Experiments on reflection processes of detonation waves on a wedge

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Abstract

An experimental study on reflection of gaseous detonation waves on a wedge is performed by using a high-speed schlieren photography and soot-track record. Mixtures are stoichiometric oxyhydrogen mixtures diluted by argon at sub-atmospheric pressures. The study is focused on the effects of multi-headed structures on the refection process. It is revealed that a Mach stem detonation is initiated after the incident wave travels a certain distance from the apex of the wedge.

Introduction

Reflection processes of detonation waves on a wedge are visualized by the high-speed schlieren photography as well as by the soot track record for a stoichiometric oxyhydrogen mixture diluted with argon. Many investigators, Gvozdeva et al.[1], Edwards et al.[2], Meltzer et al.[3], Yu at al[4][5], Li, et al.[6], and Zhan et al.[7]had contributed for this problem on the reflection of detonation waves on a wedge. The previous paper, Ohyagi et al.[8], reports on a non-diluted oxyhydrogen mixture, which reveals the overall structure of a Mach reflection and a regular reflection. It was concluded that the reflection process is similar to that of a planar inert shock wave and the effect of cellular structure of the detonation wave is small. In this paper, a focus is concentrated on the effects of the three-dimensional cellular structure on the reflection so that the mixture is diluted with argon because the cells in the diluted mixture with argon are comparably regular and large.

Experimental

Figure 1 shows a schematic diagram of the experimental apparatus. A tube with rectangular cross-section 30x25 mm and length of 3 m is used through which detonation waves propagate. It is divided into a 500-mm driver and a 2500-mm driven section by a Mylar diaphragm. The driver section is filled with a stoichiometric oxyhydrogen mixture at an atmospheric or a super-atmospheric pressure that is ignited by a spark plug. In a window section located at the most downstream position of the tube, a wedge with an apex angle θ_w is installed. The detonation waves interacting with the wedge are visualized by high-speed schlieren photographs by using an image converter camera(IMACON 792, Hadland Photonics), a Xe flash lamp with $200\mu s$ duration and two concave mirrors with 200-mm in diameter and 2000 mm focal length. Another visualization by the soot track record has been made to elucidate traces due to the three dimensional structure of the wave front. The sooted plates are installed on the sidewall as well as on the wedge surface. Pressure transducers (PCB 113A24, Piezotronics) measure pressure variations on a sidewall along the wedge. Mixtures are stoichiometric oxyhydrogen mixtures diluted with argon at subatmospheric pressures and the angle of the wedge is varied from 10 to 40°. Table 1 shows experimental conditions.

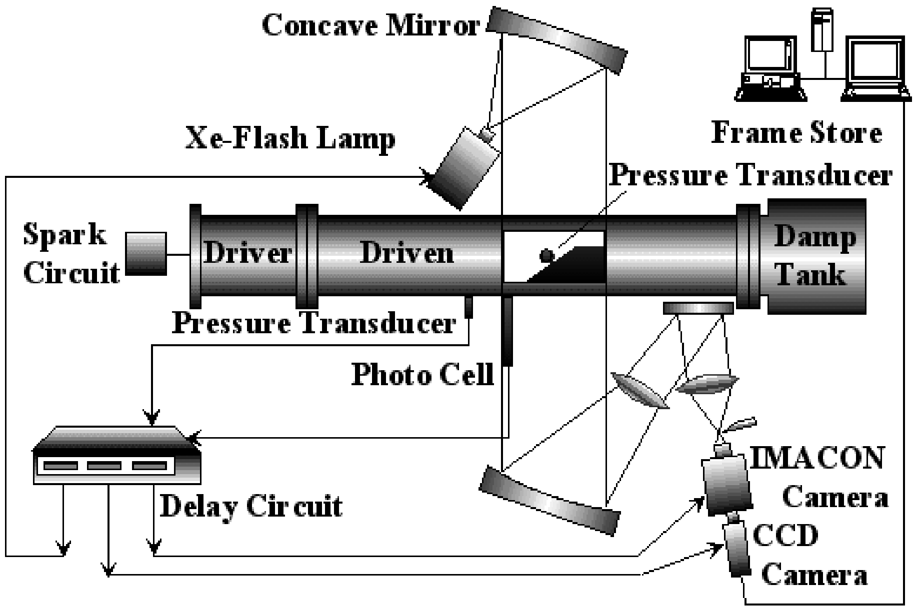


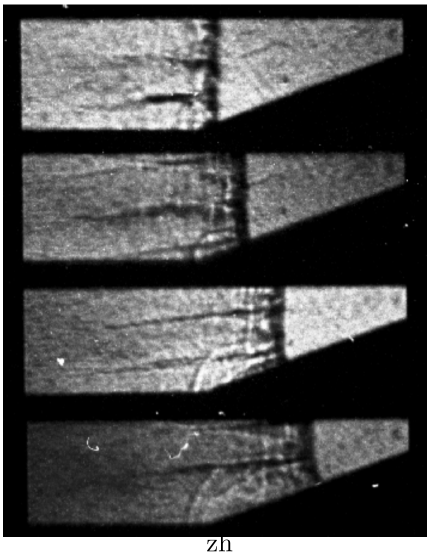
Fig.1 Schematic of the apparatus

Table 1 Experimental conditions

Driver Gas $2H_2+O_2$	101.3kPa ; 152.0kPa
Test Gas $2H_2+O_2+\beta Ar$	$\beta = 2$, 4 , 7 ; 101.3 , 53.3 , 34.7kPa ; 29.3kPa
Wedge Angle θ_W (deg)	10 , 20 , 30 , 35 , 40

Results and discussions

Figures 2(a) and (b) show typical schlieren photographs and soot-track record on the sidewall respectively. The detonation wave travels from left to right and four schlieren snap shots of 1 μs duration and 5 μs interval are shown in Fig.2 (a). A mixture is $2H_2+O_2+7Ar$ at 29.3kPa and an angle of the wedge is 20°. The detonation front is slightly curved on the wedge surface and a thin reflection wave starts from the deflection point of the detonation wave front. This case may be classified in the Mach reflection. However, the reflection wave seems to be very weak as compared with those from the triple points of the detonation wave itself. In the third snap shot, the detonation triple point appears in the Mach stem so that it can be said that the Mach stem detonation wave is established. In the soot track record (Fig.2 (b)), the fish-scale pattern can be clearly generated to show that tow pairs of triple points exist in this tube which is also interpreted from the schlieren pictures (Fig.2 (a)). The white broken line indicates the line below which the cellular structure is distorted by the existence of the wedge. It corresponds to the trajectory of the triple point of the Mach reflection that can be also seen from Fig.2 (a). This trajectory cannot be a simple straight line started from the apex as in the case of inert shock waves but it seems to take some distance for establishing the clear triple point. In Fig.3 (a) and (b), soot track records on the sidewall and the wedge surface are shown respectively (with sketches in Fig.3 (a') and (b')) are shown for the case of β=2 and p_0=29.3kPa. It seems that the Mach stem detonation wave with small cells appears after the incident detonation travels some distance. This distance may be interpreted as an induction distance for the Mach stem detonation wave to be initiated and should be determined by the mixture properties as well as the wedge angle.



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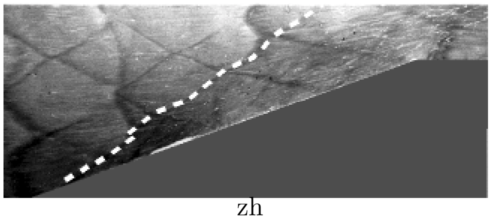
Exposure Duration : 1μs
Interframe Time : 5μs
(a) Schlieren photographs



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(b) soot track records

Fig.2 Typical schlieren photographs (a) and soot-track record on the sidewall (b) for $2H_2+O_2+7Ar$ at 29.3kPa and an angle of the wedge is 20°.

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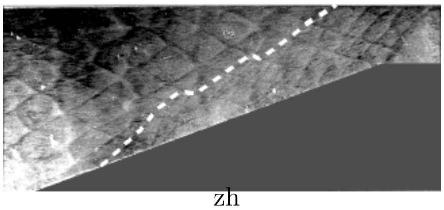

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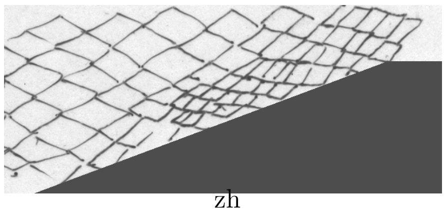
(a) Side wall



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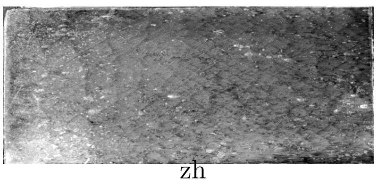
(a') Side wall



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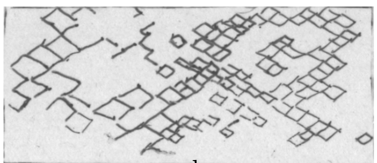
(b) Wedge surface



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(b') Wedge surface

Fig.3 Soot track records on the sidewall (a), (a') and the wedge surface (b), (b') for $2H_2+O_2+2Ar$ at 29.3kPa and an angle of the wedge is 20°.

Figure 4 shows a pressure profile behind the wave front near the wedge for the case of $2H_2+O_2+7Ar$ at 29.3kPa and an angle of the wedge is 20°. A period between two vertical broken lines is a time for visualization. The front pressure peak is overdriven to about $1.28p_{CJ}$. It decays due to the Taylor expansion and again it is increased due to a reflected wave from the top wall. Some oscillations are caused by the transverse waves. Figure 5 shows the peak pressure nondimensionalized by the initial

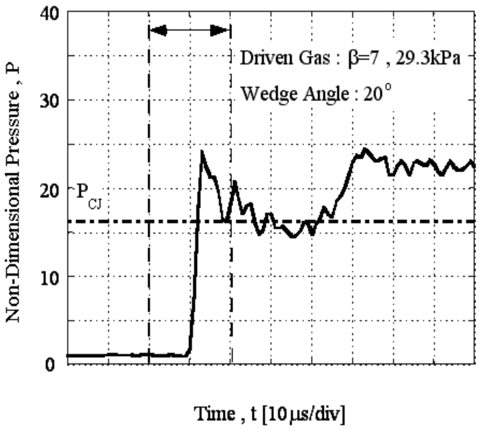

Fig.4 Pressure profile behind the Mach stem for $2H_2$+O_2+7Ar at 29.3kPa and an angle of the wedge is 20.

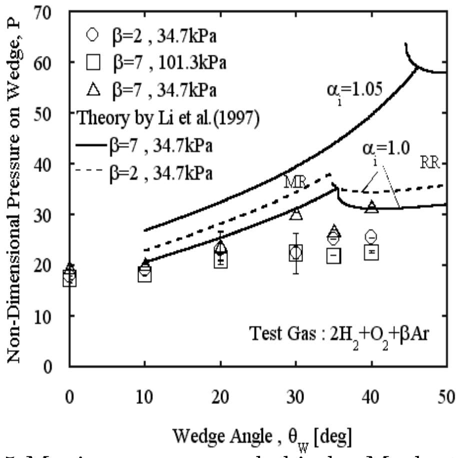

Fig.5 Maximum pressure behind a Mach stem to the wedge angle and comparison with the theory.

pressure versus the wedge angle. It increases gradually with the angle up to 30°and decreases a little as the angle increases to 35° and 40°. It may correspond to the transition from the Mach reflection to the regular reflection predicted by the three shock theory (Li et al., [6]) which neglects the three dimensional structure of the detonation wave. α_i denote the degree of overdriven. The theory also does not consider the Taylor expansion so it predicts a little higher pressure. For conditions with larger cells (large dilution or lower pressure), the peak pressure increases a little.

Conclusions

The experimental study on the reflection process of the multi-headed detonation wave on a wedge has been made. The following conclusions are derived:

(1) The triple point trajectory due to the Mach reflection is not straight in the initial stage of reflection. There is an induction distance to establish the Mach stem detonation.

(2) The pressure behind the detonation front exceeds the CJ value in the Mach stem and it increases with the angle of the wedge until the transition to the regular reflection as is predicted by the planar three-shock theory.

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