Shape recovery in shape memory alloys (SMAs) occurs against external stress by means of a reversible thermoelastic solid state phase transformation typically between so-called austenite, martensite and R-phase phases. The ability to do work enables their use as high-force actuators in automotive and aerospace applications while superelastic NiTi is of interest in biomedical devices such as stents. Both R-phase and martensite can detwin, reorient and undergo a thermal or stress induced transformation. For these reasons, it is difficult from ordinary macroscopic measurements to decouple elastic and inelastic contributions (from their respective phases) from the overall deformation. In situ neutron diffraction is ideally suited to probing these microstructural and micromechanical changes while they occur under external stress fields.

Despite SMAs typically operating under multi-axial stress states in applications, most previous in situ neutron diffraction based investigations on SMAs have been limited to homogenous stress states as a result of uniaxial loading. The current investigation spatially maps thermoelastic deformation mechanisms during heating and uniaxial/torsional loading of shape memory and superelastic NiTi by recourse to in situ neutron diffraction, performed at Oak Ridge and Los Alamos National Laboratories. SMA spring actuators were also used to experimentally validate the ability of a recently developed model to predict the evolutionary deformation response under multi-axial loading conditions.

By recourse to in situ neutron diffraction, martensite variants were tracked during isothermal, isobaric, and isostrain loading in shape memory NiTi. Results show variants were equivalent for the corresponding strain and more importantly, the reversibility and equivalency was immediately evident in variants that were first selected isobarically but then reoriented to a near random self-accommodated structure by isothermal deformation. Variants selected isothermally were not significantly affected by a subsequent thermal cycle under constant strain.

During uniaxial/torsional loading and heating, thermoelastic deformation mechanisms in non-uniform states of stress in superelastic NiTi were spatially mapped. The preferred selection of R-phase variants by reorientation and detwinning processes were equivalent for the corresponding strain (in tension and compression) and was reversed by isothermal loading. The variants selected were consistent between uniaxial and torsional loading when the principal stress directions of the stress state were considered (for the crystallographic directions considered here). The similarity in general behavior between uniaxial and torsional loading, in spite of the implicit heterogeneous stress state associated with torsional loading, pointed to the ability of the reversible thermoelastic transformation to accommodate both stress and strain mismatch associated with deformation.

Overall, various thermomechanical combinations of heating and loading sequences yielded the same final texture (preferred selection of variants), which highlighted the ability to take different paths yet still obtain the desired response while minimizing irrecoverable deformation mechanisms. These paths have implications for minimizing the number of cycles required to train an SMA, which limits the amount of work required for stabilizing their evolutionary response thereby increasing the fatigue life and overall durability of the SMA. This finding is valuable to the aerospace and medical device industries where SMAs find current application.

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