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IR DIAGNOSTICS FOR DYNAMIC FAILURE OF MATERIALS

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LDRD Engineering Project 04–ERD–005
IR DIAGNOSTICS FOR DYNAMIC FAILURE OF MATERIALS

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Project Overview

This project explores the thermodynamics of dynamic deformation and failure of materials using high-speed spatially-resolved infra-red (IR) measurements of temperature. During deformation mechanical work is converted to different forms of energy depending on the deformation processes. For example, it can be dissipated as heat in purely plastic deformation, stored as strain energy in dislocations in metals and in oriented polymeric molecular structures, and expended during the generation of new surfaces during damage and fracture. The problem of how this work is converted into these various forms is not well understood. In fact, there exists a controversy for the relatively simple case regarding the amount of work dissipated as heat during uniform plastic deformation. The goals of this work are to develop dynamic IR temperature measurement techniques and then apply them to gain a better understanding of the dynamic failure processes in both metals and polymeric composite materials. The experimental results will be compared against predictions of existing constitutive models and guide the development of higher fidelity models if needed.

Project Goals

The first goal of this project was devoted to characterizing the fractional conversion of mechanical work to heat, also know as the Taylor-Quinney coefficient, β, in uniform plastic deformation experiments. A controversy existed between those expecting values of $\beta = 1$, i.e. all of the mechanical work is dissipated as heat, and others expecting $\beta < 1$. LS-DYNA modeling was used to identify the circumstances required to achieve nearly adiabatic conditions for the different materials tested at different stain rates. An IR imaging system based on a 16-element linear high-speed detector array will be used in the uniform plastic deformation experiments. The next goal will be to study the more complicated problem of fracture of metals and HE simulants. This will require a higher resolution 2-dimensional IR detector with a 64-element 8x8 array. Shear banding and other forms of deformation are known to precede crack propagation in ductile materials and our ability to temporally and spatial resolve temperature gradients due to these incipient failure mechanisms ahead of a crack tip will provide valuable insight into the failure process.

Relevance to LLNL Mission

This project will develop a more complete understanding the mechanisms of material failure and produce advanced capabilities to acquire IR thermographic data for materials undergoing dynamic deformation and for other dynamic events leading to temperature gradients. Potential DOE applications of the IR temperature measurement technology include machining and safety aspects of explosives, precision machining (including modeling temperature factors at the diamond/piece interface), laser optics *in situ* inspection, hydrodynamics, temperature effects associated with rapidly moving wavefronts, NIF target modeling, and plasma deposition processes.

FY05 Accomplishments and Results

In Figure 1 LS-DYNA modeling results show that adiabatic conditions prevail away from specimen ends during intermediate strain rate deformation suggesting that results of IR measurements can be directly compared with thermocouple measurements. Initial experiments to discern whether or not β= 1 under uniform strain were undertaken using thermocouples welded to the samples. As shown in Fig. 2 these results on aluminum show that β can be significantly less than 1 under uniform loading conditions and that β is strain dependent. Other experiments with thermocouples on tantalum samples showed evidence of shear banding. In the development of the IR imaging system it was determined that the Newtonian optical system was not suitable for these types of experiments. The optical system was redesigned to incorporate Cassegrain optics and a linear IR imaging system based on the Fermionics 16-element high-speed array was constructed. Studies showed that the emissivity showed changes after deformation. Studies of appropriate surface finishes were made to ameliorate this issue. Also, Insignificant differences were observed when IR measurements were done in vacuum versus in atmosphere.

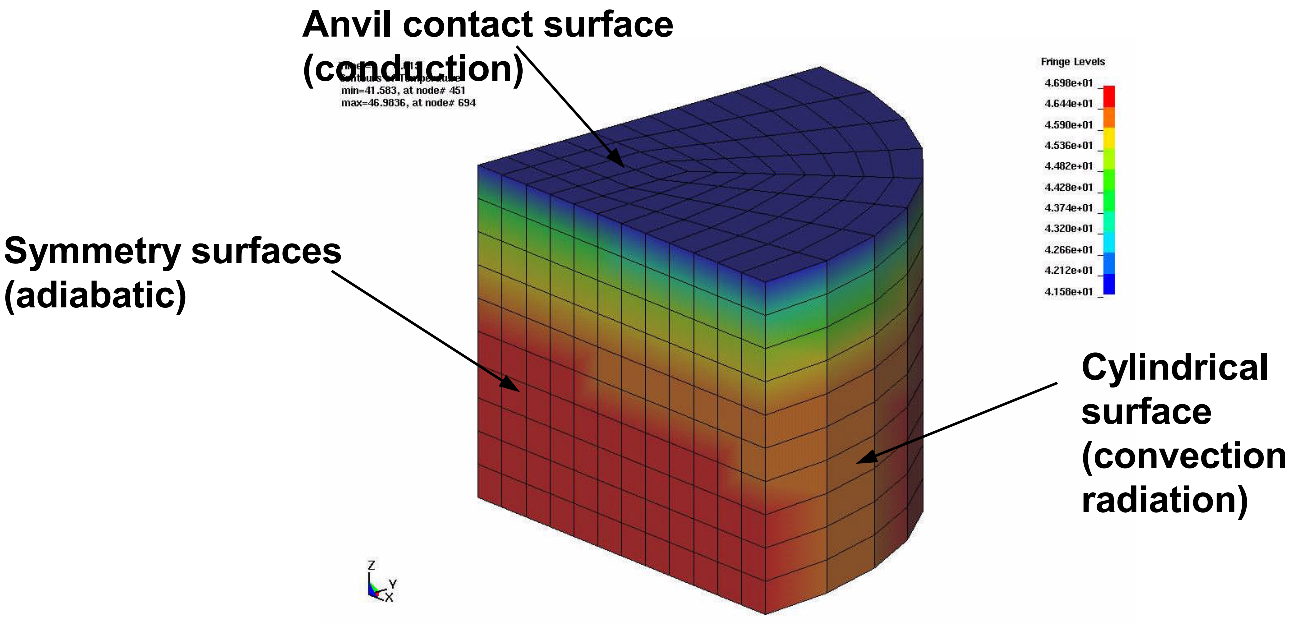

Figure 1. Modeling results show that adiabatic conditions prevail away from specimen ends during intermediate rate deformation.

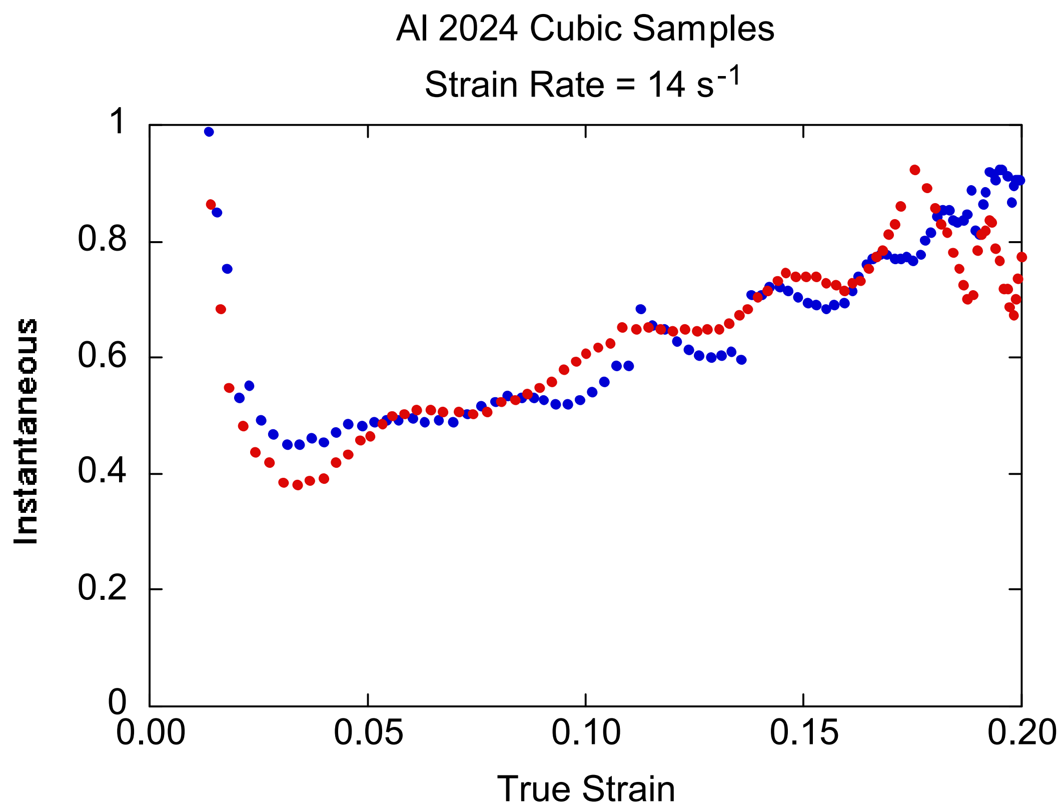

Figure 2. Fractional conversion of mechanical work to heat, the Taylor-Quinney coefficient, β, is shown to be dependent on the strain in aluminum samples subjected to uniform strain. This result resolves the important controversy over whether $\beta = 1$ or if $\beta < 1$ for uniform strain conditions.