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Title:	Kinetics of Solid-Solid Phase Transitions in Metals using Proton Radiography (U)
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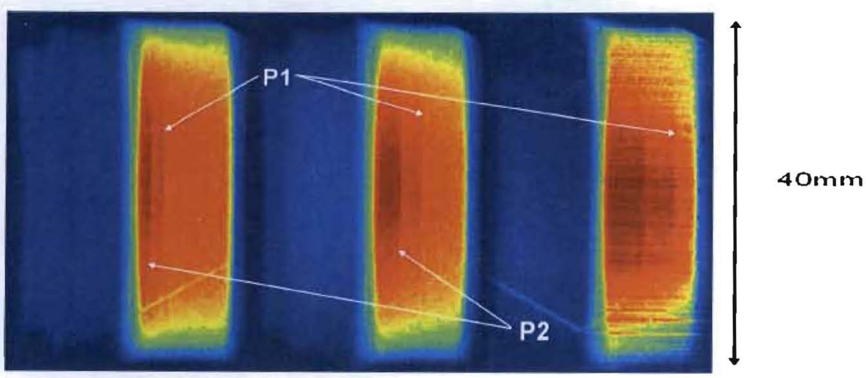
DETAILED DESCRIPTION OF THE EXPERIMENT OR ACTIVITY

(Describe the science of engineering research being addressed, importance, and a description of how this experiment campaign will contribute to the progress of this research.)

Introduction

When a compressed material changes phase it doesn't do so instantly. Instead it transitions through a mixed phase as it transforms to the end state phase for a given pressure, volume and temperature. Common phase diagrams show the phase boundaries as sharp lines when compression has been slowly applied and held for an infinite amount of time. When the compression is applied with high strain rate, however, the phase boundaries are no longer crisp as the kinetic effects of the crystal reorientation delay the transitions, resulting in regions of mixed phase. This opens up the possibility that some degree of metastability exists for such transition in dynamic compression. The compression path can go past the equilibrium phase boundary and the transition happen from a metastable state because of the very short timescale of the compression process. Molecular dynamics (MD) simulations recently have been used to examine shock-induced phase transitions in single crystal materials illustrating an orientation dependence of the transition stress, mechanisms, kinetics, and Hugoniot response.[1] For example, the [100] orientation of iron had a simulated transition stress higher than the experimentally determined polycrystalline value of 13 GPa by 2 GPa. Previously, dynamic experiments on iron have observed a non-zero transition time and width in the solid-solid α-ε phase transition.[2,3] Using Proton Radiography at the Los Alamos Neutron Science Center, we have performed plate impact experiments on iron to further study the α-ε phase transition which occurs at 13GPa. A 40mm bore powder gun was coupled to a proton radiography beam line and imaging system and synchronized to the impact of the projectile on the target sample with the proton beam pattern. A typical experimental configuration for the iron study, as shown below in 3 color-enhanced radiographs, is a 40mm diameter aluminum sabot impacting a 40mm diameter sample of polycrystalline ARMCO iron. The iron is backed by a sapphire optical window for velocimetry measurements. The aluminum flyer on the left of the iron is barely visible for visual display purposes.



Direct density jumps were measured[4] which agreed with calculations to within 1% using a WONDY multi-phase equation of state model. In addition, shock velocities were measured using an edge fitting technique and followed that edge movement from radiograph to radiograph, where radiographs are separated in time by 500 ns. Preliminary measurements give a shock velocity (P1 wave) of 5.251 km/s. The projectile velocity was 0.725 km/s which translate to a peak stress of 17.5 GPa.

One of the advantages of using Proton Radiography for these experiments is that we can make *in situ* measurements of the shape, velocity and density jumps of the P1 and P2 waves in the bulk of the sample, instead of inferring these properties by deconvolution of their effects on surface diagnostics.

If the P1 wave rise time is taken to be instantaneous compared to the radiographic resolution of our system, we are able to calibrate the chromatic, motion, object and camera blur by measuring the width of the P1 wave. If not, then focusing objects will need to be used. This approximation works in this case since each of the two density jumps are small compared to the density of the test object. Subtracting the measured width of the P1 wave in quadrature from the width of the P2 wave gives a preliminary measurement of the transition length of 265 μm. Therefore, a preliminary measured phase transition relaxation time τ = transition length/u_s = 265 μm/5.251 km/s = 50 ns.

Both Boettger[2] & Jensen[3] conclude that the transition rate and likely the transition mechanisms depend on the impact stress and the sample thickness. Since Proton Radiography can measure directly the transition length as well as the shock velocity, a transition time can be directly calculated.

Experimental Proposal

We propose to perform a series of experiments to measure the phase transition relaxation time, τ, as a function of drive pressure and crystal orientation for prototypical materials. This proposed work is in combination with P. Rigg's ongoing study into solid-solid phase transitions on metals (see Rigg FY2012 proposal). These experiments require use of the 40mm powder gun, a HE-driven flyer or other HE drive. Some knowledge or control of the drive pressure is needed.

We chose iron as one of the materials because the α-ε solid-solid phase transition is well studied and our results can be compared to known results.[3] Tin was chosen since its relatively low pressure β–γ solid-solid phase transition is easily accessible and the large density changes of the transition make it ideal for pRad measurements. Some comparison can be made to known results on tin[5], but these proposed direct *in situ* measurements will allow for refinement of the kinetic model, in particular a refined measurement of the relaxation time, τ. Finally, zirconium was chosen to further understand the effects of polycrystalline versus single crystal orientation on the α–ω transition kinetics.

The following table outlines the series of proposed shots. Some shots (*) can possibly be combined with Rigg's proposal if designed appropriately.

Shot Number	Material	Orientation
1	Fe	Poly*
2	Fe	[100]
3	Sn	[100]
4	Sn	[TBD]
5	Zr	Poly
6	Zr	[111]
7	Zr	[100]

We will make measurements similar to those described above for polycrystalline iron, and results will be used to refine our understanding of the phase transition processes in these materials. Results will be turned over to customers in group T-1 for use in better constraining phase transition models for use on materials of more direct relevance to the weapons program.

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2. J.C. Boettger and D. Wallace, "Metastability and dynamics of the shock-induced phase transition in iron", Phys. Rev. B **55**, 2840 (1997).
3. B.J. Jensen, G.T. Gray III and R.S. Hixson, "Direct measurements for the α-ε transition stress and kinetics for shocked iron", Journ. Appl. Physics **105**, 103502 (2009).
4. P.A. Rigg, C. L. Schwartz, et al., "Proton radiography and accurate density measurements: A window into shock wave processes", Phys. Rev. B **77**, 220101 (2001).
5. Anderson, W.W., et al., "Phase Transition and Spall Behavior in β-Tin", AIP Conference Proceedings, Vol. 505, p. 443-446 (2000).