Characterization of recovered iron samples after laser shock loading

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Abstract

Many metals undergo solid-solid phase transitions under dynamic loading. Since post shock microstructures very often exhibit grain orientations that were not present in the initial microstructure, the analysis of recoverd samples is a promising way to investigate their transformation history. Twinning is also a frequent deformation mechanism under high strain rates and induces a change in lattice orientation. Reversion variants are then difficult to interpret because they can be induced by several sequences of phase transformations mediated by twinning. For instance, in the case where there is a single generic A-B transformation possible in pressure, one has to consider (if plausible) the scenarios :
- twinning of A ;

- A-B then B-A ;

- A-B then twinning of B then B-A.

We propose a software tool to handle such a large number of possible variants (1). Reaction Pathway Graphs (RPGs) (2) associated with each displacive transformation sequence are built, and all possible final crystal orientations are obtained as leaves of the graphs. These orientations are then compared with experimental ones to assess the most plausible transformation scenarios, if any. Iron was chosen as a test material to validate this approach. Iron transits from a body-centered cubic (bcc) phase to a hexagonal compact (hcp) phase around 15 GPa following the Burgers mechanism. Single crystal iron samples with a thickness of 100 micrometers were shock loaded above the alpha-epsilon transition pressure in the GCLT laser facility at CEA. A momentum trap apparatus was used to prevent damage within the regions of interest. After testing, the samples were cut and polished in their cross-section. Electron backscatter diffraction (EBSD) mappings of crystal orientations were then performed.

Reversion variants within the post mortem microstructure were further divided into two categories. First, variants for which bcc twinning and a transformation sequence involving the Burgers mechanism were the most plausible scenarios. Both are known to produce identical orientation relationships, preventing them to be distinguished from orientation data only. However, RPGs bear the information of transformation strains. An analysis based on Hadamard's compatibility conditions was then implemented to complement orientation analysis. It shows satisfactory results in the quick discrimination between twinning and Burgers

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variants.

Second, variants for which neither bcc twinning nor Burgers scenarios were plausible. We show that all these orientations can be accounted for when taking into account transformation scenarios mediated by twinning of the high pressure phase of iron. A twinning system is inferred from the analyses that is consistent with previous in situ observations, thus highlighting the richness of data on solid-solid phase transformations that can be gathered from recovered samples after shock loading.

(1) Bruzy et al., *Identification of diffusionless transformation sequences from crystal orientation data*, to be submitted, 2024
(2) Denoual and Vattré, A phase field approach with a reaction pathways-based potential to model reconstructive martensitic transformations with a large number of variants, JMPS **90** (91-107), 2016