Damage Mitigation From Non-Ideal Explosions

PI: J. E. Shepherd, Students: J. Damazo, K. Chow-Yee, J. Karnesky
California Institute of Technology, Pasadena, CA, joseph.e.shepherd@caltech.edu

Abstract

Non-ideal explosions such as those caused by fuel-air explosions or improvised explosive devices (IEDs) are capable of producing extensive damage on neighboring structures. Using detonations of gaseous reactants in closed pipes as a model, we are examining methods to mitigate the amount of plastic deformation (damage) resulting from non-ideal explosions. In the present study, we examine the effect of introducing a polyurea coating to the exterior of stainless steel pipes. It will be shown that substantial damage mitigation is observed due to the polyurea coating.

Relevance

Polymer coatings have been shown to mitigate damage caused by loading profiles comparable to those observed in explosion experiments. Amini et al. [1] and Chen et al. [2] observed that the degree of plastic deformation was lessened by a polymer coating on the side of a structure opposite that of a blast loading. This work builds on that of previous researchers by examining the detonation loading where both high pressures and high temperatures are present. Fig. 1 portrays damage caused by internal gaseous detonation.

Figure 1: Unprotected tubes after detonation.

Technical Approach

Reflected gaseous detonations are used to create high-pressure impulsive loadings applied to the inside of 304 stainless steel tubes. Herein we present data for six experiments exploring detonations of different strengths and external polyurea coatings of different thicknesses. Note that we have an internal pressure loading and an external protective coat. This is motivated by: 1) Amini et al. [1] observed a favorable effect from an analogous condition with impact loadings. 2) It is more practical to coat the exterior of tubes and hence of greater value if this geometry mitigates damage. Two experiments (tubes 9 and 10) use no polyurea coating and serve as the control. These control experiments exhibited a ripple effect on the tube wall (see Fig. 1).

"Low" Pressure Loading

Stoichiometric ethylene-oxygen of initial pressure two bar was used to produce our "low" pressure loading. As observed in the plot, both 3 and 4 mm polyurea coats substantially mitigate plastic deformation (by 14 and 9% respectively). Whether damage mitigation is due purely to structural reinforcement or if wave mechanics play a role remains an open question.

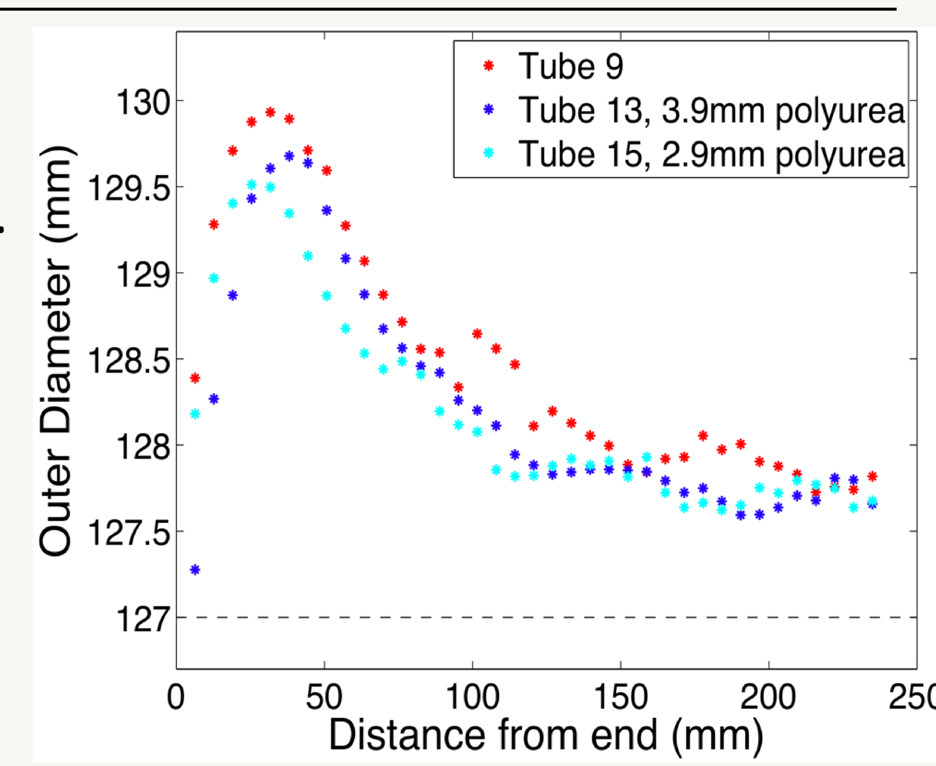

Figure 2: Plastic strain from 2-bar detonation.

"High" Pressure Loading

Damage resulting from three bar stoichiometric ethylene-oxygen is displayed on the right. Similar to the "low" pressure load, polyurea is observed to reduce damage in both cases. Unlike the "low" pressure experiment, a thicker coat yields greater damage mitigation. In this case, peak deformations were reduced by 11% for a 4 mm polyurea coat and 21% for a 7 mm coating.

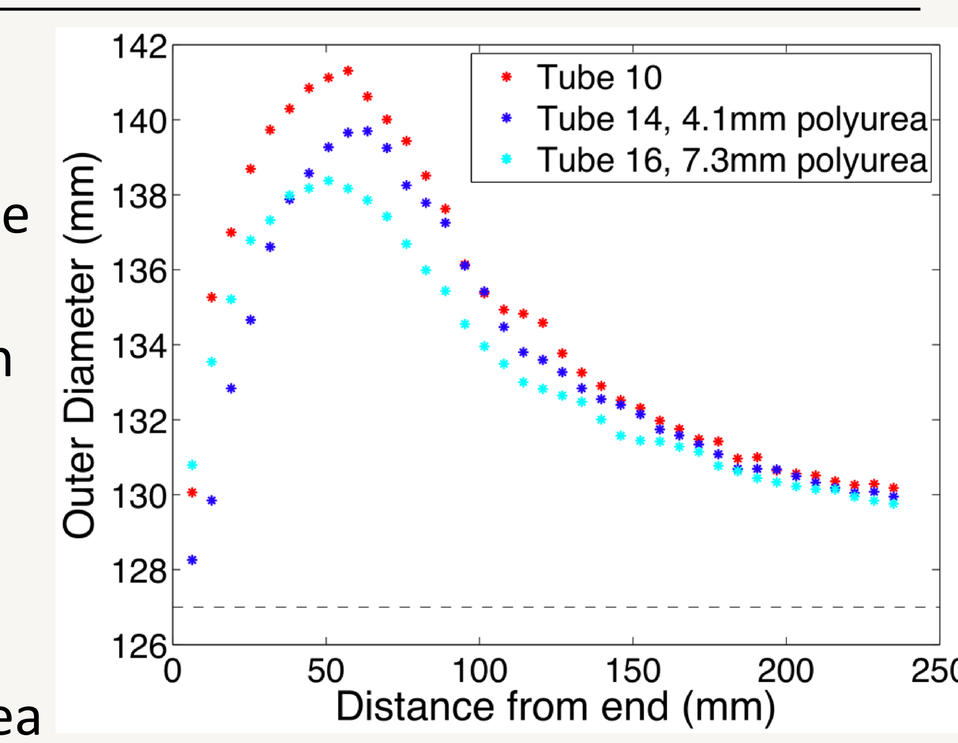

Figure 3: Plastic strain from 3-bar detonation.

Accomplishments Through Current Year

Measurements on 304 stainless steel tubes demonstrated strain reduction up to 20% with polyurea coatings. Rippling effect shown in Fig. 1 explained as wave interference of reflected shock wave with elastic oscillation of tube wall, verifying previous results with mild steel specimens.

Future Work

Fluid-Structure Interaction: Pursue coupled fluid-structure computations to account for the feedback between deformation and gas dynamics.

Shock Wave—Boundary Layer Interaction: Experimentally examine the interaction between the boundary layer induced by the incident detonation with the reflected shock wave using schlieren photography and thermocouple gauges to measure heat transfer.

Opportunities for Transition to Customer

This work demonstrates that polyurea coatings—which are already used for protecting equipment from external blast and shrapnel—may also play a role in protecting pipelines and structures from internal explosions. The "low" pressure loading suggests a to-be-determined optimal thickness.

References

[1] Amini, M.R., J. Isaacs, S. Nemat-Nasser. Investigation of effect of polyurea on response of steel plates to impulsive loads in direct pressure-pulse experiments. Mech Mater 2010; 42:628-39.

[2] Chen, Y., Z. Zhang, Y. Wang, H. Hua, H. Gou. Attenuating performance of a polymer layer coated onto floating structures subjected to water blasts. Eur J of Mech A/Solids 2009; 28:591-8.

Publications Acknowledging DHS Support

Plastic response of thin-wall tubes to detonation. J. Karnesky, J. Damazo, J.E. Shepherd, A. Rusinek. Proceedings of the ASME 2010 Pressure Vessels and Piping Conference; July 18-22, 2010; Bellevue, USA.

Structural Response to Non-ideal Explosions. J. Karnesky, J. Damazo, J.E. Shepherd. DHS COE Workshop at the University of Rhode Island; March 3, 2010; Kingston, USA.

Plastic response of thin-wall tubes to detonation. J. Karnesky, J. Damazo, J.E. Shepherd. ASME Pressure Vessels and Piping Conference; July 18-22, 2010; Bellevue, USA.

Investigating Shock Wave-Boundary Layer Interaction Caused by Reflecting Detonations. J. Damazo, J. Ziegler, J. Karnesky, and J.E. Shepherd. 8th ISHPMIE; 2010 September 5-10; Yokohama, Japan.

Mitigating Effect of Polymer Coating on Deformation from Non-Ideal Explosions. J. Damazo, K. Chow-Yee, J. Karnesky, J.E. Shepherd. IMPLAST, SEM Fall Conference, University of Rhode Island; October 14-21, 2010; Providence, USA.

Shock Wave-Boundary Layer Interaction in Reflecting Detonations. J. Damazo, J.E. Shepherd. 63rd Annual Meeting of the APS Division of Fluid Dynamics; November 21-23, 2010; Long Beach, USA

This material is based upon work supported by the U.S. Department of Homeland Security under Award Number 2008-ST-061-ED0001. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied of the U.S. Department of Homeland Security.