Chapter 11
Application of High Speed Imaging in Particle Dynamics Study with Explosives

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Abstract High-speed imaging can provide invaluable information during any explosive testing. An explosive detonation includes a shock and stress wave propagation phase and a fragmentation phase. In order to analyze what happens in a detonation event a high-speed camera is used to visualize the two different phases. This visualization capability allows for analysis of the explosive detonation. The focus of this study is to measure the performance of the explosive using ultra-high-speed photography.

Keywords High speed imaging • Shock wave • Particle velocity • Explosive detonation • Explosive characterization

11.1 Introduction

Advanced Explosives Processing Research Group (AXPRO) at the Colorado School of Mines (CSM) conducted testing on explosive material. The charges were detonated in an aquarium filled with water at the Explosive Research Laboratory (ERL) test site. The purpose of these studies is to better characterize the explosive performance using high-speed imaging. In order to record an optimal set of images, a ultra-high-speed framing camera is setup for the test. These images are later used as the primary data for all further analysis, such as velocity of detonation, detonation front area, gas expansion shapes, and any other explosive properties directly observed from the slow motion analysis.

Coordinate points were graphically selected from the Specialised Imaging fast framing camera (SIM) in order to define both the shock and the case expansion profile. It was assumed that any distortion of the observed image due to the aquarium glass is negligible. The shock profile is as it appears in the image and the use of a polynomial fit to the shock profile data will correct for the refraction on the observed position of the case expansion data points.

11.2 Experimental Analysis

The steps for analyzing the images from an aquarium test are image calibration, detonation front characterization, correct image of case expansion for distortion from refraction at shock wave boundary in water, and slit velocity calculations.

In order to better visualize the event, the detonation occurs in a water filled glass aquarium. Parallel sides of the aquarium walls are very important for producing the least amount of image distortion during the test. A camera image of a transparent plastic cylinder filled with Ammonium Nitrate Fuel Oil (ANFO) is shown during underwater detonation in Fig. 11.1. The measurements taken all lie in the plane that contains the axis of the undetonated charge, which is located at the center of the aquarium. This plane is parallel to both the front and rear faces of the rectangular aquarium. This plane is referred to as the image plane.

There are two primary methods to calibrate an image. The first would be to use the known diameter of the undetonated charge observing the left and right edges in the image plane. However, there are difficulties in determining where these edges

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DOI 10.1007/978-3-319-06995-1_11,

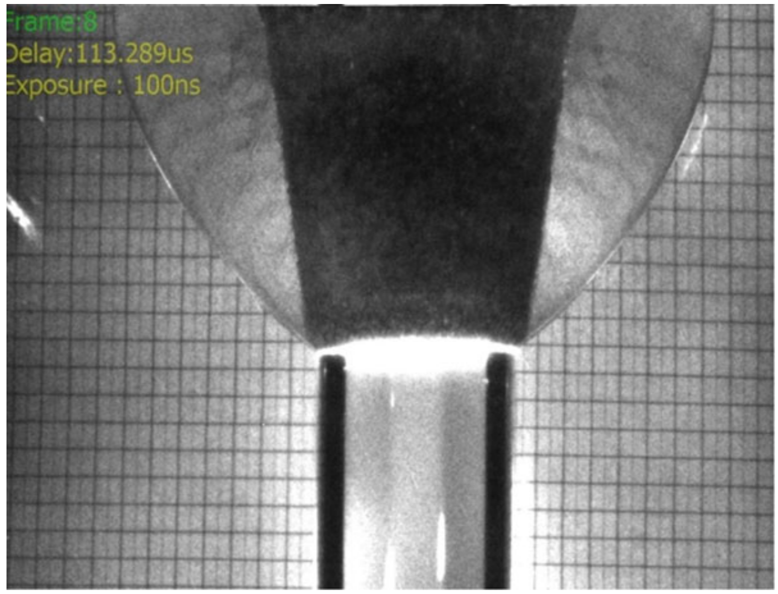

Fig. 11.1 Underwater ANFO cylinder during detonation

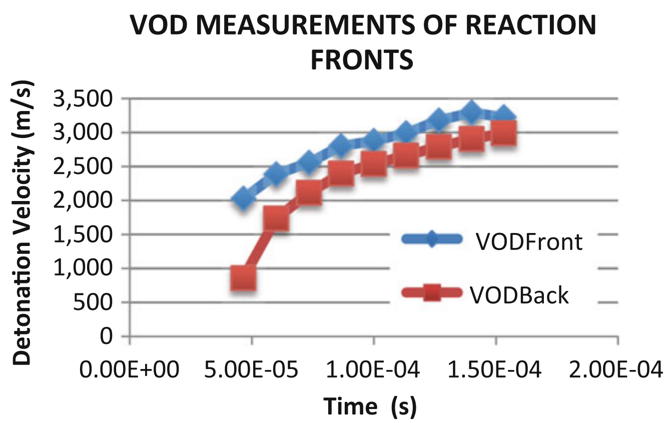

Fig. 11.2 Velocity of detonation for the reaction front

of the undetonated charge are in this image. A second method would be to use the ratio of the distance between the camera and image plane, and the distance between the camera and rear aquarium surfaces, where a one-inch fiducial grid is placed. The grid provides a known dimension in the image, which is scaled using the distance ratios between camera and the back of the aquarium. A reasonably accurate calibration distance can be obtained by using this method. Measuring the distance between many squares can optimize this calibration.

Detonation front characterization was completed from images by plotting its distance over time from images. The bright white area in front of the case expansion indicates this zone, as seen in Fig. 11.1. The detonation front velocity was calculated to be a realm error steady throughout the explosive detonation (Fig. 11.2). Velocity of detonation (VOD) calculation is conducted similar to the image analyzed in Fig. 11.3.

There are two boundaries expanding from the detonated ANFO region. The first is the shock wave running through the water, and the second is the case expansion. The water between the shock wave and the case expansion has a different optical index of refraction, which distorts the image of the case expansion. Correcting for this refraction is complex by the fact that the shock wave running through the water is curved which requires three-dimensional computations to be performed. It is assumed that the shock boundary in water and the case expansion boundaries are axisymmetric with the Z axis (along the length of the cylinder), and all light rays recorded by the camera were parallel to each other. Figure 11.4 shows an example of the results obtained for the shockwave and case expansion profiles after corrections were made. Note this is a non-ideal detonation, using commercially available ANFO as the primary explosive.

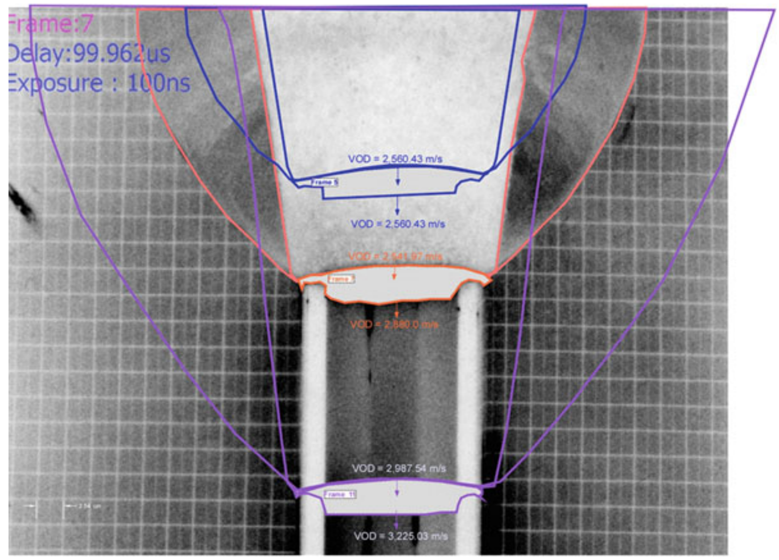

Fig. 11.3 Velocity of detonation (VOD) analysis of individual image frames

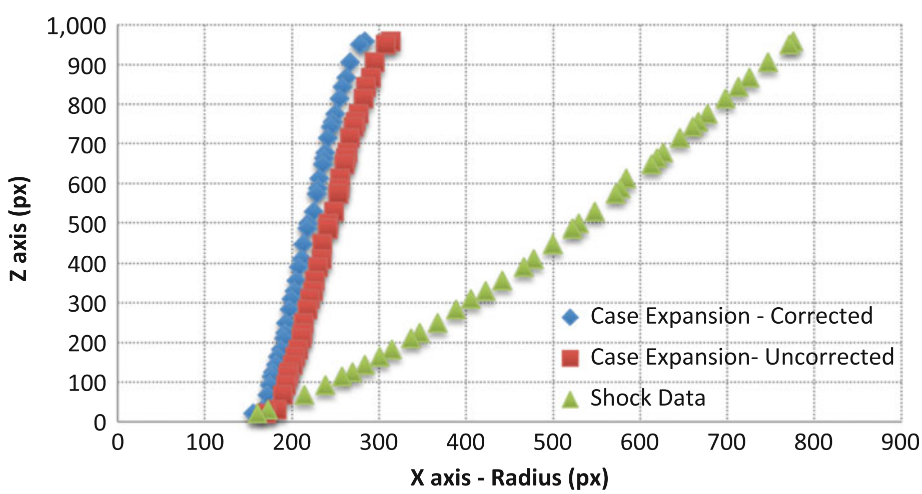

Fig. 11.4 Shock and case expansion profiles for an individual SIM camera image frame

11.3 Theoretical Detonation Physics of ANFO

The detonation theoretical model for ANFO consists of a two-component mixture of fuel (reactance) and oxidizer (product). The initial density of the material is denoted in Eq. (11.1) below.

$$\rho_0 = \frac{1}{V_0} = 0.85\ g/cc \tag{11.1}$$

A Jones–Wilkins–Lee (JWL) based equation of state (EOS) for explosives is used to calculate the explosion results. Equation (11.2) explains the relationship between shock and particle velocity.

$$U_s = c + su \tag{11.2}$$

where U_s is the shockwave velocity, u is the particle velocity, c is the bulk sound speed, and s is a material constant. The internal energy is given by e_s in Eq. (11.3) below:

$$e_s = e_{sh} + \frac{\nu_0}{\Gamma_0}(p_s - p_{sh}) \tag{11.3}$$

The subscript s is used to denote the reactant state. The calibrated parameters are:

c = bulk sound speed = 0.0977 cm/μs
s = explosive material constant = 1.42
Γ_0 = coefficient of Grüneisen = 0.967
D_{CJ} = 4,000 m/s, V_{CJ} = 0.8174 cc/g, P_{CJ} = 0.05695 g/cm μs^2.

11.4 Other Findings

Ideal detonation was also framed with the SIM camera. A RP-1 detonator was tested in water in order to analyze its charge shape and the shock wave it created in the water, among other explosive properties. Figure 11.5 shows a captured image from this test. Note the symmetrical shock wave created around the detonation. Figure 11.6 represents another example of ideal detonation for a 7.5 grain detonating cord underwater. Note the shockwave in this case is not a curve but rather a straight line back. This is due to differences in explosive properties, which are clearly seen in this type of data.

11.5 Conclusions

Analysis conducted with respect to the observed coordinates of the high speed framing camera images confirmed booster velocity at time zero. Angle corrections for the detonation front tilt from normal were conducted and accounted for when calculating the detonation velocity. Refraction corrections through water medium were applied to the data set. Images were corrected for refraction where the shocked water is visible during detonation. Both, the corrected and uncorrected cylinder

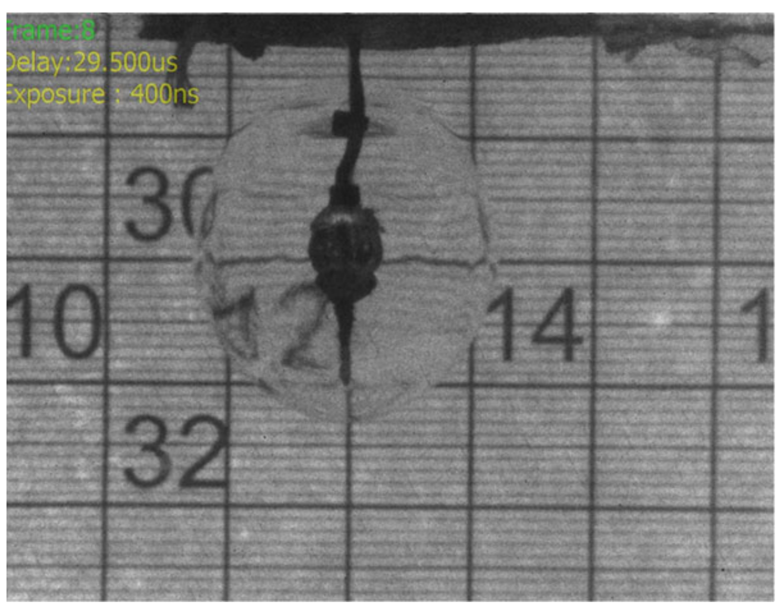

Fig. 11.5 Underwater RP-1 detonator during ideal detonation

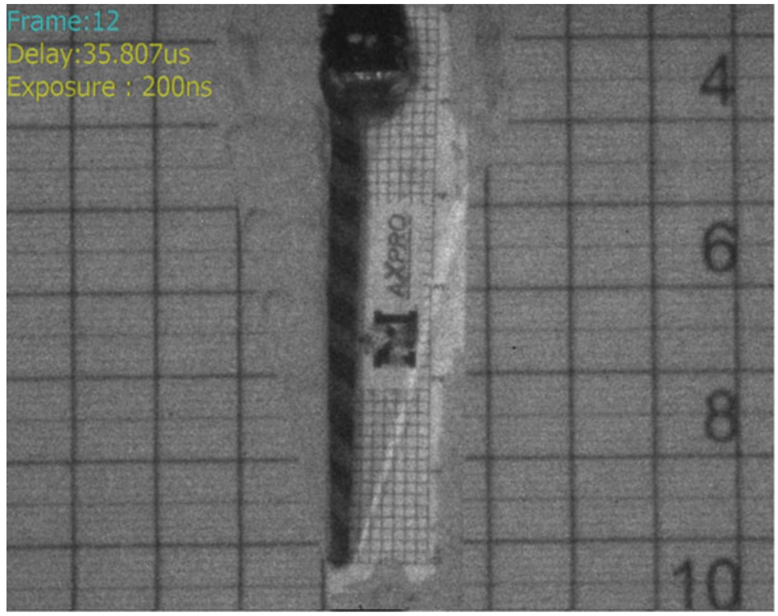

Fig. 11.6 Underwater detonating cord during ideal detonation

profiles are plotted against the shock profile. An average of 9.4 % difference was calculated for the corrected profiles. Further analysis may include developing a numerical model, which will validate the current results for this study.

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