Shape Memory Adaptive Materials Systems: Correlating Macroscale Shape Memory Response to Underlying Physical Mechanisms

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The laser directed energy deposition (LDED) additive manufacturing technique is used to deposit Ti-rich NiTi shape memory alloys (SMAs) to a specific blend ratio (52 wt.% here). SMAs fabricated using additive manufacturing (AM) techniques inherently exhibit microstructural features distinct from that of conventionally processed SMAs which influence the bulk response and properties. We consider LDED AM SMAs as a type of adaptive material system; with a matrix which undergoes the shape memory transformation within a host structural hierarchy. The hierarchy is made up of grain boundaries, precipitate morphologies, and local substructures of differing characteristic grain sizes/orientations and microconstituent phases, orientations, sizes, and spacing. Innovative experimental characterization approaches are needed to correlate the LDED structural hierarchy to the multi-scale deformation mechanism of the SMA: an atomic structure change begets a reversible martensitic microstructure solid-state phase transformation (MT) that facilitates shape recovery. This work aims to characterize macroscopic shape memory responses with the aim of using the bulk scale stress-strain measurements to interpret structure-property relations and link them to the underlying shape memory transformation. Macro-scale deformation analysis is coupled with in-situ digital image correlation analysis for exposing the evolution of local strains associated with the MT morphology. Here we report the mechanical strength properties and characterize the behavior resulting from the stress-induced shape memory response. DIC analysis allows for interpreting the underlying transformation morphology and elucidating the microstructure-property relationships. For benchmarking, we contrast the thermo-mechanical characterization of conventionally processed NiTi alloys whose compositions are equivalent to the AM NiTi SMAs.