Experimental study of three-dimensional DDT and the effect of micro-fragment shattering on it

Makoto Komatsu and Kazuyoshi Takayama

Shock Wave Research Center, Institute of Fluid Science, Tohoku University, Katahira 2-1-1, Aoba, Sendai 980-8577, Japan
@
E-mail address: takayama@ceres.ifs.tohoku.ac.jp

Keywords: Micro-explosive, Three-dimensional Detonation, DDT

1.Introduction

In the Shock Wave Research Center, Institute of Fluid Science, Tohoku University a hypervelocity detonation driven shock tube is being developed, in which detonation waves will be generated in stoichiometric hydrogen/oxygen mixtures by the use of a micro-explosive. The present paper is primarily related to the exploitation of a detonation driven hypervelocity shock tube. First of all characteristics of initiation of detonation waves inside its initiation tube by the ignition of micro-explosives are studied. Then the process of a transition of deflagration driven shock wave to three-dimensional detonation wave is experimentally investigated using holographic interferometry. When a micro-explosive was detonated in hydrogen/oxygen mixture, a deflagration wave drove a spherical shock wave. With the elapse of time it sometimes takes place that the spherical shock wave transits to detonation wave.
Unlike DDT caused by electric spark discharges or laser beam focusing, DDT caused by explosions of micro-explosives is more depending upon gasdynamic processes. The higher the initial pressure of stoichiometic hydrogen/oxygen mixture is and the more amount of explosives is increased, the easier DDT will be expected to take place. However, upon the ignition of micro-explosives by irradiation of pulsed a YAG laser beam, very small particles shatter from the explosive surface which presumably consist of unburned fragments or debris removed from it. It is then suspected that DDT is influenced by the shattering of fragments.

In this paper the effect of shattering fragments on DDT is experimentally discussed. To produce fragments flying at supersonic speed silver azide pellet from 1 mg to 10 mg in weight was coated with very small SiO_2 powders. When the pellet was detonated by irradiation of a pulsed YAG laser beam the powders were shattered in space, which dragged wakes behind. The wakes at the same time created mixing layers which would promote the acceleration of deflagration waves inducing their transition to detonation waves. Observations were carried out by means of double exposure holographic interferometry.

2.Experiments

Figure 1 shows an experimental arrangement. A detonation chamber of 290 mm diameter, 270 mm in width and 30 mm in wall thickness was filled with stoichiometric hydrogen/oxygen. The chamber had acrylic observation windows of 350 mm diameter and 30 mm in thickness. In side of the windows 2 mm thick protection acrylic plates were inserted. A micro-explosive of 1 to 10 mg silver azide , manufactured and supplied by Shugoku Kayakau Co. Ltd, whose weight varied from 0.1 mg to 10 mg }1% error was glued on a thin cotton thread was placed at the center of the chamber. Fig. 2 shows the schematic diagram of the ignition system and holographic interferometric observation. The position of micro-explosives was marked with He-Ne laser beams so as to focus a pulsed YAG laser beam of 25 mJ/pulse and 7 ns pulse duration. The 10mg micro-explosive that is heaviest in the experiments has a cylindrical shape of 1.5 mm diameter and 1.5 mm height. The smaller micro-explosives are made by squeezing the cylindrical explosives, so that these have irregular shapes. Weights of these smaller ones have measured with a precision balance of 1 microgram accuracy.
Detonable gas mixtures are stoichiometric hydrogen/oxygen. The pressures of the mixtures are filled in the chamber is varied from 30 kPa to 150 kPa. Same experiments are carried out in inert case. In this

case, hydrogen/nitrogen mixtures which the molecular ratio of nitrogen is same as that of oxygen are fed in chamber.

Double exposure holographic interferometry is employed for visualization. Figure 2 shows the optical arrangement of visualization. Visualization is carried out at specified time instant.

For investigation of flying debris of explosive, observations of flying SiO_2 particles are carried out. SiO_2 particles are glued with acetocellulose solution on the surface of 10 mg cylindrical explosive, and same experiments which are written previously are done.

3.Results and discussion

Photographs of Figure 3 are holograms of experimental results, and the relationship between average radius of fronts against elapsed time from ignition is described on Fig. 4. Fig. 3(a) shows an interferogram of 100 kPa hydrogen/oxygen mixture at 30 microseconds after ignition of a 1 mg explosive. Explosives are detonated very spherically. Fig 3(b) shows an interferogram of 100 kPa hydrogen/oxygen mixture at 30 microseconds after ignition of a 10 mg explosive. In this case, fronts are also spherical, but radius of fronts is much larger, and looking of fronts is very different from 1 mg case. Fig. 4 says that expansion speed of fronts in 10 mg explosive case is much faster than that in 1 mg case, and that speed is near the experimental C-J velocity of Ref. 3(2837 m/s). From these results, the transition from deflagration driven shock wave to detonation wave is completed in 100 kPa stoichiometric hydrogen/oxygen mixture of 10 mg explosive.

Fig. 3(c) is an interferogram in 60 kPa hydrogen/oxygen mixture at 30 microseconds from ignition of 10 mg explosive. Conical shock waves are formed at the individual fragments which are precursory to the deflagration driven shock wave. But shock waves which are made with smaller explosives are very spherical.

Fig. 3(d) is a result with explosive on whose surface SiO_2 particles are glued in same condition of Fig. 3(c). Wakes of debris are formed uniformly to all direction. The wave surface on Fig. 3(d) is similar to the parts of waves in Fig. 3(c) in which conical shock waves are formed. This would imply that the whole pieces of smaller explosives are ignited at once whereas the surface layer of larger size explosives are shattered unburned.

In the condition of Fig. 3(d) without SiO_2 particle, detonation is not generated in this studies. Expansion speed of waves in Fig. 3(d) is faster than that in without SiO_2 particle case, and slower than C-J velocity of Ref. 3. From these results, transition process from deflagration to detonation is behind wake of debris, so that it is probable that wakes of unburned explosive shatters invite the deflagration-detonation transition partially.

Fig. 3(e) is a photograph which describes flying SiO_2 particles in 45 kPa detonable mixture. The diameter of waves in this condition is less than that in 60 kPa detonable gas, and as same as in 30 kPa. It is expected that the initial pressure for deflagration-detonation transition by invitation of wakes of SiO_2 debris is around 60 kPa. More detail investigation to find the transition point have to continue.

The waves of flying SiO_2 particles which is generated in 60 kPa inert gas is showed on Fig 3(f). This photograph shows clearly that SiO_2 particles are precursory of the deflagration driven shock waves. The flying speed of SiO_2 particles in inert gas is faster than speed in detonable gas on these photograph. The causes about this have to be revealed.

4.Sammary and future works

Visualization of transition from a deflagration driven shock wave to a detonation wave and shattering of SiO_2 particles is carried out. Micro-explosive are used for ignition. The weight of micro-explosive is varied from 0.1 mg to 10 mg, and initiation pressure of hydrogen/oxygen mixture is varied from 30 kPa to 100 kPa.

The deflagration-detonation transition is completed in 100 kPa hydrogen/oxygen mixture of 10 mg explosive, but the transition is not confirmed in other cases. In 60 kPa detonable mixture of 10 mg explosive, conical shock waves are formed by unburned pieces of a explosive. It is observed that shock waves are accelerated partially along the wake of shatters of a explosive. This accelerated waves is similar to the waves which is generated by shattering of SiO_2 particles in same condition.

Expanding speed of waves generated by SiO_2 particles is much faster than in no particle case. It is probable that wakes of unburned explosive shatters invite the deflagration-detonation transition.

In this study, mechanism of shattering of explosive debris and acceleration process of deflagration along the wake of debris are not revealed completely. After this, these problems should be solved

In the future, the critical energy of deflagration-detonation transition for this gas mixture is experimentally sought for.

References

[1] V. F. KLIMKIN, R. I. SOLOUKIN, and P. WOLANSKY, “Initial Stages of a Spherical Detonation Directly Initiated by a Laser Spark”, Combustion and Flame 21, 1973, pp. 111-117.

[2] John H. Lee and R. Knystautas, “Laser Spark Ignition of Chemically Reactive Gases”, AIAA Journal, Vol. 7, No. 2, 1969, pp. 312-317.

[3] John H. S. Lee, “On the Initiation of Detonation by Hypervelocity Projectile”, The Zeldovich Memorial Conference on Combustion, 1994, Voronovo, Russia.

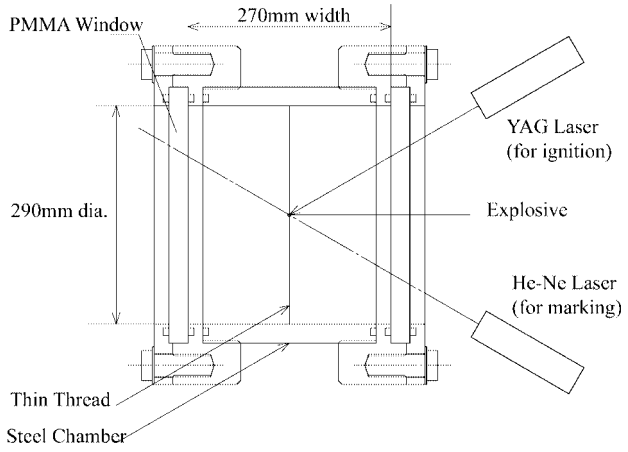


Fig. 1 Explosive Chamber

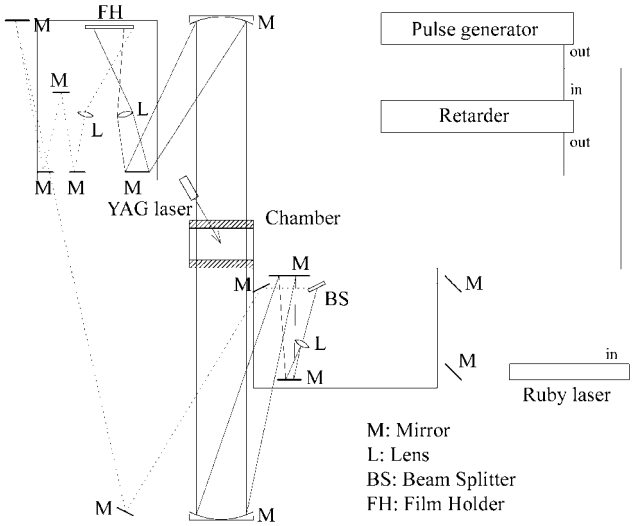
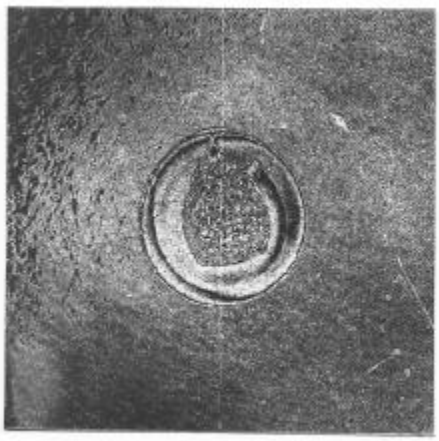
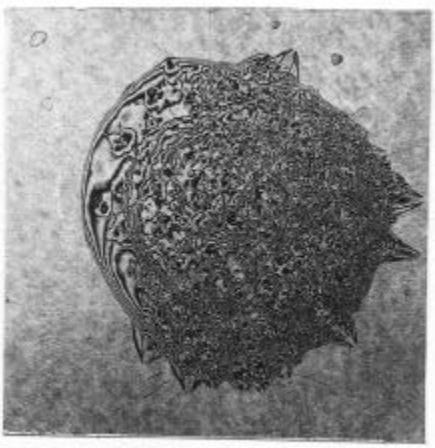


Fig. 2 Optical arrangement

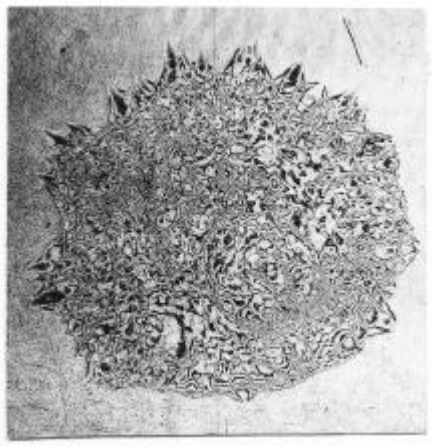


(a) 100kPa H_2/O_2, 1mg explosive

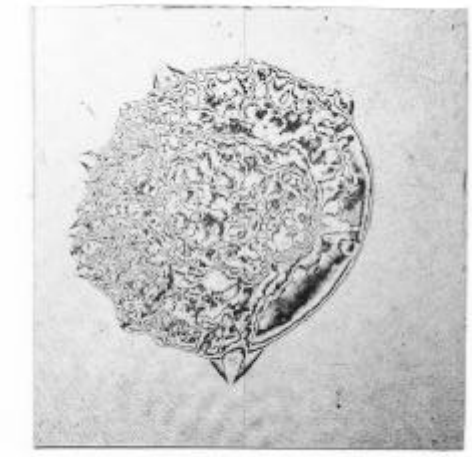
(b) 100kPa H_2/O_2, 10mg explosive



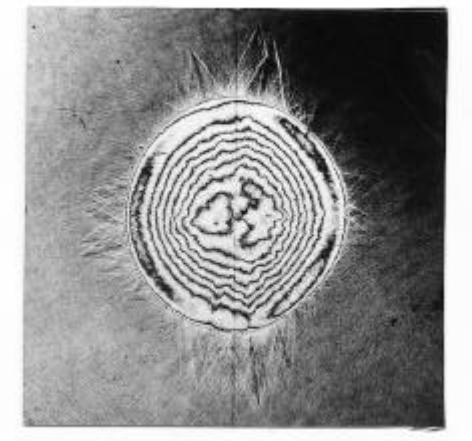
(c) 60kPa H_2/O_2, 10mg explosive



(d) 60kPa H_2/O_2, 10mg explosive with SiO_2 powder



(e) 45kPa H_2/O_2, 10mg explosive with SiO_2 powder



(f) 60kPa H_2/N_2, 10mg explosive with SiO_2 powder

Fig. 3 Interferogram at 30μs from ignition

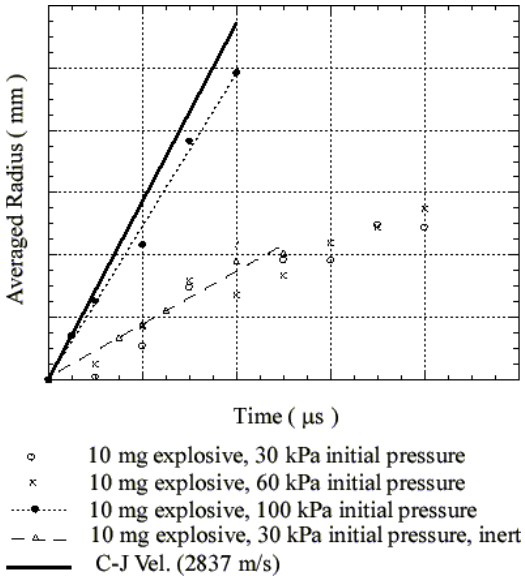


Fig. 4 Relationship between averaged radius of waves and the elapsed time at various initial pressure