Combustion of Shock-Dispersed Flake-Aluminum in a Long Tunnel Section

Peter Neuwald[1], Heinz Reichenbach[1], Allen L. Kuhl[2]
[1]Ernst-Mach-Institut, Fraunhofer Institut für Kurzzeitdynamik, Freiburg, Germany
[2]Lawrence Livermore National Laboratory, Livermore, CA, USA

Corresponding author: P. Neuwald: neuwald@emi.fraunhofer.de

Introduction

At the 19th ICDERS Colloquium, we introduced the concept of shock-dispersed-fuel (SDF) charges, and presented results from a preliminary feasibility study (Neuwald et al. 2003). To recapitulate: the miniature SDF charges consist of a spherical booster charge of 0.5-g PETN, embedded in a paper cylinder of ~ 2.2-cm^3, which is filled with powdered fuel compositions. The tests were performed in closed cylindrical steel vessels, which we call barometric bomb calorimeters, since we diagnose energy release by monitoring the build-up of quasi-static pressure in the vessel. The vessel had different volumes ranging from 6.6 l to 40.5 l and were of similar geometry with an identical length-to-diameter ratio of about 1. In these experiments flake-aluminum has proven to be the fuel with most rapid and complete combustion among the tested materials. However, as with all tested fuels, its performance decreased with increasing volume.

Similar tests have been performed in steel vessels with volume comparable to the 6.6 l bomb, but an increased length-to-diameter ratio of 4.6 and 12.5 respectively. The main result was that an increasing L/D-ratio decreases the combustion performance (Neuwald et al. 2005). This is in qualitative agreement with findings from test series with SDF charges in a small-scale model of a long, closed tunnel segment. In the following we will discuss the latter experiments.

Experimental Approach

Two different tunnel models were used in the tests. Both have an inner length of 300 cm and a square cross-section of 8 cm x 8 cm and are closed at both ends. The main difference is their construction: the initial version is assembled from individual steel plates, the later version from drawn steel tubing. The basic advantage of the initial construction is that it is easier to adapt the model to special purposes or special instrumentation, while the second model is better suited for standardized tests. For the purpose of this paper both can be assumed to be identical.

Charges were detonated a few tunnel diameters D down from one end (referred to as tunnel front). An initially spherical blast wave propagates from the charge towards the tunnel front and the tunnel end. Due to the different distances the blast wave is reflected fairly early at the tunnel front. The reflected wave typically runs up into the primary wave front propagating down the tunnel, before both arrive at the tunnel end. The end-wall is thus subjected to a single, nearly plane blast wave. This blast wave can be characterized by the its peak overpressure, the duration of the positive pressure phase and the overpressure impulse accumulated during this phase. Tests with conventional spherical PETN charges of different masses were compared to similar tests with SDF charges. We found that the peak overpressure and overpressure impulse due to the detonation of an SDF charge with a fill of 1 g flake-aluminum is equivalent to the effects caused by the detonation of approximately 1.1 to 1.3 g PETN. The SDF charge can theoretically release energy of about 6.15 kJ in the detonation and additional 33 kJ by combustion, while a 1.3 g PETN charge supplies about 8 kJ in the detonation and mere 2.7 kJ by after-burning of the detonation products. Thus the equivalency stated above indicates that only a small amount of combustion released energy feeds into the blast wave. This motivated us to study the propagation of the blast waves and other features of the system along the tunnel axis.

To this end we utilized three types of diagnostics: piezo-electric pressure gages in a side-wall of the tunnel model to monitor the strength and velocity of the blast, photo-diodes, which monitor the propagation of self-luminous regions (roughly spoken, the hot detonation-/-combustion products cloud) and a custom-made gage measuring the local electro-conductivity in the gases inside the model. The sensing element of the latter gage is basically a capacitive element immersed into the tunnel atmosphere. It is in series with a resistor and connected to a supply voltage. If the atmosphere between the two electrodes of the capacitive element is non-conductive, the voltage drop over the capacitor equals the supply voltage and no voltage drop at the resistor is observed. In contrast, a conductive atmosphere between the electrodes causes a measurable voltage drop at the resistor. Since the sensor has to be immersed into the tunnel atmosphere, this gage is intrusive and causes wave reflection and deflection, i.e., it slightly alters the environment. Thus only one electro-conductivity probe was used, though at different measurement position in repeated tests.

Experimental Results

Figure 1 shows an example for the evolution of the side-on peak overpressure down the tunnel. The graph depicts the results for three charges, each located 80 mm down from the tunnel front. Close to the detonation location an SDF charge with a 0.5-g PETN booster and a fill of 1 g flake aluminum apparently generates a slightly weaker blast than a spherical 0.5-g PETN charge. Yet the peak overpressure decreases more slowly: the combustion of the flake-aluminum is initially rapid enough to actually couple energy into the strength of the blast. Thus the peak overpressure from the SDF charge becomes essentially equivalent to the blast from a 1-g PETN charge. This is the case 600 to 800 mm down the tunnel, where the primary wave and its reflection at the tunnel front coalesce, or in terms of time about 500 to 700 μs after the detonation. Later on, no significant further enhancement of the peak overpressure is observed. However, in the long run the combustion increases the quasi-steady overpressure in the tunnel segment to about 2.5 bars compared to 1.7 bars from a spherical 1-g PETN charge.

Figure 2 presents a wave diagram for the detonation of an SDF charge, which in this case was located somewhat further down the tunnel at x = 214 mm. Besides the primary blast front and its reflection from the far tunnel end a third front is depicted. This originates from measurements with the conductivity probe. A fairly steep increase of the conductivity was observed at all measurement stations, followed by a (noisy) slow decay. The smoothed distribution of the conductivity in space and time is indicated by the color coding, which

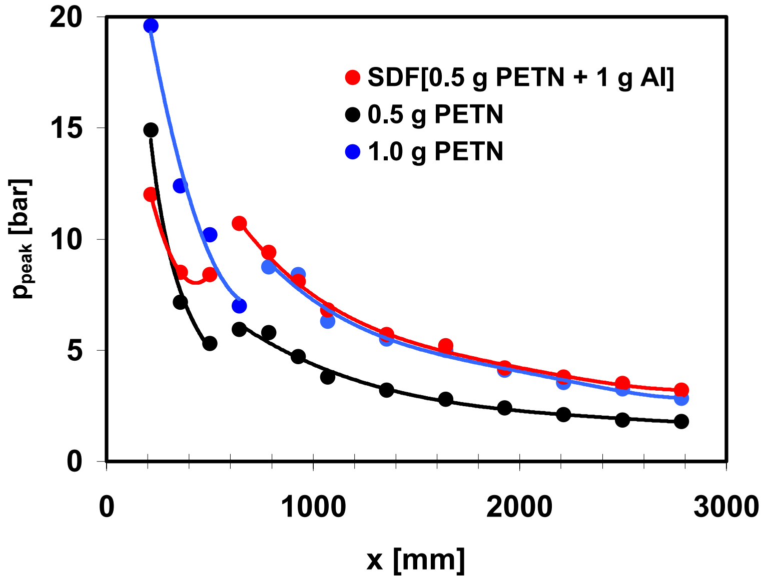

Figure 1. Side-on peak overpressure along the tunnel for three different charges. The charges were located at x = 80 mm. The jump in the curves at 600 mm or 800 mm respectively occurs when the primary blast wave and the reflected wave from the tunnel front coalesce.

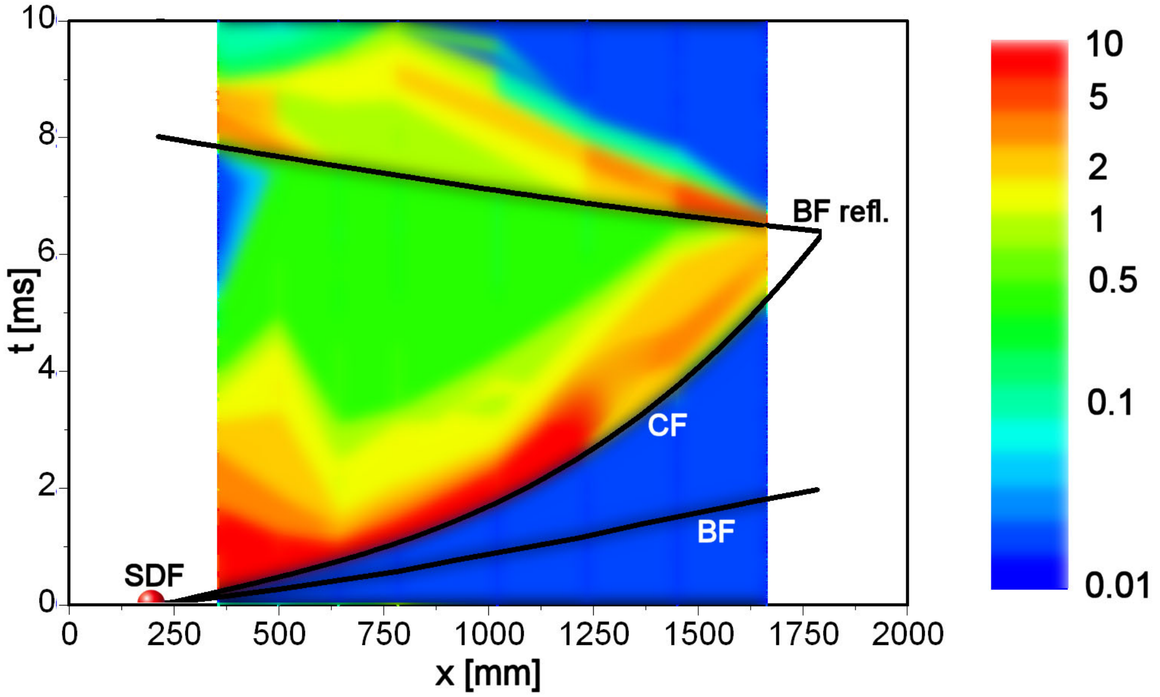

Figure 2. Wave diagram showing the propagation of the primary blast front (BF) and its reflection at the tunnel end (BF refl.) in conjunction with the front of the electro-conductive region. Color coding refers to the voltage measured at the resistor of the conductivity probe circuit.

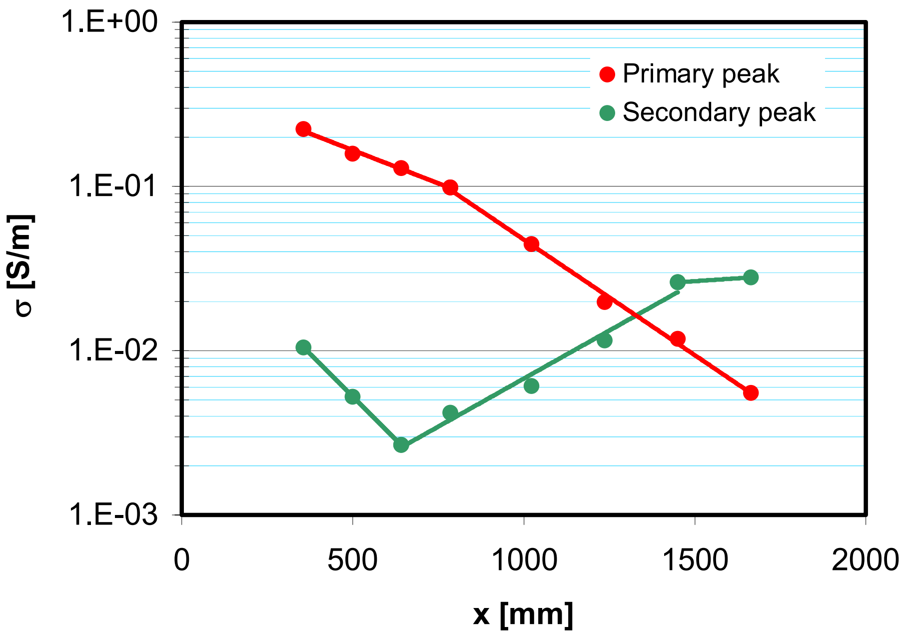

Figure 3. Evolution of the peak conductivity along the tunnel. The term secondary peak denotes the maximum conductivity after reinforcement by the wave reflection from the far tunnel end.

refers to the resistor voltage of the conductivity probe circuit. The probe characteristic is strongly non-linear with a maximum voltage of 9.4 V. Actual values of the peak conductivity are given in Figure 3. The peak value at a distance of approximately 140 mm from the charge is of the order of 0.2 S/m. At this conductivity level the probe was near to its saturation, thus momentary conductivity values in excess of 0.2 S/m are possible. 0.5 g PETN charges generate a considerably smaller peak conductivity of around $8 \cdot 10^{-3}$ S/m under the same conditions.

The wave diagram in Figure 2 indicates that the conductive region rapidly falls back behind the primary blast. If we identify the conductive region with the region of ongoing combustion, it becomes obvious, why an enhancement of the blast is limited to a small initial period. The increasing gap between both fronts soon hampers the further coupling of combustion released energy into the blast front, since combustion-induced pressure effects will typically only propagate at the local sound speed. Nevertheless combustion will contribute to the built-up of quasi-steady overpressure in the tunnel segment.

References

P. Neuwald, H. Reichenbach, A. L. Kuhl, *Shock-Dispersed-Fuel Charges – Combustion in Chambers and Tunnels*, 19th International Colloquium on Detonations and Reactive Systems, Hakone, Japan, 2003

P. Neuwald, H. Reichenbach, A. L. Kuhl, *Shock-Dispersed Flake Aluminum – Performance in Environments of Different Geometries*, proposed paper for: 36th Int. Annual Conf. of ICT, Karlsruhe, June 2005