3-D Dynamic Response of Thin Plates to Explosive Blast Loading

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PENNSTATE 1855 Gas Dynamics Lab

Introduction

Recently, there has been a push to develop polymer-based systems to protect people and equipment from explosively-generated shock waves (air blasts). This is due, in part, to anecdotal evidence that some polymers may be uniquely suited to this role due to an enhanced ability to attenuate or disperse the energy of an air blast. To investigate these claims, a quantitative, economical, and repeatable blast-testing method is needed.

The present work exposes thin polymer plates to blast waves from laboratory-scale explosive charges, and measures the 3-D, dynamic deformation of the plate at 50kHz. This time-resolved deformation map is compared with FEA simulations to validate and improve computational material models of polymers of interest.

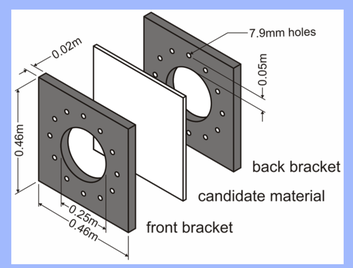
Motivation

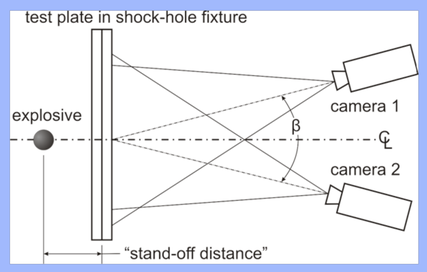
Traditional blast experiments are performed at the full-scale, often using many kilograms of high-explosive. This makes these experiments difficult to instrument and troublesome to perform, due to the many required safety precautions and the expense of a licensed outdoor explosives range. These factors severely limit the number of experiments that may be performed, and they also limit the amount and types of data that may be collected.

Testing at the laboratory scale avoids many of the pitfalls of full-scale testing: individual test cost is much reduced, while safety, repeatability and ease of instrumentation are improved.

Experimental Methods

Shock Hole fixture:

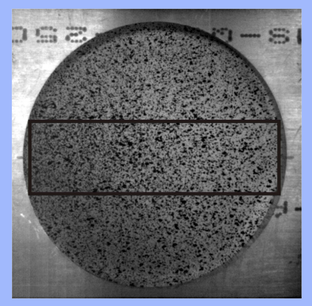




Polymer witness plates 2-3 mm in thickness were clamped in a laboratory-scale 'shock hole' fixture (above), which was modeled after a full-scale fixture in use at the US Army Aberdeen Proving Ground. These plates were then subjected to air-shock loading from the detonation of 1-1.5 g spherical high-explosive charges. The resulting motion of the plate was then observed throughout the event by high-speed videography.

Experimental Methods, continued

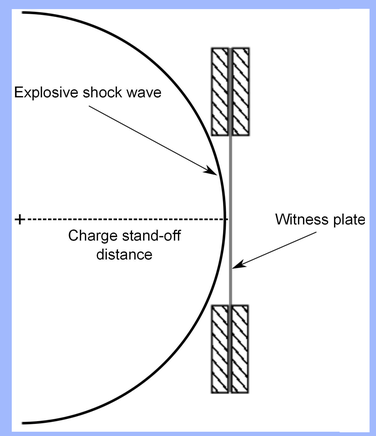
The motion of the witness plate throughout the test is recorded by two high-speed digital cameras (one Photron SA5 and one Photron SA1.1) in a stereoscopic arrangement. Illumination was provided by a lampcontaining an array of 9, 360 W halogen bulbs. The surface of the test plate facing the cameras was painted with a high-contrast random speckle pattern, shown below, applied with Krylon matte spray paint. Each camera recorded data at 50,000 frames per second, and observed a field of view of approximately 0.3 m x 0.12m.

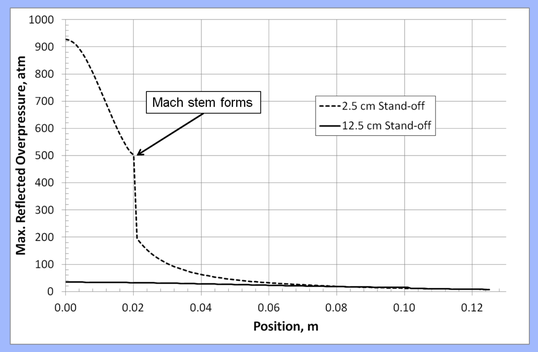


Blast Loading:

The polymer witness plates in this investigation were exposed to explosive shock waves from 0.8--1.5 g PETN charges at stand-off distances of 0.025-0.25 m. The shock-wave-generating properties of PETN as a function of stand-off distance were well-characterized in previous work.

Knowledge of these shock properties, charge mass, and charge stand-off distance allows the pressure and impulse loading on the plate to be calculated a priori from basic gas dynamics theory.



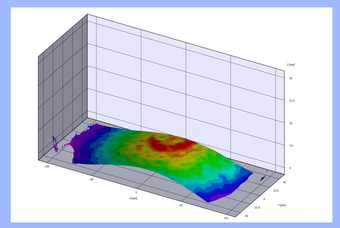


Overpressure loading as a function of plate radius

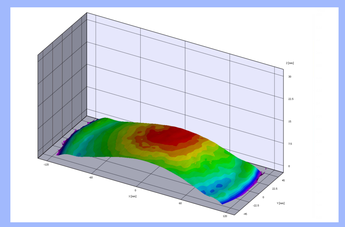
Analysis/Results

A commercial software package, VIC 3D by Correlated Solutions Inc., is used to quantitatively measure the deformation of the plate. The software first determines the position of each camera, relative to the shock-hole fixture, with a series of calibration images. The VIC 3D package then accepts speckle image pairs of the deformed plate and uses a digital image correlation technique to locate the surface of the plate in 3-D space. Post-processing of these data allows calculation of plate velocities, strains, and strain rates.

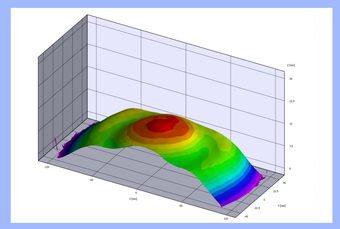
Selected deformation contours of a polyurea plate exposed to a 1 g charge at a 12.5 cm stand-off distance are shown below:



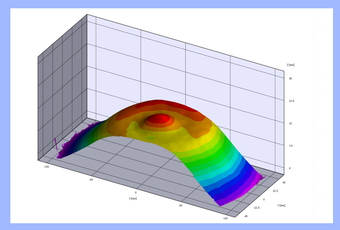
0.1 ms after shock loading



0.3 ms



0.8 ms



1.2 ms

Conclusions

2-3 mm-thick witness plates of polyurethane, polyurea, and polycarbonate in a shock hole fixture were exposed to air blast loading by the detonation of 1-1.5 g high-explosive charges at stand-off distances of 2.5--50 cm. The response of these polymer plates to the blast loading was observed by two high-speed-digital cameras in a stereoscopic arrangement. Through digital post-processing, a quantitative, time-resolved, 3-D map of the deformation, strain, and velocity of the plate was constructed for each experiment.

These shock-hole tests produced a considerable body of data which are now available for the development and validation of computational constitutive models for the materials studied in this work. The shock-hole experiment is readily modeled, having both a well-defined boundary condition and a known overpressure load. Any significant differences between the FEA and experimental results may then be attributed to the computational material model, and the model may then be adjusted until the computational and experimental results are in agreement. Polymer material modeling efforts using these data are currently underway at both the Penn State Applied Research lab and at Clemson University.