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Modeling Initiation in Exploding Bridgewire Detonators

C. A. Hrousis

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MODELING INITIATION IN EXPLODING BRIDGEWIRE DETONATORS

Constantine A. Hrousis

Lawrence Livermore National Laboratory
7000 East Avenue, Livermore, California 94550 USA

(925) 423-4744
hrousis1@llnl.gov

Abstract

One- and two-dimensional models of initiation in detonators are being developed for the purpose of evaluating the performance of aged and modified detonator designs. The models focus on accurate description of the initiator, whether it be an EBW (exploding bridgewire) that directly initiates a high explosive powder or an EBF (exploding bridgefoil) that sends an inert flyer into a dense HE pellet. The explosion of the initiator is simulated using detailed MHD equations of state as opposed to specific action-based phenomenological descriptions. The HE is modeled using the best available JWL equations of state. Results to date have been promising, however, work is still in progress.

Introduction

There is great interest in better understanding the dynamics of exploding bridgewire (EBW) performance and its role in the process of initiation in EBW detonators. Also, it is desirable to have a design tool for evaluating the merit of altered and proposed exploding bridgefoil (EBF) and slapper detonator designs. In particular, we need to better understand the mechanism by which electrical energy stored in a fireset transforms into initiating energy within a high explosive and how this mechanism is disrupted by changing materials and geometry. This work uses the LLNL-developed magnetohydrodynamic (MHD) code CALE to model the explosion of EBWs when placed in a circuit with a fireset. The models began as 1-D, but now have been generalized to 2-D with the capability of including details due to aging, such as the growth of intermetallic compounds.

The goals of this work-in-progress include: development of sufficiently accurate 2-D models for pure metal EBWs surrounded by high explosive, development of models that predict performance of aged systems, and experiments to validate the MHD models in CALE at "low" energies and the associated analyses needed for model validation. The final product will be a simulation capability for EBW and slapper initiation in arbitrary configurations, an assessment tool for detonator reliability. To date, preliminary models of initiators have been developed, with current work focused on proper addition of the initiating HE, and model validation experiments.

Methods & Results

CALE successfully incorporates state variables for current density and magnetic field, necessary for a complete MHD description of initiator burst. By supplying appropriate initiator electromagnetic material properties, a more "first principles" approach to modeling the burst is achieved, instead of relying on phenomenological descriptions of specific action to predict burst time.

One-dimensional models of wire burst have been compared with recent and historical closed-form calculations, as well as underwater wire burst experiments and full detonator test fire experiments. The 1-D models predict most metrics of interest (such as time of burst and burst current) with reasonable accuracy, but are still in need of improvement in predicting EBW pressure output. This is due in part to needed refinement in the CALE material models at these "low" energies of interest for more detailed treatment of phase changes. Figure 1 demonstrates qualitative agreement between experiment and 1-D simulation streak images.

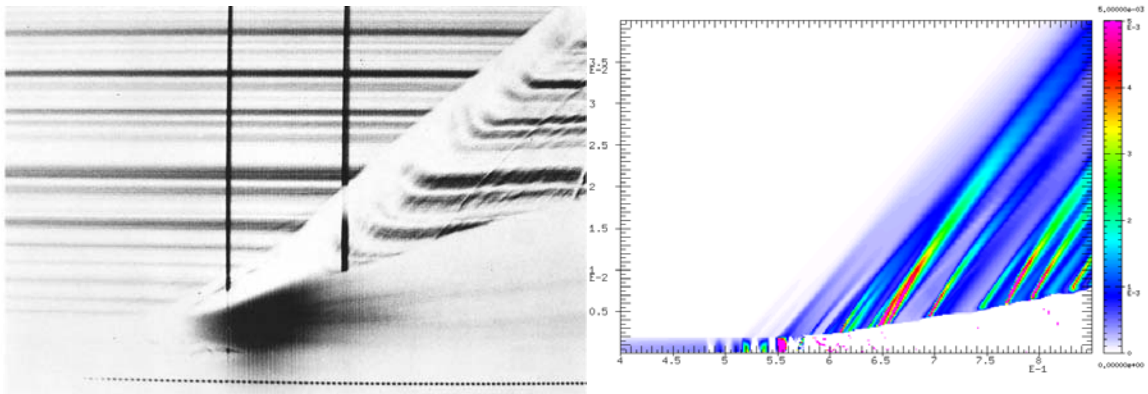


Figure 1. *Left:* Experimental streak image of a gold wire exploding in water (Wilkins, et al.) This is like a 1-D movie of an EBW cross-section as it explodes. Time increases to right, while radius increases upward. Note wire expansion, followed by the material expansion (lower sloped curve) and the shock wave sent into the surrounding medium (upper sloped curve). *Right:* 1-D simulation of the underwater EBW experiment, presented as a streak image. Colors depict pressure levels in the wire and water. CALE calculates the wire's melt, vaporization and burst times with reasonable accuracy, sending the associated pressure waves and shocks into the surrounding medium. Note that the dominant shock wave occurs at burst, with smaller shocks at other times, as in the experiment.

Also, two-dimensional models have been created to better understand both longitudinal and axial aspects of EBW performance. Figure 2 shows comparison between a longitudinal view of an exploding gold bridgewire, and a 2-D CALE simulation.

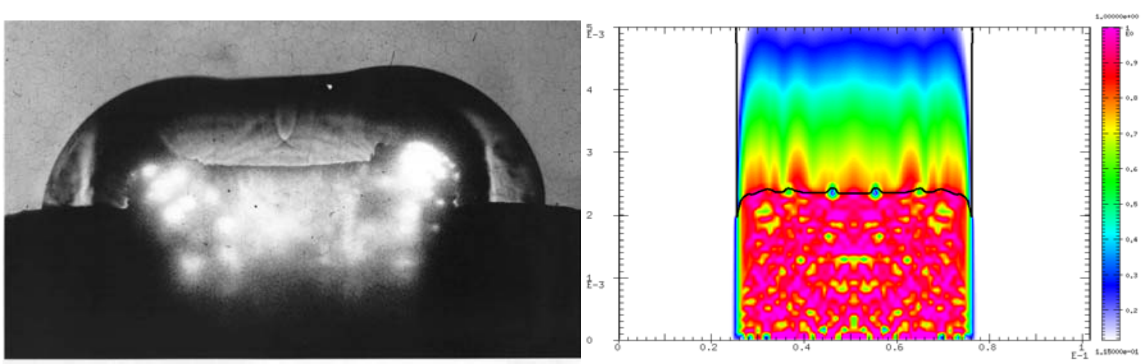
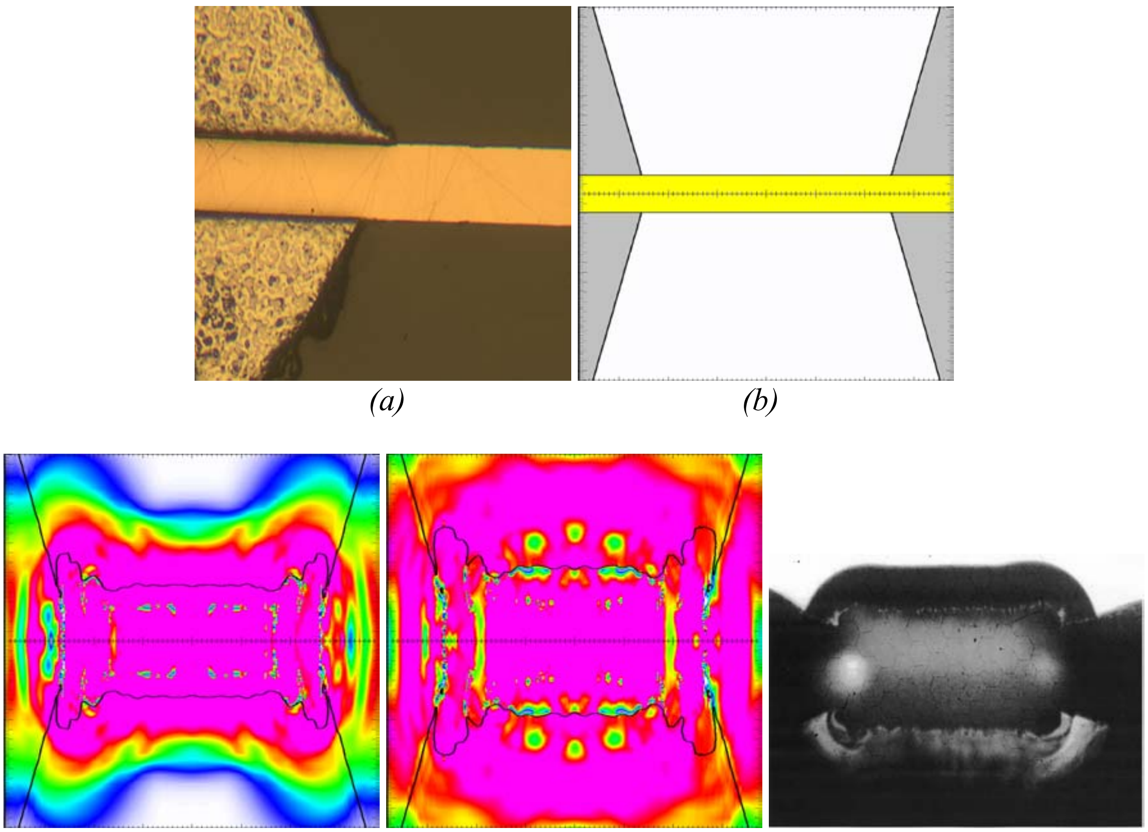


Figure 2. *Left:* Experimental frame image (side view) of a gold wire luminescing as it explodes. *Right:* Preliminary 2-D longitudinal simulation of the underwater EBW experiment. Here colors show material temperature levels. It is possible the "hot patches" of material are the code's way of indicating the luminescent spots seen in experiment.

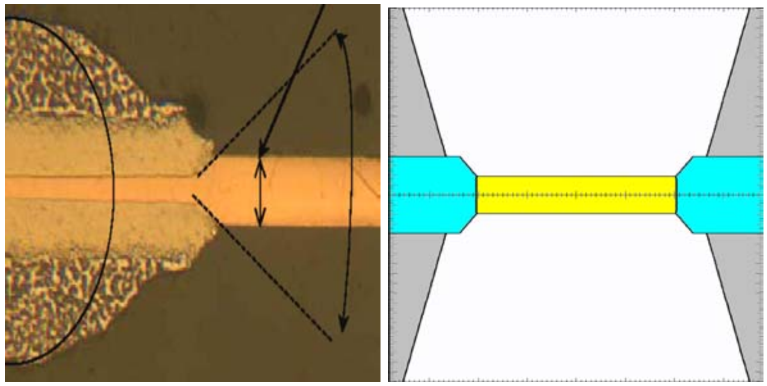
The incorporation of a preliminary material model for gold-indide is a recent accomplishment, due in part to experimental studies completed in order to find this material's coefficient of thermal expansion. This property is needed for estimation of the Gruneisen gamma, a parameter that influences both shock and MHD aspects of the material's response. Figures 3 and 4 illustrate the experimental and modeled response of pure gold and gold-indide affected EBWs.



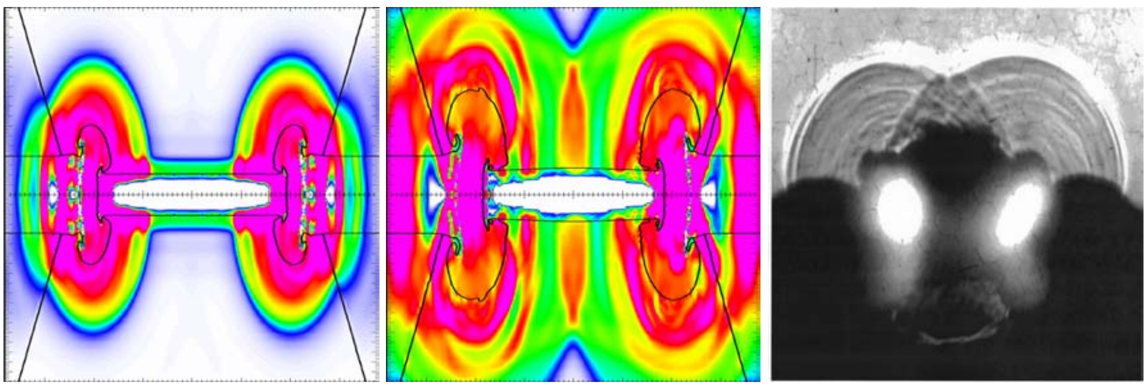
(a) *(b)*

(c) *(d)* *(e)*

Figure 3. *(a)* Axial cross-section of a new soldered gold EBW at the wire-solder mound junction. *(b)* Computational representation of a new gold EBW between two solder mounds in CALE. *(c)* Soon after burst, CALE predicts a relatively uniform burst pattern. *(d)* Well after burst, the shock emanating from the EBW remains uniform. *(e)* Experimental frame image of a new bursting EBW shows uniform shock bubble surrounding a fairly uniformly bursting gold plasma.



(a) *(b)*



(c) *(d)* *(e)*

Figure 4. *(a)* Axial cross-section of an aged soldered gold EBW at the wire-solder mound junction; the region between the pure gold and the solder is gold indide. *(b)* Computational representation of a highly aged gold EBW with gold indide present between two solder mounds in CALE. *(c)* CALE predicts the gold indide explodes well before main wire burst. *(d)* Later into the response, the burst pattern remains highly non-uniform; pressures are significantly weaker than for new EBWs. *(e)* Experimental frame image of an aged bursting EBW confirms a very non-uniform burst pattern.

Current work is devoted to developing appropriate initiation models for high explosive powders that are typically used with EBWs in detonators (for instance, PETN). Recent models incorporate half-dense PETN as an initiating medium using best-fit reactive flow models for the HE response, as provided by Clark Souers of LLNL. Resources permitting, the powder initiation simulation will be enhanced using Ignition and Growth phenomenological models developed by Craig Tarver, et al. at LLNL, and possibly the SCORE shock initiation criteria of Hugh James, et al. of AWE.

Plans for future work exist for extensive model validation through underwater burst experiments on specially made EBWs of various materials. Further refinement of axial 2-D models is needed, particularly for comparison with these validation experiments. The models will be benchmarked against pure gold, copper, aluminum and gold indide EBFs. After the validation phase, this modeling work will continue with sensitivity studies on existing and new initiation systems of interest.

Acknowledgments

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