Re-initiation Process of Diffracted Detonation Wave behind Slit-plate

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1 Introduction

A detonation wave is a combustion wave propagated with a shock wave in combustible premixed gases. The pressure and temperature of the detonation front is extremely high that may cause serious damages around the wave. Therefore, it is necessary from the safety-engineering point of view to investigate these phenomena and to minimize the damages [1, 2]. However, the quenching and re-initiation processes of the detonation wave has not been understood. The objective of this study is to investigate the quenching and re-initiation behavior of the detonation wave by using the flow visualization technique.

In this study, a high-speed schlieren movie is taken to investigate the behaviors of the detonation wave diffracted from a slit-plate, which is inserted in the detonation tube. A soot-track record is also obtained to measure the re-initiation distance of the detonation wave. The test gas is a stoichiometric mixture of hydrogen and oxygen and the initial pressure of the test gas is varied.

As a result, the detonation wave diffracted from the slit decays and the shock wave is decoupled with a reaction front. By changing the width of the slit and an initial pressure of the test gas, the behaviors of the detonation wave below the slit are classified into five phenomena.

2 Experimental

Figure 1 shows schematic diagram of experimental setup and a vertical detonation tube is used. The detonation tube has a cross-section of 50 × 50 mm and consists of a driver tube (1000 mm), a driven tube (2000 mm), an observation section (700 mm), and a dump tank (400 mm). The slit-plates of five types have been inserted in the detonation tube to investigate the diffraction and the re-initiation phenomena of the detonation wave.

Figure 2 illustrates the configuration of the slit-plate and it is called from type A to type E. The slit-plate of type A is constituted from two plates and attached to the tube-wall of opposite side, respectively. The type from B to E is containing only one slit and equipped with one or two ditch. Several pressure transducers and ionization probes were oppositely mounted in the driven tube with 100 mm intervals in order to record pressure histories of the shocks and detect ionized gas accompanied with the detonation wave respectively. The propagation velocity of the detonation wave before the slit-plate is confirmed to be within 5% of the C-J velocity. A schlieren optics is a Z-configuration with a YAG laser as a light source and a high-speed video camera (developed by NHK Science & Technology Research Laboratories).

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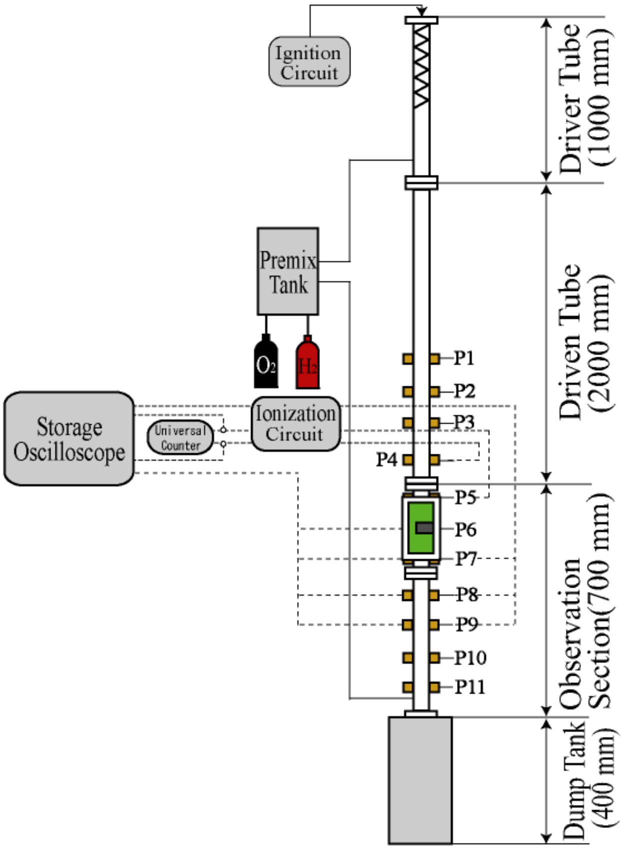

Figure 1. Schematic diagram of experimental setup.

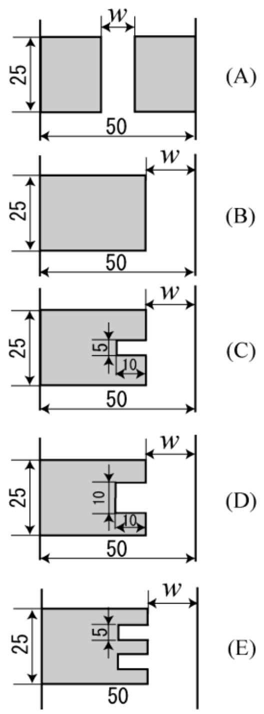

Figure 2. Configuration of the slit-plate.

3 Results and Discussion

Figure 3 shows a typical high-speed schlieren photograph obtained for an initial pressure of p_0 = 50 kPa, slit width of w = 15 mm of type A. The time indicated in the figure shows the elapsed time from the detonation diffraction. This photograph is taken with the frame interval is 0.5 μs and an exposure time of 125 ns. The first frame (62 μs) shows that the incident shock wave is decoupled from the reaction front, when the detonation wave is diffracted from the slit, expansion waves are generated at the corner of the slit and are overtaken the detonation front to decrease the pressure and the temperature of the detonation front. The diffracted shock wave is eventually reflected from the tube-wall. The post-shock region may reveal a high-temperature and high-pressure value to cause a local explosion. The reflected shock wave propagates with time and interacts with the incident shock wave that may also force the temperature and pressure to the higher value (from 73 μs to 80 μs). In the next frame (82 μs), the reaction front propagates to the post-shock regions and generates local explosions that results in the re-initiation of the detonation wave (87 μs and 96 μs).

Figure 4 shows a pressure histories corresponding to Fig. 3. The vertical axis indicates the non-dimensional pressure normalized by the initial pressure p/p_0, and the horizontal axis indicates the elapsed time t from the detonation wave diffraction from the slit-plate. The position of P4, slit-plate, P6, P7, P8 are corresponding to the pressure measuring position indicated in Fig. 1. The rise time of the pressure and ionization current are simultaneously recorded at the positions of P6, this suggests that the detonation wave has been already re-initiated at position P6, and this behavior can be also confirmed in Fig. 3.

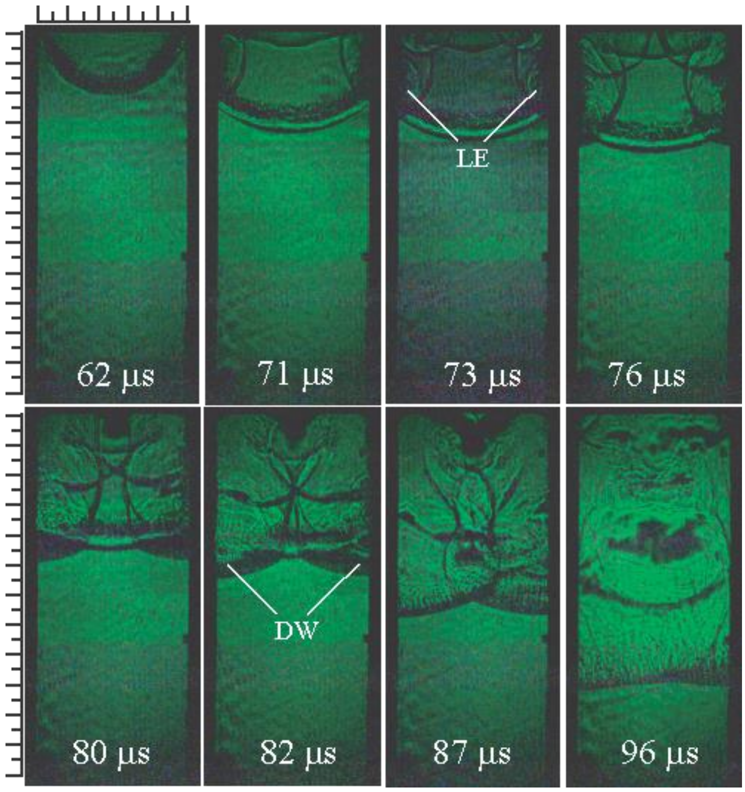

Figure 3. Schlieren photographs ($2H_2$+ O_2, p_0 = 50 kPa, Type A, w = 15 mm).

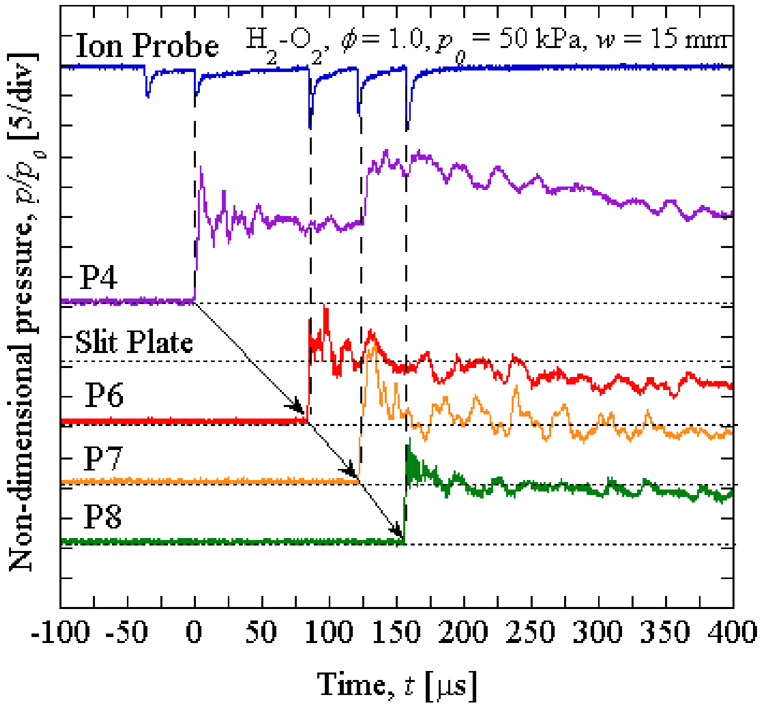

Figure 4. Pressure histories ($2H_2$+ O_2, p_0 = 50 kPa, Type A, w = 15 mm).

To obtain the re-initiation distance of the detonation wave, soot-track records are obtained by changing the slit-plate. Figure 5 shows the soot-track record obtained under the same conditions of the test gas by changing the slit-plate from type B to type E. Since the incident shock wave was decoupled from the reaction front, the detonation wave was quenched temporarily, and a cellular structure is not shown just belows the slit-plate. However, the detonation wave is re-initiated below the slit-plate by the following mechanisms:

i) The detonation wave is re-initiated before the diffracted shock reaches the side wall. (detonation propagation: DP).

ii) The detonation wave is once quenching below the slit-plate, but the detonation wave is re-initiated when the diffracted shock wave is reflected from the tube-wall (re-initiation by the first shock-wall interaction: SWI).

iii) The detonation wave is re-initiated by the interaction of the shock waves (re-initiation by the interaction of shock-shock: SSI).

iv) The detonation wave is re-initiated by the several reflection of the shock wave from the tube-wall (re-initiation by the several interaction of shock-wall: SWI2).

v) The detonation wave is quenched below the slit-plate (detonation quenching: Quenching).

For the slit-plate of type B, C, D, the detonation wave is re-initiated before the shock wave reaches the side wall. Because the transverse detonation wave propagates along the decoupled shock region to cause mutual interaction between transverse wave and diffracted shock wave [3]. This figure also shows that the re-initiation distance becomes longer by increasing the number of the ditch on the slit-palte.

Figure 6 shows the relationship between the re-initiation distance of the detonation wave from the slit D_{ri} and the width of the slit w by changing the slit type and initial pressure of the test gas. The vertical axis indicates the non-dimensional re-initiation distance normalized by the width of the detonation tube D_{ri}/L, and the horizontal axis shows w/λ, where λ indicates the cell-width of the C-J detonation wave. In this figure, the re-initiation distance using the slit-plate of type E is longer than other slit-plate, and the detonation wave is re-initiated by the mechanism of type (ii).

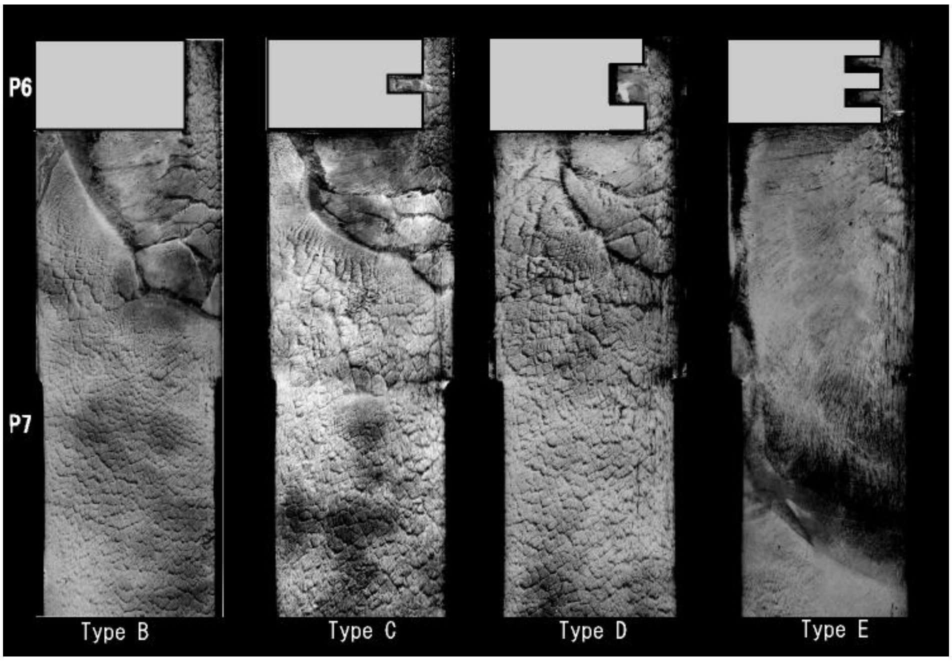

Figure 5. Soot-track record for Type B, C, D and E ($2H_2$+ O_2, p_0 = 60 kPa, w = 8 mm).

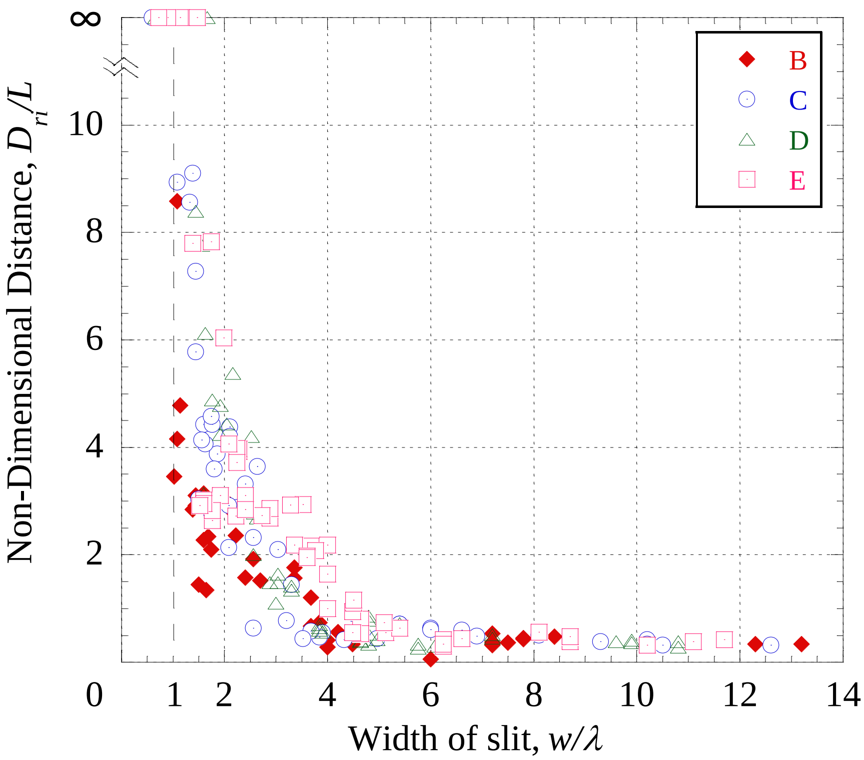

Figure 6. Relationship between non-dimensional re-initiation distance *Dri*/*L* and non-dimensional slit width w/λ.

For the slit-plate of type B, the detonation wave is quenched for the experimental condition of w/λ< 1.0, it is important that the width of the slit should be smaller than the cell-width of the CJ detonation wave in order to quench the detonation wave. This means that the separation of the shock wave with the reaction front inside the slit-plate may result in the detonation quenching. Furthermore, the type of DP occurs under the condition of $w/\lambda \geq 3.7$, while the type of Quenching under the condition of $w/\lambda < 1.0$. The type of SWI2 is observed under the condition of $1.0 \leq w/\lambda < 1.6$. There, the detonation is re-initiated when the local explosion occurred by the shock wave interacted with the tube-wall more than two times. The detonation is re-initiated with SWI under the condition of $1.6 \leq w/\lambda < 3.7$. The detonation wave is re-initiated when the shock reflected from the tube-wall with the first local explosion. Between the types of SWI and SWI2, there has the type of SSI. The detonation wave is re-initiated when the shocks interacted on the central axis, namely, the second local explosion cause the re-initiation of the detonation wave.

References

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[3] Nagura Y et al. (2012). Comprehensive visualization of detonation-diffraction structures and sizes in unstable and stable mixtures. Proc. Combust. Inst. (http://dx.doi.org/10.1016/j.proci.2012.07.078).