SAND2018-12891C

Fiber Light Relay System (FLRS) in Non-Ideal Granular Explosives for Shock Front Monitoring

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Abstract. The performance of non-ideal explosives, especially granular or heterogeneous blends, has been studied with numerous instrumentation techniques. Traditional techniques such as flash x-ray, embedded electromagnetic or pressure gauges, and timing pins are practical in a lab or small-scale experiments. Consequently, as the experimental size grows and depending on the explosive macrostructure, these methods become logistically challenging, cost prohibitive, or technically inappropriate to deploy. In recent experiments, measuring the shock front position and shape were desired through the length of columnar and rectangular charges. The Fiber Light Relay System (FLRS) was developed to cost effectively collect shock front time-of-arrival over one or several spatial planes during a single experiment. The individual and time grouped points can then be resolved to calculate shock velocity and shape relative to position and time respectively.

Introduction

To understand the reactive front behavior in non-ideal granular or heterogeneous blended explosive formulations, in-situ shock position measurements are desired. While traditional techniques such as flash x-ray, embedded electromagnetic or pressure gauges, and timing pins are practical in a lab or small-scale experiments design they become logistically challenging, cost prohibitive, or technically inappropriate to deploy as the experimental size grows (e.g. 50 lbs. or greater). When appropriately spatially resolved with sufficient acquisition points, the individual and time grouped points can then be resolved to calculate shock velocity and wave front shape relative to position and time respectively. The Fiber Light Relay System (FLRS) was developed to cost effectively collect shock front time-of-arrival over one or several spatial planes during a single experiment.

To determine the validity of using the FLRS to monitor the shock front in granular non-ideal explosives, the system was deployed experimentally in parallel with traditional instrumentation techniques simultaneously in two test trials using the charge configuration shown in Fig 3. Piezoelectric pins[1] and a continuous velocity probe[2] were used as the baseline time of shock arrival and velocity measurement techniques respectively. FLRS parameters, fiber end preparation and output light signal focusing lenses, were varied to determine the impact on the recorded fiber optical output.

Experimental Setup

The FLRS consists of an explosive charge with 1 mm diameter PMMA fibers embedded in the

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charge column at known heights and internal radii from the charge centerline or at the explosive charge wall interface. The output fiber end was routed to an output panel that aligns the fibers toward a high-speed camera. The overall test schematic (not to scale) is shown in Fig. 1. A Phantom 2511 was used with 128x32 pixel resolution and recording speed of 1,000,000 frames per second.

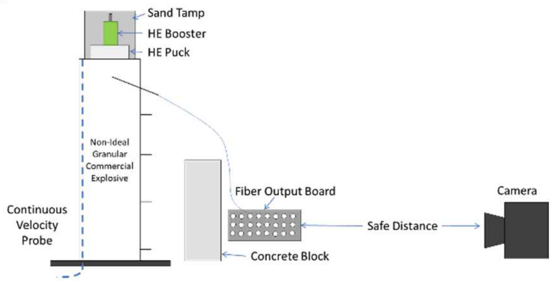

Fig. 1. Test schematic.

The fiber panel is shown in Fig. 2. In the front panel images, half of the fibers have output focusing lenses (0.5" diameter). In the lower image of Fig. 2. Both polished and cleaved fiber preparations were evaluated. In test trial 1, two fiber preparation methods were used; all polished fibers, ½ with and ½ without output lenses. In test trial 2, two fiber preparation methods were used; all cleaved fibers, ½ with and ½ without output lenses. The holes in the plate were separated sufficiently to allow each point to be resolved by the camera independently.

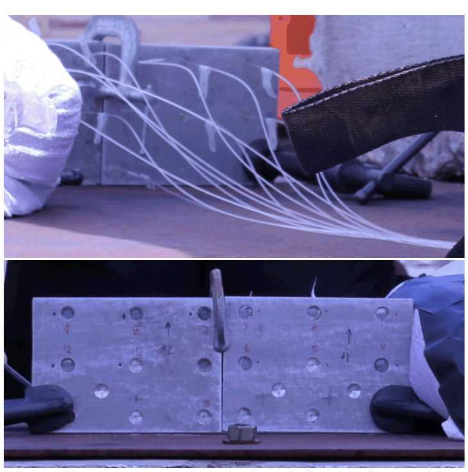

Fig. 2. Fiber panel (top) back/insertion side and (bottom) front/output side.

Twelve fibers were placed in the charge with 6" vertical and 120º radial resolutions respectively. Three radial placements at from the charge center line were instrumented; r=1", 2", and 3" respectively. Continuous velocity probes were aligned along the charge centerline and outside the charge wall aligned with the charge axis. Piezoelectric pins were aligned along the axis wall and along the base plate.

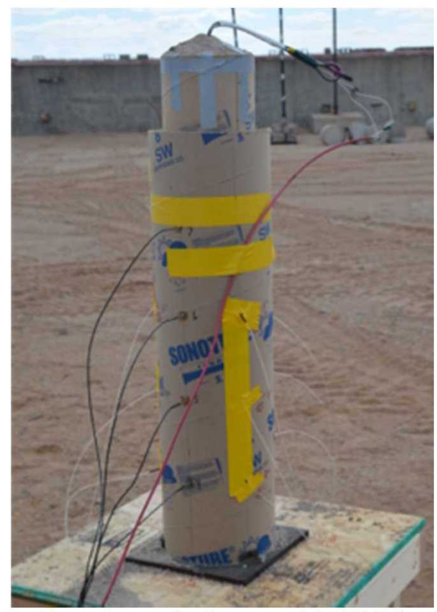

Fig. 3. Experimental charge with FLRS, timing pins, and continuous velocity probes installed.

Results

The fiber full spectrum light output intensity was measured relative to time to evaluate the validity of the FLRS technique to detect a shock time-of-arrival in non-ideal granular explosives. In the video data captured, the few pixels associated with a given fiber were evaluated in a software program for relative white/black scale at each frame. The fiber output signal intensity varied greatly depending on the FLRS parameters used as shown in Fig. 4. The time-of-arrival for each signal was documented as the peak half height for each fiber signal. The initial light intensity in each trace is from the booster and subsequent charge detonation fireball displayed in a mirror to serve as an event start video fiducial.

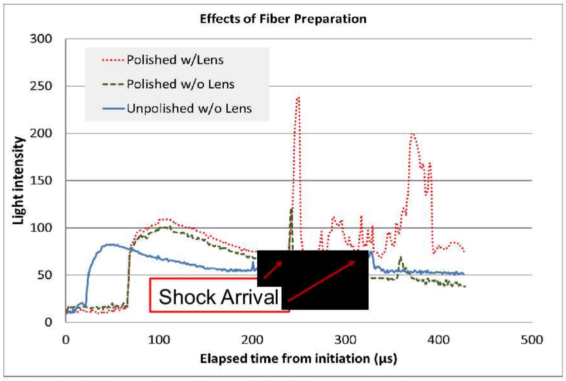

Fig. 4. Fiber signal vs. FLRS parameters.

The inter-sensor shock velocity was calculated from each instrumentation type. The results were compared in Table. 1. and resulted in a maximum variance of 3.6% for the FLRS velocity measurement as compared to either the piezoelectric time-of-arrival pins (TOA) or continuous velocity probes (CVP) for each test. The data is for two shots as indicated by groups 1 and 2 in the instrument names. Velocity was determined by four and five points for the FLRS and TOA systems respectively along the length of the charge column. A commercial MREL CVP with a copper probe rounded out the comparable techniques.

Table 1. Instrumentation Velocity Measurements.

Instrument	Velocity (mm/μs)	Deviation
CVP 1	3.51	
FLRS 1	3.54	0.9%
TOA 2	3.51	
CVP 2	3.42	
FLRS 2	3.39	1.0% (CVP) 3.6% (TOA)

The variation in shock arrival time and average inter-sensor shock velocity at a given distance into the charge were used to approximate the shock position as a function of radius. The estimated shock front profiles at each distance into the charge are plotted in Fig. 5. with symmetry assumed across the charge axis. Unfortunately, no data was taken along the charge centerline or at the charge interface with the booster to better resolve curvature of the wave front as the primary goal was to determine the validity of the FLRS to determine shock velocity as compared to comparable techniques. The final set of data at 27” down in Fig. 5 indicate the arrival at the charge baseplate.

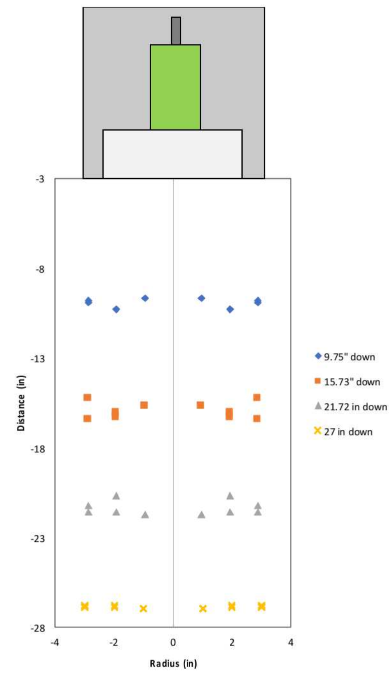

Fig. 5. Shock positions detected by FLRS in-situ fibers.

Conclusion

In any shock time-of-arrival instrumentation technique, an intense signal with a rapid rise is desired to uniquely identify shock arrival from the instrument noise baseline. To achieve this with the FLRS, both ends of the fibers need to be polished and a focusing lens should be used on each fiber to obtain a sufficient signal strength. Without these parameters, the output signal is not sufficiently above the baseline and background light intensity noise levels to confidently differentiate shock arrival.

The small variation in FLRS calculated shock velocity as compared to both the piezoelectric pins and continuous velocity probe measurements confirms the FLRS technique is a valid system to monitor the shock position with time.

The shock front curvature could be resolved more accurately with increased fiber location resolution at a given distance into the charge. In addition, the fiber tips can be coated with a thin film that illuminates rapidly in a shock environment. This could further increase the signal intensity and therefore confidence in the shock arrival time.

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