

## Particle response to shock waves in solids: dynamic witness plate/PIV method for detonations

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### 1. Introduction

To achieve PIV measurements in blast waves resulting from micro-detonations it is essential for the particle markers to follow the extreme accelerations characteristic of shocks. A new method to study this type of flow has been introduced by Murphy et al. (2005). In this method detonator output is characterized by placing a transparent polymeric witness plate adjacent to the detonation and observing the shock-induced velocity field within the witness plate by pulsed schlieren imaging and particle image velocimetry (PIV). In principle, the high density of the polymer, relative to that of the gas, makes the particles much more responsive to accelerations, thereby making the PIV measurements more accurate.

### 2. Particle slip velocity

Using an approximate expression for particle slip velocity at finite Reynolds number (Adrian 1991) given as

$$|\mathbf{v}_p - \mathbf{u}| = \left( \frac{2}{3} \frac{\rho_p}{\rho} \frac{d_p}{C_D} \left| \frac{d\mathbf{v}_p}{dt} \right| \right)^{1/2},$$

the lag velocity is shown to be proportional to the square root of the ratio of particle density to fluid density,  $(\rho_p/\rho)^{1/2}$ . For the typical case of liquid particles in air, the quantity  $(\rho_p/\rho)^{1/2}$  is approximately 30. By replacing the gas with a solid having seed particles embedded in it, the slip velocity can be reduced by roughly 30:1, since  $(\rho_p/\rho)^{1/2}$  is now approximately unity.

### 3. Current efforts

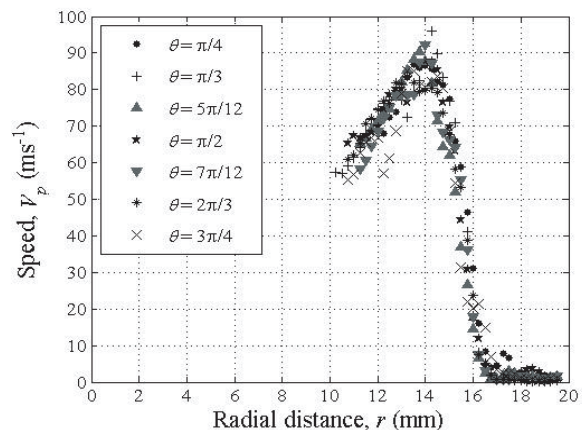
By demonstrating feasibility, the witness plate/PIV method has only been introduced as a viable means of obtaining quantitative data of micro-detonator output, like the exploding bridge wire (Murphy et al. 2005). Current efforts focus on introducing the effectiveness of the method by demonstrating significant improvement in particle response in regions containing detonator-induced shocks. This is accomplished by making quantitative comparisons of velocity profiles across the shock waves in air and in polydimethylsiloxane (PDMS) witness plates. The profiles are obtained from vector fields of shock-induced material velocities in the polymer.

In this work it will be shown that the dissimilar outputs of two types of exploding bridge wires (EBW) and slapper detonators can be characterized and compared using the witness plate/PIV method complemented by schlieren photography employing continuous laser backlighting. Evidence of large improvement in particle response is demonstrated in PDMS witness plates as compared to gaseous trials.

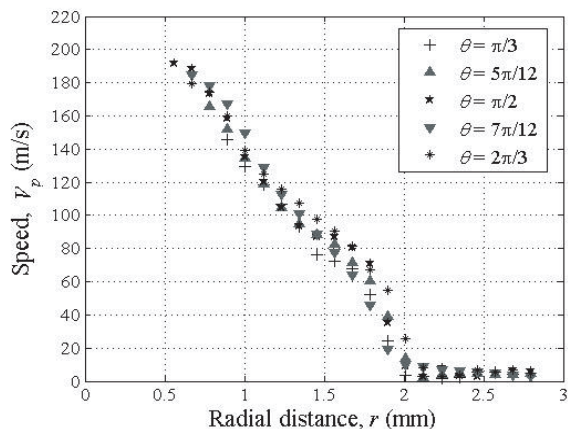
### 4. Results

Plots of speed versus radial distance are shown in Fig. 1 and Fig. 2 corresponding to velocity vector field data from PIV experiments in air and PDMS witness plates, where EBW-induced shocks are under investigation. These plots are obtained by interpolating the vector field data along radial lines at polar angles ranging from  $\pi/4$  to  $3\pi/4$  radians.

Observing the plot in Fig. 1 one notices strong particle lag occurs that does not permit the location of the shock front to be determined inside a spatial range of 3 mm. On the other hand, the result of the PDMS trial shown in Fig. 2 shows a large improvement over the gaseous trials with respect to resolving the location of the shock front. Specifically, in this case the shock wave is resolved to within the spacing of two velocity vectors, or 220  $\mu\text{m}$ . Hence, the spatial resolution of the velocity field in the region of the shock wave is improved from 3 mm to 220  $\mu\text{m}$ , which is an improvement of a factor of 13.



**Fig. 1** Speed versus radial distance in air 19.5  $\mu\text{s}$  after EBW burst.



**Fig. 2** Speed versus radial distance in PDMS 1.044  $\mu\text{s}$  after EBW burst.