Geophysical Research Abstracts,
Vol. 10, EGU2008-A-12040, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-12040
EGU General Assembly 2008

Martensitic Phase Transitions and Shape Memory

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Martensitic phase transitions are thermodynamically first-order paraelastic-ferroelastic phase transitions. Accordingly, self-accomodating ferroelastic twin patterns develop in the martensitic phase. Upon the application of a stress field conjugate to the order parameter, ferroelastic twin domain switching occurs as the microstructure in the material accomodates to the new boundary conditions. This usually results in a macroscopic shape change. For a true martensite, such as the phase bearing that name in steel, the change in volume at the phase transition or any other coelastic strains are insignificant, allowing a polycrystalline material to be cycled many times through domain reversals or through the phase transition without catastrophic failure. One of the resulting properties of practical importance is shape memory. If the martensite is thermodynamically stable, a twin domain microstructure which has accomodated to an external stress field will stay even if the stress is released. However, the original state of the stress-free self-accomodated microstructure can be recovered by heating into the paraphase (the "austenite") and subsequent cooling in the absence of macroscopic stress. Thus the original macroscopic shape is recovered. Superelasticity is the phenomenon where, starting from the thermodynamically stable "austenite" paraphase, the application of stress drives the system into the martensite state (with stress-accomodated twin microstructure). When stress is released, the material transforms back into the stable austenite state and the macroscopic shape is recovered in a rubber-like stress-strain curve. For the NiTi alloy the recoverable strain is in the order of 6-7%.

The stress-accomodation of martensite twin domains can be measured in-situ and visu-

alized using hard synchrotron x-rays, able to penetrate millimeters of NiTi in a tensile test sample.

Thermodynamic models have been developed [1] which explain the observed intensity distribution on the basis of domain orientation texture in the applied field [2].

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[2] M. Hasan, W.W. Schmahl, K. Hackl, R. Heinen, J. Frenzel, S. Gollerthan, G. Eggeler, M. Wagner, J. Khalil-Allafi and A. Baruj (2007) Hard X-ray studies of stress-induced phase transformations of superelastic NiTi shape memory alloys under uni-axial load.- Materials Science and Engineering A, doi:10.1016/j.msea.2007.02.156, in press, 2008