Modeling hierarchical branching near austenite–martensite interfaces: a phase-field study

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In most shape memory alloys (SMAs), a direct interface between the austenite phase and a single variant of martensite is typically not observed. Instead, compatibility is generally considered in an averaged sense through laminates composed of two variants of martensite, commonly referred to as twinned martensite. Within the framework of crystallographic theory of martensite, these laminate structures are postulated to be macroscopically stress-free. However, local incompatibilities still develop at the austenite–twinned martensite (A–MM) interface, which gives rise to microstructural morphologies within the transformation zone. Experimental studies indicate that a branched microstructure or a reduction in twin spacing occurs in the vicinity of the A–MM interface. This refinement is occurred to minimize elastic strain energy near this interface, even though it leads to an accompanying increase in twin boundary energy.

Early mathematical modeling of branching was introduced by Kohn and Müller [2], in which a scaling law for branching generations was proposed. Subsequently, Seiner et al. [3], based on the concept of a discrete branching framework and estimates of the elastic strain energy, twin boundary energy, and elastic micro-strain energy near the A–MM interface, calculated the number of branching generations in SMAs. More recently, Stupkiewicz et al. [4] proposed a one-dimensional model for twin branching based on the principle of energy minimization, in which the twin spacing varies continuously.

Accurate representation of branched microstructures in SMAs via the phase-field approach necessitates the use of highly refined meshes in order to resolve successive branching generations in the vicinity of the A–MM interface. This requirement significantly increases computational expense, thereby limiting the feasibility of capturing higher-order branching generations. Accordingly, an alternative modeling strategy is required.

The present work aims to establish a methodology for simulating branched microstructures in SMAs within a phase-field framework. To alleviate computational demands while preserving the morphological features of branching, the austenite phase is approximated by linear springs that mimic the elastic strain energy of the austenitic bulk material. By adjusting the stiffness of these springs, different branching levels can be represented, corresponding to various stages of microstructural refinement. The proposed approach is validated through comparison with previously reported results in the literature [3,4].

References

[1] C. Zhang, G. Qin, S. Zhang, X. Chen, Y. He, Hysteresis effect on austenite-martensite interface in Ni-Mn-Ga single crystal, Scripta Materialia 222 (2023) 115029.

[2] R.V. Kohn, and S. Müller, Branching of twins near an austenite-twinned-martensite interface, Philos. Mag. A 66 (1992) 697–715.

[3] H. Seiner, P. Plucinsky, V. Dabade, B. Benesova, R. D. James, Branching of twins in shape memory alloys revisited, J. Mech. Phys. Solids 141 (2020) 103961.

[4] S. Stupkiewicz, S. Amini, M. Rezaee-Hajidehi. Twin branching in shape memory alloys: A 1d model with energy dissipation effects. Eur. J. Mech. A/Solids, 113 (2025) 105671.