Glass Ampoule Analysis Capability Transition

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(U) Abstract: (U) *The U.S. Army Combat Capability Development Command – Armament Center (DEVCOM-AC) is developing an accurate method to perform the analysis and evaluation of glass ampoule designs, with the goal of transitioning this capability to industry partners who develop liquid reserve batteries. The government has partnered with several members of the glass ampoule community as well as modeling subject matter experts to pursue this effort. The project, which is a continuation of work previously started at DEVCOM-AC, leverages mature government created technologies such as the Elastic-Plastic Impact Computations (EPIC) software as a tool for finite element modeling and simulation. The overall mission of this project is to reduce the number of iteration cycles required to develop and troubleshoot glass ampoule designs by improving upon the industry's current design methodology. This is being accomplished through custom material model creation, simulation models, and the characterization of ampoule geometry parameters. The results of all these points will be discussed.*

(U) Keywords: Modeling & Simulation; Liquid Reserve Battery; Ampoule; Glass; Compression Testing; Computational Study; Fracture, Impact; EPIC.

(U) Introduction

(U) Munition power source technologies are a continual source of concern by the Joint Fuzing Community. Fuzing power source performance requirements necessitating higher power density, longer run times, faster rise times, higher reliability, faster component availability, and reduced cost. These have not until very recently been addressed with adequate attention to overcome the technological roadblocks to enable advancement necessary to meet the rapid expansion in programmatic requirements.

(U) Previously, U.S. Army DEVCOM Armaments Center began exploring accurate methods to model glass ampoule fracture behavior to assist industrial partners in reducing the number of iteration cycles required to develop and troubleshoot ampoules used in liquid reserve batteries. The ampoules, which contain the electrolyte solution prior to activation, are a large source of battery performance variability, a long lead item, and currently designed using a design-test-iterate development methodology [2].

(U) The focus of this effort is for government fuze subject matter experts to transition software and modeling & simulation knowledge to industry so that industry can effectively develop enhancements to their liquid reserve battery technologies.

(U) At the conclusion of the project, the team will understand the best practices to analyze glass ampoule behavior using government developed Elastic-Plastic Impact Computations (EPIC) finite element software, transition of EPIC software and DoD HPC access, and capability development within DEVCOM Armaments Center to support the use of EPIC by industry for these specific battery analyses.

(U) The purpose of this paper is to highlight the various stages of the project for a better understanding of how the team will reach the project goals.

(U) Technology Maturity

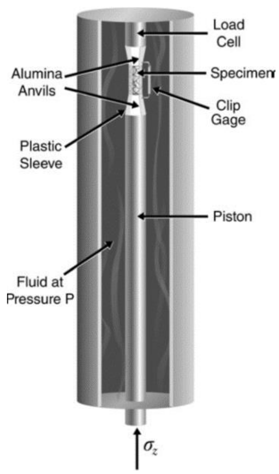
(U) In this project the government has brought together several advanced technologies to provide high-value and much sought after capabilities that have proven to be elusive to date. The mature technologies leveraged by this effort include EPIC finite element software [1], EPIC Variable User Material (VUMAT) models made available in ABAQUS CAE, and ampoule manufacturing expertise developed by industry partners. Industry partners have invested in and developed the industrial know-how to produce glass ampoules for countless liquid reserve battery configurations over the years. Developing this new capability will reduce the number of cycles required to identify an effective glass ampoule solution for any application. This reduction will aid industry in providing faster and cheaper design solutions to the government.

(U) Glass Material Testing at SwRI

(U) The project partnered with Southwest Research Institute (SwRI) who has a depth of knowledge and experience using compression testing to extract the necessary parameters to create material models for the

EPIC software. For this effort, triaxial compression tests were performed on cylindrical specimens provided by two government contractors. Both contractors are involved in producing glass ampoules using their specific form of borosilicate glass and have partnered with the government on this project. Both contractors provided tempered un-tempered glass cylinders to SwRI for this testing. The idea being that the two glass variants will show the effects of residual stresses from the thermal glass forming process.

(U) All the experiments used SwRI's unique high-pressure testing vessel, and a schematic is presented in Figure 1. The cylindrical glass specimen is placed between two alumina anvils and a thin polymeric membrane is placed around the specimen extending over the alumina anvils protecting the specimen from the confining fluid. Rubber O-rings are used to compress the membrane onto the piston and load cell preventing fluid infiltration. The results are recorded at specimen failure and include the fluid pressure, axial stress, hydrostatic pressure, P, and the von Mises equivalent stress [3].



(U) Figure 1. Southwest Research Institute's High-Pressure Testing Vessel [3].

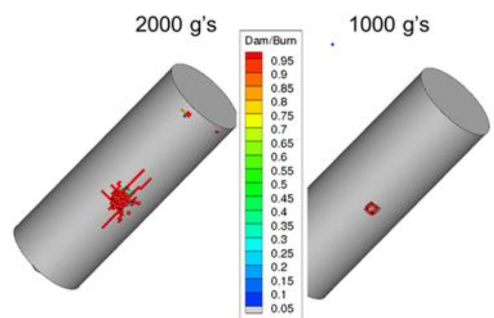
(U) SwRI completed the glass cylinder testing for both contractors and provided a report of the results to the government. Specific results of this glass material testing are not provided in this paper to protect the intellectual property of the contractors. The results of these tests do indicate the necessary parameters of glass material to generate material models in EPIC that are good representation for both contractors. SwRI has further discussed the implementation of the glass material models for use with the EPIC software.

(U) Computational Parametric Study with SwRI

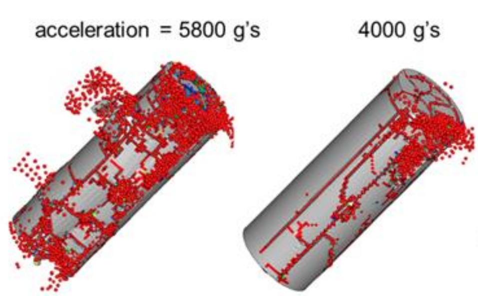
(U) An additional effort of the contracted SwRI effort was to perform EPIC computations of glass ampoules subjected to various impact conditions and orientations. This effort was completed between the government and SwRI members. Since this conceptual effort was performed in parallel with the glass material testing, all computations were completed using the existing borosilicate glass model available in the EPIC software.

(U) A critical design requirement of the ampoule is to survive five-foot drop tests but always break under gun launch conditions that activate the battery. It is time consuming and expensive to experimentally evaluate all the different design concepts that are proposed, but accurate and efficient computations can provide valuable insight into these concepts, identifying the most promising designs and eliminating the ones with issues. The parametric study provides some demonstrations of how computations can be used to help design and evaluate glass ampoules and activation concepts.

(U) One glass ampoule activation concept has been modeled for survivability in a gun launch environment. Only the ampoule model itself, filled with water, is shown here. Several gun launch accelerations were evaluated by changing the initial slope of the applied velocity-time history response. Figures 2 and 3 present the glass ampoule damage when the activation subsystem is subjected to various accelerations. Glass damage occurs in all four loading conditions with only a very small amount resulting from the lower acceleration loads [4].



(U) Figure 2. Sample Glass Ampoule damage computation in gun launch conditions [4].



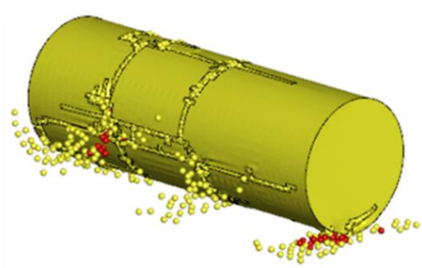
(U) Figure 3. Sample Glass Ampoule damage computation in higher gun launch conditions [4].

(U) Additional activation concepts and ampoule battery package designs were modeled for this contracted effort but are not presented here to protect contractor intellectual property. The effects of changing ampoule geometric and material parameters were also completed in collaboration with SwRI and government.

(U) EPIC Software Transition & Modeling with Industry Partners

(U) Ongoing efforts between the government team and industry partners include the modeling of battery package assemblies with the EPIC software, leveraging the glass models developed by SwRI previously. Working with Army Research Laboratory, a copy of EPIC 2021 Lite has been provided to the industry partners which they can use indefinitely. The explicit dynamics code implements a user defined 'projectile' hitting the 'target' in, among other applications, high velocity impacts. Thus, the government and industry team can model the ampoule and battery packages in drop and gun launch environments to determine ampoule survivability and breakability. Figure 4 shows a sample ampoule, isolated from the assembly, breaking under launch.

(U) Industry partners are sharing battery configurations that support active government programs and are modeling these assemblies with realistic accelerations. The software allows the teams to upload custom designed geometries and assemblies. Current efforts include variations to the glass breaking features within the battery assembly to determine survivability of the glass. This collaboration is not only transitioning the government's knowledge of the EPIC software to industry, but also supporting government programs that will be using these ampoules. Again, no images or specifics about these models are shared here to protect contractor intellectual property.



(U) Figure 4. Isolated view of glass ampoule breaking at specific time after loading is applied.

(U) Utilization of the DoD HPC

(U) Modeling 3-dimensional battery assemblies can be very time and processor consuming, and so the government has assisted contractors in accessing DoD High Performance Computing (HPC) resources. These high-level computing resources are available for routine use by the government research and development community. Extending use to the government contractors allows collaboration through sharing models and results on the HPC servers. In addition, it takes the burden of running these time-intensive analysis jobs away from the individual contractor's computer and use the servers instead. Contractors are actively using these resources to support this effort and will have access to the servers after the project ends, thus allowing industry to continue analyzing ampoule and batteries in the future.

(U) Project Path Forward

(U) As the project is nearing its end, the government and contractor teams are working to continue modeling ampoule battery assemblies. The contractor teams are working on modeling additional battery packages. Results of this project effort will be included in reports from industry as well as government.

(U) Project Transition Potential

(U) Programs relying on such power sources would be immediately affected by an increase of effective and efficient ampoule analysis. This will reduce the number of iteration cycles required to deliver analyzed and effective glass ampoule design. Target joint service programs have been identified and are being pursued [5].

(U) Acknowledgements

(U)The author wishes to thank members of DEVCOM Armaments Center Fuze Division and Analysis Division, Army Research Laboratory, Air Force Research Laboratory, Southwest Research Institute, and liquid reserve battery industry partners for their roles and support with this project.

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