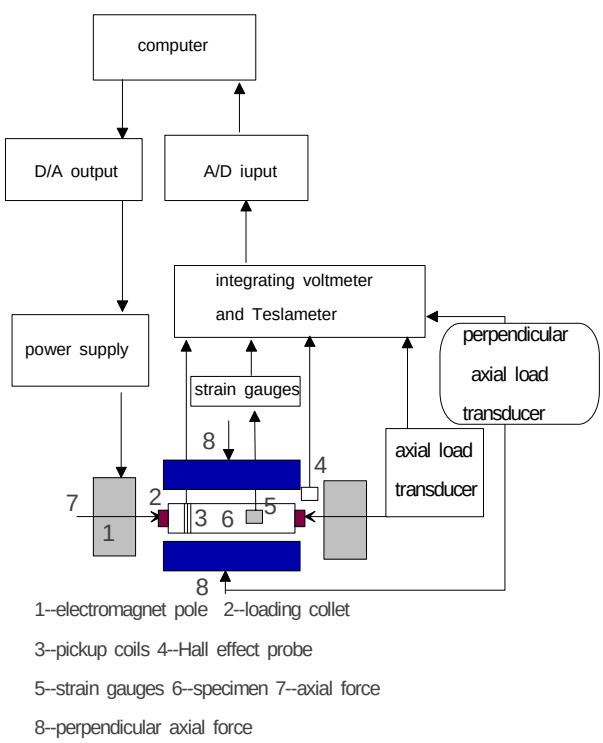

Figure 1: Schematic of the setup. The industrial PC controls the electromagnet supplier and monitors the magnetic H, magnetic induction B and the magnetostriction of specimens by an A/D-D/A interface card.

2. The response of ferromagnetic materials is dependent on the loading history because of energy dissipation, which was similar to the classical plastic theory. According to the Karafillis-Boyce model of the eanisotropic plastic theory, the general constitutive model for ferromagnetic and magnetostrictive materials, based on the internal variable theory, is developed. The remnant magnetization and strain are considered as internal variables, and a three-dimensional constitutive relation can be built in general. Based on the magneto-mechanical yield surface measured by the authors, a non-quadratic magneto-mechanical yield surface is introduced for both isotropic and anisotropic materials (see Fig. 2). The anisotropy includes both magnetic anisotropy and elastic anisotropy, which can be described by introducing a set of irreducible tensorial state variables. The linear transformation from anisotropy to isotropy is presented. Then, the proposed model is generalized for both isotropic materials and anisotropic materials. Furthermore, the magneto-mechanical yield surface of the magnetostrictive material Terfenol-D was measured and the magneto-mechanical hardening moduli can be determined by Helmholtz free energy. The macroscopic features of ferromagnetic materials, such as hysteresis loop, magnetostrictive, magnetostrictive hysterisis, can be predicted. Figure 3 shows that the calculated results are consistent with the experimental data well .

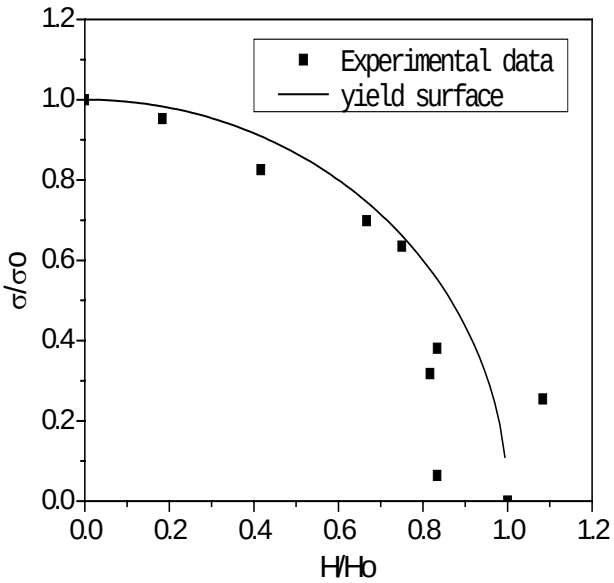

Figure 2. The dimensionless initial yield surface of Terfenol-D

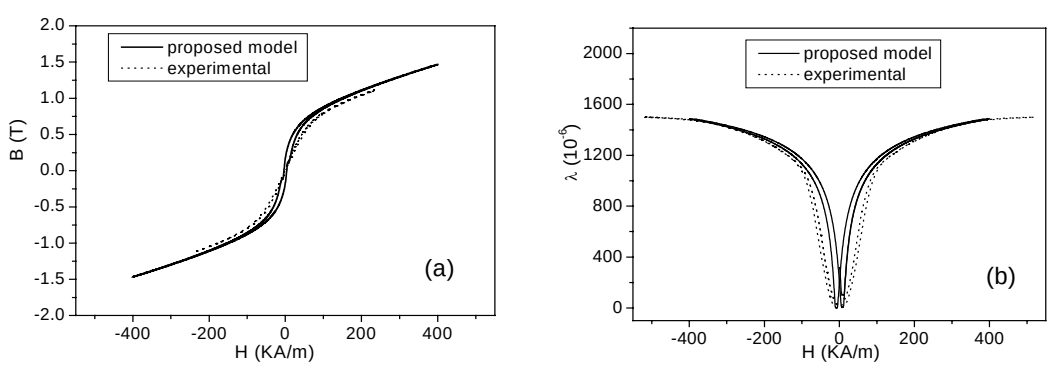

Figure 3. Comparison of the theoretical and measured results under magnetomechanical loading with 3MPa compressive stress: (a) the hysteresis curve; (b) the magnetostrictive curves.

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