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# The Mesoscopic Theory of Ferromagnetic Shape Memory Alloys

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## Summary

Magnetoelastic domains in ferromagnetic shape memory alloys (FSMA) evolve through either variant rearrangement or magnetization rotation, resulting in large or small magnetic field-induced strain depending on the magnitude of applied compressive stress. A mesoscopic theory is developed to study the magnetoelastic behavior of FSMA to account for both variants rearrangement and magnetization rotation. A multi-rank laminated domain configuration is constructed first under the constrained theory, which is then relaxed by allowing the magnetization to rotate away from its easy axis, resulting in incompatibility in both magnetization and magnetostrictive strain. The internal magnetoelastic field is then analyzed using a hierarchical lamination theory, where the stress and magnetic field in the multi-rank laminate induced by incompatibility at two distinct length scales are evaluated. Microscopic variation of magnetization is evaluated on a unit cell using periodic boundary condition, while mesoscopic variation is evaluated on the specimen using averaged magnetization and actual boundary condition, utilizing a recently developed nonlinear homogenization theory of ferroelectrics. It is observed that microstructure evolution of FSMA is dominated by rearrangement of variants when the applied stress is small, but such rearrangement is blocked when the applied stress is relatively large, under which magnetization rotation takes over as the dominant mechanism for microstructure evolution. When the energy dissipation is considered through twinning stress, excellent agreement between theoretical predications and experimental measurement is observed. The critical stress beyond which variants rearrangement is disfavored is also estimated in good agreement with experiment. Furthermore, a novel phase-field simulation is carried out to verify the variant rearrangement and magnetization rotation process in FSMA, confirming our theoretical analysis.


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