Visualization of Blast Waves in the Early Stage of Milligram Charge Explosions

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1 Introduction

In a systematic study on the characteristics of blast waves generated by small explosive charges with charge masses of a few milligrams, it has been shown [1] that the scaling laws obtained for large-scale explosions also apply for these small-scale events, which can safely be investigated in a laboratory environment. This enables one to reproduce the wave patterns of large-scale explosions rather faithfully on a reduced scale and also provides a fast and valuable validation of computer codes for blast wave simulation.

The charges (silver azide, with masses between 0.5 mg and 10 mg) are ignited by the irradiation of an Nd:YAG laser. The threshold energy for ignition was determined by reducing the laser energy density until no ignition could be obtained[2]. This investigation also showed that within the accuracy of the measurement(less than 1μs) there is practically no ignition delay even when the irradiation energy is close to the threshold value.

The early stage of the explosion of these milligram charges and some of the ignition characteristics are the subject of this paper. Experimental visualization results are compared with a numerical simulation of the process.

2 Materials and methods

The blast waves, which were generated by the ignition of silver-azide pellets, were visualized by a direction-indicating color schlieren method [3] [4]. While the standard monochrome knife edge schlieren method detects the magnitude of density gradients in one predetermined direction (i.e., perpendicular to the knife edge), the direction-indicating technique allows one to record the direction of all density gradients in the projected view of the flow field. The obtained pictures are particularly useful for a qualitative and phenomenological description of the investigated process.

The experimental setup of this visualization system is shown in Fig.2 (abbreviations: C.M.:concave mirror, L:convex lens, C.S.:color source mask, P.H.:pinhole, P.S.:power supply). Since the coding of density gradient directions is done by colours, the light source has to provide light over the whole spectrum covered by the filters. In addition, one has to be aware of the fact that the system has an inherent low light-usage efficiency: more than eighty percent of the light provided by an adequate light source are already lost in the filter mask assembly of the optical system (indicated by C.S. in Fig.2). The technique requires therefore a high-intensity 'white' light source. For the visualization of transient events and high-speed phenomena, an additional requirement with respect to the pulse duration has to be met. In most cases, a pulse duration of less than 1μs is needed. For discharge light sources, however, the requirements of high intensity and short duration are unfortunately contradictory so that a compromise has to be found. For this reason, much lower pulse durations (in the 100 ns range) are usually unattainable. One system that meets the listed demands is the NANOSPARK 4000P (800ns pulse duration (FWHM), 16kW/sr, YOKOHAMA KENKYUJYO Inc.) [5], which was used for this experiment. The light source and the ignition system for the charges were synchronized so that it was possible to take single frames of the explosion process at predetermined instants with a jitter of less than 1μs.

In this particular part of the investigation silver-azide pellets with a mass of 10mg were used. These pellets have a cylindrical shape and an aspect ratio of unity (1.5mm long, 1.5mm in diameter). Figure 1(a) shows a schematic of such a charge, whose bottom surface is seen in Fig.1(b). The pellets were ignited by irradiating them with the pulse of an Nd:YAG laser (wavelength:1064nm, energy:14mJ/pulse, pulse width:9ns). The transmission of the irradiation as well as the respective orientation of irradiating laser beam and observation direction influence the results. These conditions may be classified in three categories: (1) irradiation transmission methods (direct or via an optical fiber), (2) irradiated surface (bottom or side), (3) visualized plane of the flow field (perpendicular or parallel to the ignition direction). This leads theoretically to eight possible experimental conditions, however, only four of them have significant differences in realistic experimental procedures.

3 Results and discussion

The experimental results confirm an expected feature, namely that the shape of the silver-azide pellet has much influence on the shape of the generated blast waves. This effect is clearly seen in the experimental and numerical records.

Figure 3 shows the visualized blast wave flow field at 180μs after subjecting the pellet to the laser irradiation. The ignition conditions obviously influence the flow and the shape of the blast wave. According to Fig.3, significant distortions can be seen for conditions (a), (b), and (c). In case (d) the wave appears undistorted, which is, however, a result of observing the flow in the direction of the igniting laser beam (in other words, a distortion is present but not visible). The resulting blast waves are always distorted as a result of a strong jet of combustion products along the pellet axis. The cylindrical shape of the pellet makes the axis a preferred direction for the expansion of the combustion products. The expansion in radial direction, however, is very uniform and reproducible, as numerous records with an observation direction parallel to the charge axis (as in (d)) and perpendicular to it have shown. The latter results, which correspond largely to the situation shown in case (a), indicate that the distortion is limited to a bubble-like portion ahead of the main spherical wave. The amplitude of this distortion is not very reproducible, but the affected area of the otherwise almost perfectly spherical wave is largely constant [1].

If the shape of the pellet becomes irregular, the preferred direction introduced by the cylindrical geometry disappears and the distorted portions of the blast wave are greatly diminished. This can be seen in the flow field that is established after the ignition of a 0.5 mg silver azide charge, which is depicted in Fig.4. Figure 4 is one frame of a time-resolved monochrome schlieren visualization obtained with a high-speed image converter framing camera (IMACON 468). In this case, the ignition direction was perpendicular to the observation direction (similar to case (a) in Fig.3, however, with the charge mounted on a thread). The resulting blast wave is highly symmetrical and practically free of distortions, while the cloud of combustion products still indicates signs of asymmetry caused by the directional ignition. Charges with masses below 10 mg are made by dissecting a standard 10 mg cylindrical charge. This procedure usually yields an irregularly shaped charge.

In a preliminary numerical analysis, the flow field was calculated using AUTODYN-2D [6], a commercially available numerical code for shock analysis. The calculation was performed in cylindrical coordinates using the Euler equations and the JWL equations of state. The conditions for the explosive were as follows: 10 mg silver-azide charge; cylinder axis were directed to horizontal. Two different surfaces from which the detonation was assumed to start were simulated: bottom-surface and side-surface ignition. For side-surface ignition it was assumed that the ignition started simultaneously along the whole surface, since AUTODYN-2D is a two-dimensional code and cannot represent three-dimensional distributions. Numerical and experimental data are presented in Figs. 5 and 6, where the upper half shows the numerical results, while the lower half gives the corresponding experimental visualization record. It is obvious from these figures that the numerically and experimentally obtained flow fields exhibit reasonable to good agreement.

In Fig.5, a strong jet of combustion products along the cylinder axis can be observed. Accordingly, the otherwise largely spherically symmetric blast wave is distorted along this portion affected by the jet. In addition, the numerical simulation indicates the presence of three vortices, marked A, B, and C, at the boundaries of the combustion product cloud.

In Fig.6, the differences between the calculated and the experimentally observed wave pattern is more pronounced. This is caused by the unrealistic assumption in the calculation that the whole peripheral side surface is ignited simultaneously. The calculated pattern is therefore more symmetric than in the experiment, where a directional dependence is introduced by the fact that only one part of the cylinder surface is ignited.

4 Conclusions

In this study, the ignition methods of silver-azide pellets with charge masses in the milligram range and the resulting blast wave patterns were examined. The following results were obtained:

(1) The cylindrical shape of the charges introduces a preferred direction for the expansion of the combustion products, usually seen in form of a strong jet along the cylinder axis. This jet distorts the established blast wave, but the distortion is confined to a small region of the wave. Experimental and numerical wave shapes were seen to be in good agreement.

(2) The amount of distortions introduced by the geometry of the charge is minimized, when the charge is:

(a) irradiated and ignited at its bottom-surface and

(b) held by a mounting system that minimizes the influence on the wave pattern, such as a thin thread.

(3) Charges with a shape that does not introduce a preferred direction for the combustion products to expand generate blast waves with a significantly lower degree of distortions.

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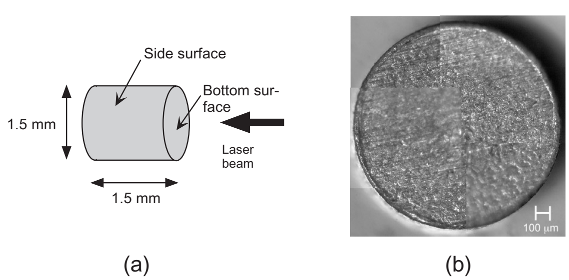

Fig. 1 0.5mg silver-azide charge. **a** dimensions; **b** magnified bottom-surface

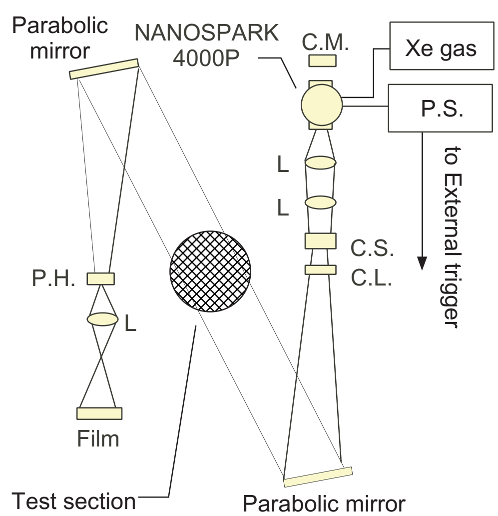

Fig. 2 Schematic configuration of experimental setup

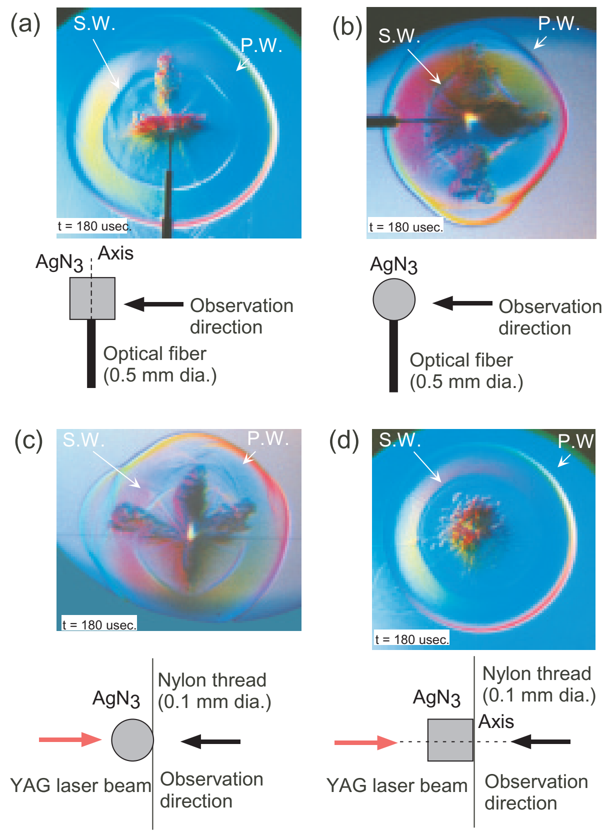

Fig. 3 Visualized blast wave patterns. **P.W.**:primary blast wave; **S.W.** secondary blast wave

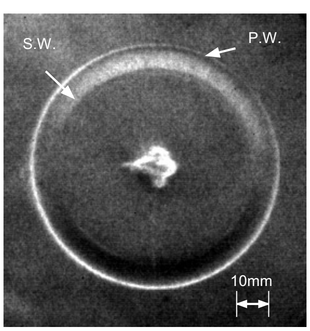

Fig. 4 Shock wave generated by 0.5mg silver-azide charge

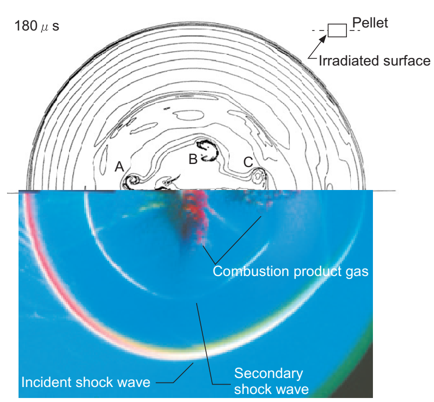

Fig. 5 Bottom surface ignition. Upper half: numerical result, lower half: experimental result

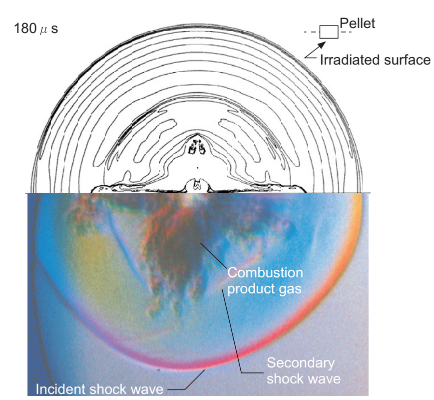

Fig. 6 Side surface ignition. Upper half: numerical result, lower half: experimental result