Acceleration of polymer bonded powder metal liner

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Abstract:

Polymer bonded, copper powder metal flexible sheet, called "plastic-metal" by these authors, is used as a liner in linear shaped charges for cutting metals in demolition, or works in which precise cut is needed in such as oil well works. In the experiments described in this paper, this liner material is subjected to explosive acceleration, and its velocity is measured using photonic Doppler velocity technique. Due to the poor reflectivity of liner to the laser beam, several setups were explored, with different levels of success. Preliminary results indicate that use of reflective foil on the liner surface or/and an extra layer of material to keep particles together is necessary to get back enough laser reflection to be able to perform any measurements. Preliminary results suggest that it should be possible to use PDV for measurement of surface velocity.

Keywords: PDV; shaped charges; Photon Doppler velocimetry; liner; metal acceleration

1 Introduction

Linear cutting shaped charges are employed in special demolition works in which accuracy and minimal effects to the surrounding areas are important. They are able to penetrate metal structures due to the formation of a fast moving jet, explosively formed by plastic deformation of a metal liner. This jet can attain speeds that are over the yield strength limits of the target material, and great penetration depths can be obtained [1].

The liner material made of a mixture of copper powder and a polymer binder is used in this work. Such material is used in flexible linear shaped cutting charges and although it is currently commercialized, little scientific information is available on its properties. Material characterization, in special response to explosive shock loading, may allow future modelling and simulation of jet formation and target penetration of charger using this material.

Various methods can be employed to determine properties of the liner material under explosive generated shock loading. In this article we decided to summarize some initial results of particle velocity measurements using PDV, as this technique is much more cost effective than pressure measurements using manganine gauges and gives data with a better resolution than shock velocity measurement using time of arrival probes.

2 Experimental

In this section three main features are approached: charge setup, measurement technique and data evaluation.

2.1 Charge setups

A charge of A IX 1 (pressed 95% RDX and 5% binder, 1.66 g/cm^3 density) in a cylindrical shape 40 mm high and 40 mm diameter is used to accelerate the liner. The plastic-metal was cut in a circular shape, with 40 mm diameter from a sheet 3 mm width, and put over the charge with a thin layer of silicon wax in between them, to avoid air gap. In order to confidently initiate the charge, 20 g of Semtex 1A was shaped by hand into an approximate cylinder of 40 mm diameter and placed under the charge. A detonator was inserted into the Semtex. Scheme of charge is shown in figure 1:

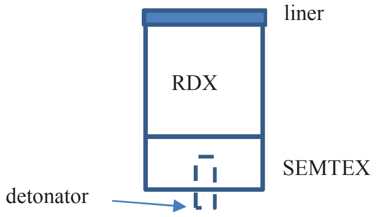
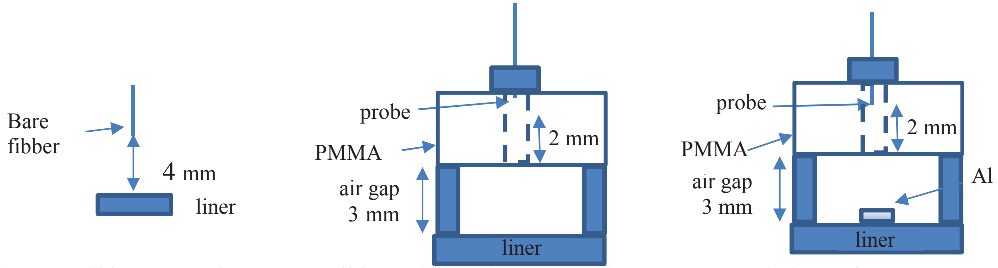


Figure 1: Scheme of charge.

For probe positioning, five variations were explored. In some, other materials as polymethylacrylate (PMMA), aluminum and solid copper were also used. Figure 2 summarizes schemes of the probe set ups tested.



1) Bare fibber as probe, 4 mm from liner surface

2) Fibber with probe, mounted on a PMMA 3 mm thick, standing 3 mm from liner. The probe tip is 2 mm deep into the PMMA plate

3) Variation of set up 2, placing a 0.145 mm thick aluminum foil at center of charge

4) PMMA 3mm thick is placed over the liner, to extend its integrity

5) Same as 4, with a copper foil (0.028 mm thickness) at center of the liner

Figure 2: Summary of the five configurations tested.

2.2 Measurement technique

The measurement set up consists of similar assembly to that used by [3] to measure aluminum plate acceleration with PDV technique. A modern variant of this technique was proposed in 2004 by O. Strand [4] as a way to measure velocity of fast moving reflective surfaces, including those accelerated by explosives, lasers, or gas guns, with good time accuracy.

The principle involves the Doppler effect, in which a laser reflected from a moving surface will have an slightly shifted frequency from that of the laser source. Both unshifted and shifted light interfere and produce new frequency (f_b) that is much lower than either of the two. It shows as a beating in the signal with frequency that is within the range of today´s photodetectors and digitizers. [5].

After being recorded in an oscilloscope as voltage signal, the moving surface velocity can be derived from the beat frequency f_b and the original laser wavelength λ according to equation 1:

$$v = f_b \cdot \frac{\lambda}{2} \tag{1}$$

Simple scheme of set up for single channel PDV technique is shown in figure 3. Measurement set up is in figure 4.

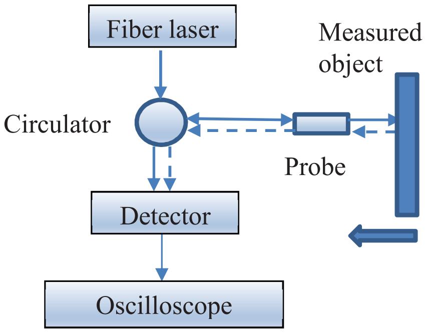


Figure 3: Scheme of measurement set up for one channel PDV [9].

Figure 4: One channel PDV measurement set up.

2.3 Data evaluation

Data recorded by the digitizer in voltages, is later analysed by routines that identify f_b (and then calculate v), such as sliding Fourier transform [3]. Examples of digitizer output and spectrogram are displayed in figures 5, and 6. Figure 7 shows the extracted velocity history profile of the relevant part of the signal.

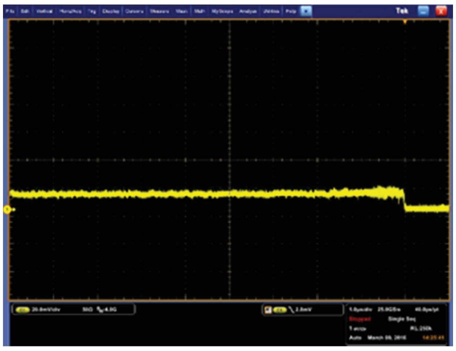


Figure 5: Digitizer output-voltage vs time.

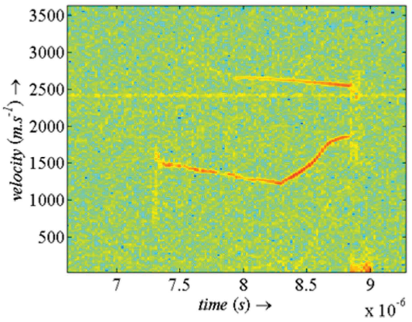


Figure 6: Spectrogram- velocity vs time.

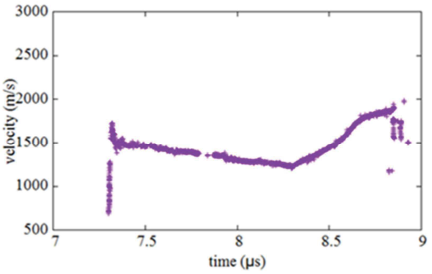


Figure 7: Extracted velocity profile, velocity (m/s) vs time (s).

3 Results and discussions

Various degrees of success were obtained for the five set ups tested, and also different velocity profiles were observed, due to the variety of materials employed. Results for each of the configurations are presented in the following sections with respect to the applicability of PDV for such measurements. More experiments are needed for interpretation of the results and such task is therefore not included in detail this contribution.

3.1 Set ups 1 and 2

No relevant signal was recorded, maybe due to bad alignment of fibber tip, in case of set up 1, poor reflectivity of plastic-copper liner, or pulverization of liner before reflection could be sent back to probe. This result is expected as liner demonstrated some reflectivity, but very low back reflection, in preliminary tests with laser used in this experiments. Behavior of the surface at the time of shock wave emergence will be investigated using high speed framing camera.

3.2 Set up 3

Figure 8 shows velocity profile obtained for shot with Al reflector placed directly on the liner. Considering the shock impedance of Al reflector and of the plastic bonded copper it seems reasonable to assume that the signal represents the first step in Al acceleration after which the two surfaces separate and the Al flies towards the probe without further interaction with the liner. Integration of the curve in figure 8 over time, gives a value of travelled distance equal to 4.51 mm. It is close to nominal 5 mm distance between probe and liner, it is reasonable to assume that the signal represents most of the phenomena.

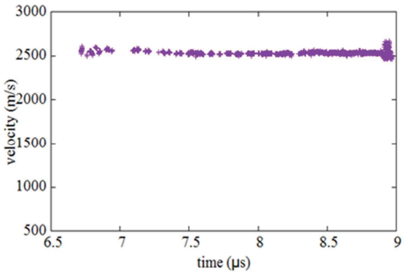


Figure 8: Velocity profile for set up 3, velocity (m/s) vs time (s).

3.3 Set up 4

This set up was shot twice, and signals obtained for both were similar in shape, speed and duration. Spectrogram obtained with this set up is presented in figure 9. It clearly indicates that the reflectivity of the liner itself cannot be easily measured using through the PMMA backing window. The only signal seen in figure 9 is the acceleration of the back surface of the PMMA window.

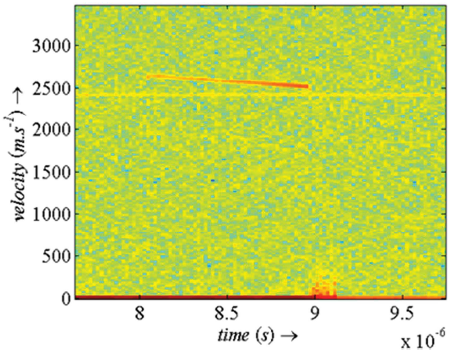


Figure 9: Spectrogram for set up 4, velocity (m/s) vs time (s).

3.4 Set up 5

It can be seen in figures 10and 11 that for this set up two signals were obtained, a faster one at later times and a slower one starting earlier. This configuration was shot twice providing similar in both cases. The upper signal is very similar to the one obtained in set up 4, and is related to the PMMA back surface acceleration to the air.

The signal observed at lower velocities is reflecting the acceleration of the copper foil reflector placed between the plastic bonded copper liner and the PMMA backing window. Unlike in the case without the window the reflector survived long enough to provide reasonably long signal.

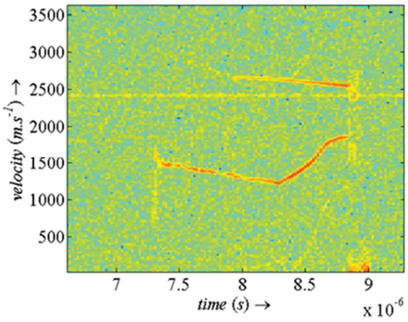


Figure 10: Spectrogram for set up 5, velocity (m/s) vs time (s)

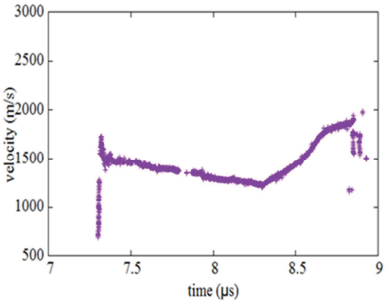


Figure 11: Velocity profile of slower signal (m/s) vs time (μs) for set up 5.

4 Conclusions

In this work, preliminary data on particle velocity measurements of polymer bonded copper powder were presented. PDV technique has proven to be able to provide reasonable repeatability, in different set ups, although some limitations have been identified.

From results of set ups 1 and 2, it is clear that reflectivity of the plastic bonded copper itself is not sufficient and it is necessary to use reflective material over the liner, in order to achieve reflection that can be captured by the probe. The failure of the free surface velocity measurement and resulting need for a backing window indicates low tensile strength of the material.

Set up 5 has proven so far to be the most suitable to the experiment, but some further consideration is still needed to correctly interpret the signals obtained. Future investigations will include this test configuration, and possible variations of it.

Acknowledgments

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