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Iron and Aluminum at Ultrahigh Strain Rates

JONATHAN CROWHURST, Lawrence Livermore National Laboratory

In recent years, techniques based on table-top laser systems have shown promise for investigating dynamic material behavior at high rates of both compressive and tensile strain. Common to these techniques is a laser pulse (the "pump") that is used in some manner to rapidly deliver energy to the sample; while the energy itself is often comparatively very small, the intensity can be made high by tightly focusing the pump light. In this way pressures or stresses can be obtained that are sufficiently large to have relevance to a wide range of basic and applied fields. Inherent to these techniques too, is relatively low cost and high throughput. Also, by using additional laser pulses (the "probe") to measure the response of the sample, very high time resolution can be achieved. The latter in particular is desirable when studying, for example shock waves, in which the time for the material to pass from undisturbed to fully compressed (the "rise time") can be extremely short (order 10 ps or less) even at fairly small peaks stresses. Since much of the most interesting physics comes into play during this process it is important to be able to adequately resolve the shock rise. Furthermore, the associated time scale is comparable to that typically considered in state-of-the-art molecular dynamics simulations which are emerging as the theoretical tool of choice for investigating shock waves in condensed matter. It should be pointed out however, that a general drawback to these techniques is that, depending on the aim of the experiment, a small pump energy imposes limits on the nature of the sample; if for example the aim is to study steady shock waves, the compressed region has to be thin, and its internal structure cannot vary on a scale that is not much smaller than the compressed dimensions. We consider and illustrate these concepts in the context of various metals, primarily aluminum and iron, and show how current methods are capable of making meaningful and useful measurements of material behavior at ultrahigh strain rates up to or exceeding 10^{10} s^{-1}, corresponding to more than 40 GPa in aluminum. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344 with Laboratory directed Research and Development funding (12ERD042), as well as being based on work supported as part of the EFree, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Award No. DESC0001057.