Plastic Deformation of Tubes due to Detonation

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1 Introduction

A series of experiments were performed in the Explosion Dynamics Laboratory at Caltech on thin-walled steel tubes to obtain data on the plastic deformation resulting from propagating and reflected detonations. These studies build on the previous work of [1, 2], by performing similar experiments but with better defined boundary conditions and more detailed measurements—the differences between the two studies are discussed in detail below.

The experiments were performed with stoichiometric C_2H_4-O_2 at pressures varying from 0.8 bar to 3 bar. As we increased the pressure, we saw three regimes: For low pressures, there was no plastic deformation. Mid-range pressures saw plastic deformation on the reflected wave only. At high pressures, plastic deformation was observed on both the incident and the reflected waves. Tube deformation and movement measurements were obtained with strain gauges, a displacement gauge, and a high-speed camera. It is the goal of these experiments to obtain a guideline such that, given an initial pressure, one may predict whether plastic deformation occurs and, if plastic deformation does occur, to what extent. Experimental results were compared with a single degree of freedom plasticity model as discussed in [2].

2 Experimental Setup

The deformable test specimens for the experiment consisted of flush controlled welded, cold-rolled steel tubes constructed to ASTM specification A513, type 2, material type C1010 with a minimum yield stress of 220 MPa (32 ksi), and an ultimate tensile strength of 310 MPa (45 ksi). The initial experimental setup is shown in figure 1, and consisted of two gland sealed plugs on either end of the tube held together by 4 threaded rods. PCB Pressure transducers were located on each plug to record the pressure at the end walls, and the tubes were instrumented with strain gauges at various locations along their lengths. Because direct measurement of the detonation wave as it traveled down the tube could not be made in this geometry, each test condition was first tested in another tube of the same internal dimensions, but comprised of 316L stainless steel and with a wall thickness of 12.7 mm. This tube was instrumented with PCB gauges at various ports in its side walls, so the development of the detonation could be measured, and compared with the deformations found in the thin tube.

This geometry suffered from ill defined boundary conditions, as the tube was neither free nor rigidly held on either end and the detonation pressure would cause oscillation in the threaded rods, and movement of the reflecting surface. To address these issues, a new geometry was devised in which the thin test tubes are mated to the thick tube via a gland seal. The thick tube acts as a driver, so that a fully developed detonation transitions into the thin tubes. This revised setup is shown in figure 2.

In order to ensure a built in boundary condition at the end wall, the tube end was clamped between an internal plug and an external collet, as shown schematically in figure 3. To keep the explosion pressure from separating the two tubes, the collet mount bracket was affixed to the thick tube flange with chain.

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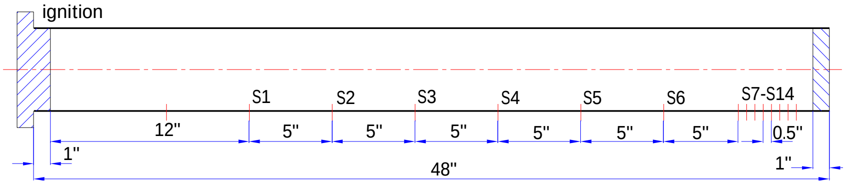

Figure 1: Preliminary experimental setup. The end flanges were held together by four 1/2” threaded rods. S1-S14 denote strain gauge locations.

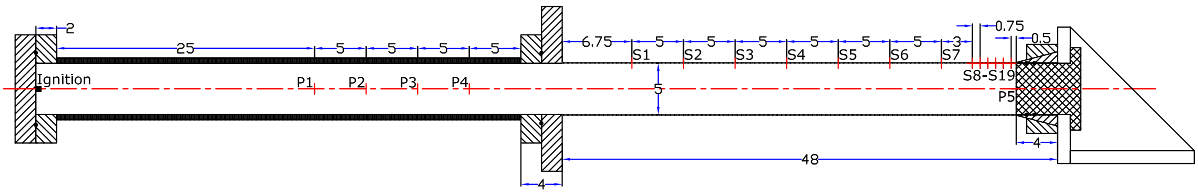

Figure 2: Revised experimental setup. P1-P5 denote PCB pressure transducer locations, while S1-S19 denote strain gauge locations. Dimensions in inch.

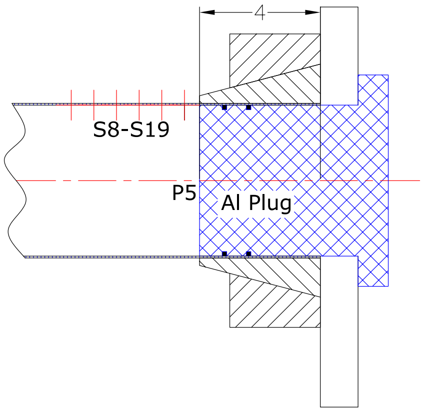

Figure 3: Detail of clamped boundary condition with collet, collet ring, and plug.

3 Preliminary Results

The initial experimental configuration where the detonation was initiated in the thin tube itself (rather than in the thick tube as in the later configuration) has yielded some preliminary results. The test mixtures were stoichiometric ethylene-oxygen mixtures with initial pressures varying between 0.8 and 3 bar. Three categories of phenomena were observed: for low initial pressures, the deformation in the thin tube remained elastic for the complete duration of the test. For moderate pressures, plastic deformation was observed in the reflected wave, while at the highest initial pressures, both the incident and reflected detonations caused plastic deformation.

Combustion is initiated at the ignition flange via a glowplug, and detonation is either initiated promptly or by transition due to flame acceleration over the obstacle geometry which is described in [2]. The pressure and velocity of the detonation are measured by P1-P4, and the resulting strains are recorded by the strain gauges. The largest deformation occurs at the reflecting end wall, where it is recorded by strain gauges, high speed video, and a laser displacement gauge. The reflected pressure is recorded by P5. Figure 4 shows strain data from a test at 1.5 bar initial pressure with strain gages (hoop orientation) located as shown in figure 1.

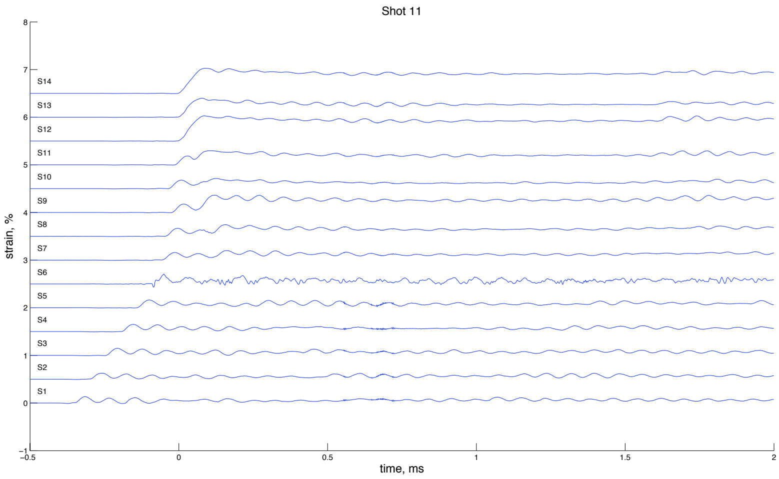

Figure 4: Strain data from a test with a propagating detonation.

Experimental results can be compared with the simple single degree of freedom model given in [2]. This model assumes a cylindrical shell structure under an axi-symmetrical internal load with a elastic-linearly plastic model of material response. Comparisons of experimental data with this model and more realistic finite-element simulations will be given in the final presentation.

References

[1] Liang Z., Karnesky J., Shepherd J. E. Detonation Testing of Thin-Wall Tubes. Caltech May 2007.

[2] Pintgen F., Shepherd J. E. Elastic and Plastic Structural Response of Thin Tubes to Deflagration-to-Detonation Transition Events. Explosion Dynamics Laboratory Report FM2005-008. Caltech April 2006.

[3] Beltman W. M., Burcsu E., Shepherd J. E., Zuhal L. The Structural Response of Cylindrical Shells to Internal Shock Loading. J Press Vessel Technology, 121:315-322, 1999.

[4] Beltman W. M., Shepherd J. E. Linear Elastic Response of Tubes to Internal Detonation. J Sound Vib, 252(4):617-655, 2002.

[5] Sauvelet C., Rusinek, A. Elastic and Plastic Deformation Waves in Tubes With Internal Gas Explosion. Paper MCMAT2007-30024. ASME Applied Mechanics and Materials Conference. June 3-7, 2007.

[6] Biggs J. Introduction to Structural Dynamics. McGraw-Hill, Inc. 1964.

[7] Jones N. Structural Impact. Cambridge University Press, 1989.