Computational Support of Beryllium Investigation

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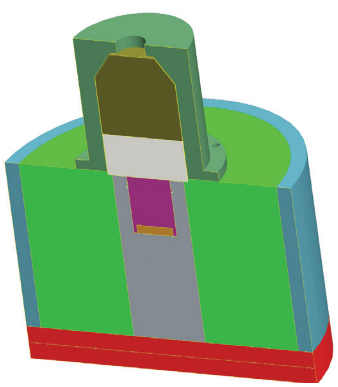
An investigation was conducted to explore the ability of the equation-of-state, rate-dependent plasticity, and dynamic-failure models to address the deformation characteristics of beryllium. It was concluded that excellent agreement of the equation-of-state and plasticity models was provided with the experiments that were considered. Comparisons with the damage models, however, were inconclusive. Information regarding the growth of damage as well as the potential for shear failure under compressive loads was not available. Consequently, additional experiments were considered and designed in an effort to pursue these issues.

Fig. 1. Final design of the HE-driven Be experiment {10}.



Beryllium (Be), which is a material of interest to the Department of Energy (DOE), Department of Defense (DoD), and aerospace communities, exhibits a number of complex phenomena when it is deformed under the conditions of high strain rate. Past experimental data is difficult to utilize for the purpose of quantifying the dynamic response of Be because the pedigree of these materials is not well known. Issues related to the initial texture, residual-processing strains, grain size, chemistry, and defect density must be known to develop constitutive models. Beryllium is a low-symmetry (hexagonal close-packed) material. Pressure, temperature, and strain rate play an important role in the inelastic deformation characteristics of the material. Beryllium exhibits different characteristics under the conditions of tension and compression. While large ductility results from deformations under the conditions of compression, the material can exhibit a brittle behavior under tension. There is a brittle to ductile transition at approximately 200°C under tensile conditions. Texture may develop even for an initially isotropic material. The fracture characteristics of Be are also pressure-, temperature-, and rate-dependent.

In this investigation, the analyses of plate impact and high explosively driven experiments were considered to pursue the ability of existing equation of state (EOS), strength, and damage models. Excellent agreement was obtained between simulations [1] and data obtained for plate impact experiments from the SNL Z-machine. The comparisons provided confidence in the strength and EOS models. The simulations also determined that the experiments exhibited a greater influence on the strength of the lithium-flouride (LiF) window as opposed to the strength of the Be. Two gas gun Be-Be plate impact experiments also were considered [2]. Nominal thicknesses for the flyer and target plates were 2 mm and 4 mm, respectively. Impact velocities for the two experiments were 0.721 mm/ms and 1.246 mm/ms. Both an Arbitrary Lagrangian Eulerian (ALE) code [3] and a Lagrangian analysis [4] where used to assess the EOS and strength models. The ALE code used the Sesame EOS tables, Mechanical Threshold Stress (MTS), and Preston-Tonks-Wallace (PTW) plasticity models. The Lagrangian analyses used an analytic EOS with the Johnson-Cook (JC), MTS, and PTW plasticity models. The Lagrangian analyses also considered a ductile (TEPLA) and a brittle (DCA) damage model. The models relied on parameters that were determined from high- and low-rate experiments [5].

A comparison of the simulations, using the ALE code without damage [3] and experiments, indicated that the Sesame EOS #2024 with the PTW strength model provided excellent agreement. Including a tabular shear modulus (Sesame EOS # 92024) made a negligible difference in the comparisons. The MTS strength model resulted in early arrival times and low particle velocities and in general provided poorer agreement with the data. Based on these simulations, it was concluded that improved strength models, which included twinning and texture, should be considered.

Similarly, comparisons of simulations and data, using the Lagrangian code without damage and an analytic EOS, indicated that peak values of the particle velocity could be captured. The PTW plasticity model provided excellent agreement in matching the Hugoniot Elastic Limit (HEL). Again, the MTS strength model was not successful in accurately

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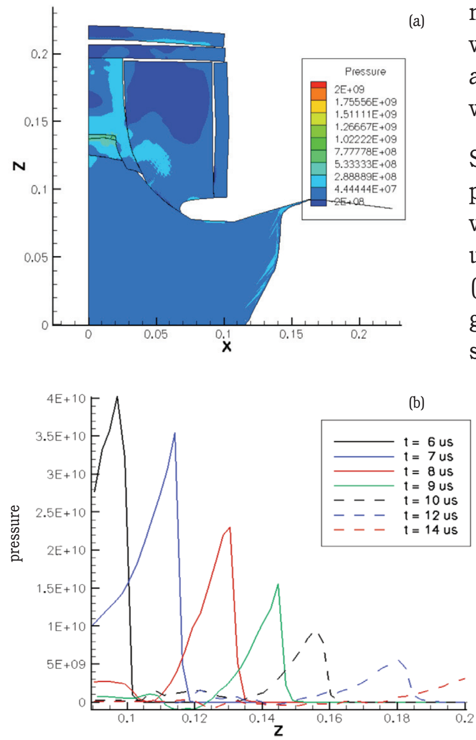

Fig. 2. Simulations of the HE-driven experiment (a) contours of pressure profiles at t= 50 us and (b) pressure distributions along the axis [4].

modeling the HEL. Consequently, improved MTS parameters were pursued. The improved model [5] provided better agreement with data. However, the comparisons using MTS still were poorer that the agreement obtained using the PTW model.

Simulations using two damage models were made for the Be-Be plate impact experiments. It was observed from the particle velocity history that the "pull-back" response was captured using the coupled TEPLA-PTW model. The evolution of damage (porosity) also was considered. For the TEPLA model, damage growth is experienced only in tensile regions. In the simulations, the "pull-back" signal is a result of failing a computational cell once the modified Hancock-Makenzie (HM) criterion is met. It was concluded that the plate impact experiments were more useful in providing information for the failure (HM) criterion than in providing information for the growth of damage. It was suggested that obtaining the post-mortem porosity distributions from either plate impact or Taylor cylinder experiments, which experience incipient spall, could provide more information regarding the evolution of damage.

Simulations using a brittle damage model (DCA-PTW) with an analytic EOS also were pursued. For this model, damage now can be accumulated in compression (shear cracks) as well as tension (open cracks), and the growth of damage is represented by an average crack size. The energy release rate, which was obtained from values for the mode I stress intensity factor (KI), did not provide good agreement with the data. The effect of including a critical crack size, at which complete failure of a computational cell is achieved, was investigated. It was observed that the inclusion of a critical crack size was effective in producing an acceptable "pull-back" signal. It is hoped that a third damage model, FRAZ [6], which includes both mode I and mode II failure, may be considered in the future.

Based on the above investigation, it was decided to consider additional experiments to pursue the inelastic response of Be under the conditions of high-strain rates and compression. Computational simulations using the ALE code [7] and Lagrangian analyses [4] were used to guide the design of two experiments. The first experiment was a shock-release-reshock plate impact experiment [2]. In this experiment a layered plate composed of Al-Cu-Al-Ta (aluminum-copper-aluminum-tantalum) is launched into a Be sample plate that is backed with an LiF window. Approximate thicknesses chosen for the layers were 20 mm (Al), 1.0 mm (Cu), 1.0 mm (Al), 0.8 mm (Ta), 4 mm (Be) and 20 mm (LiF). Preliminary simulations using the Lagrangian analysis for flyer plate velocities of 0.140 cm/ms and 0.014 cm/ms were provided. The second proposed experiment considered a Be sample that was embedded in an Al container and subjected to a high explosively driven wave [8]. Again simulations using the ALE code [9] and Lagrangian analyses [4] were used to guide the design. The final design of the HE driven experiment is provided in Fig. 1 [10]. The ALE code [9] pursued the potential for the rapid opening and closing of the containment surrounding the Be sample and the potential for cracking. Simulations of the final design (Fig. 2) using the Lagrangian analysis [4] pursued the sample offset (Fig. 2a), the effectiveness of the momentum traps, and pressure levels within the sample (Fig. 2b).

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[1] Bronkhorst, C.A. and Carrington, D.B., unpublished data
[2] Adams, C.D. and Anderson, W.W., unpublished data
[3] Prime, M.B., unpublished data
[4] Addessio, F.L., unpublished data
[5] Chen, S.-R., unpublished data
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