Detonation Propagation in Hydrogen-Oxygen Mixtures with Concentration Gradients

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1. Introduction

Propagation mechanism of detonation waves in layered mixtures, which correspond to mixtures with step-like concentrations, are investigated experimentally(1) and numerically(2). The present work focuses on detonation initiation and propagation in mixtures with concentrations changing continuously in the direction normal to propagation direction.

2. Experimental apparatus

The detonation tube used in the experiment is shown in Fig. 1. It has a rectangular cross-section of 40 mm $\times$ 20 mm and its total length is 500 mm. The dilution gas chamber is attached to the detonation tube and is separated from it by a partition plate of 5 mm in thickness. This plate can be slid so that oxygen in the dilution gas chamber is diffused into the detonation tube in which a stoichiometric hydrogen-oxygen mixture was initially charged.

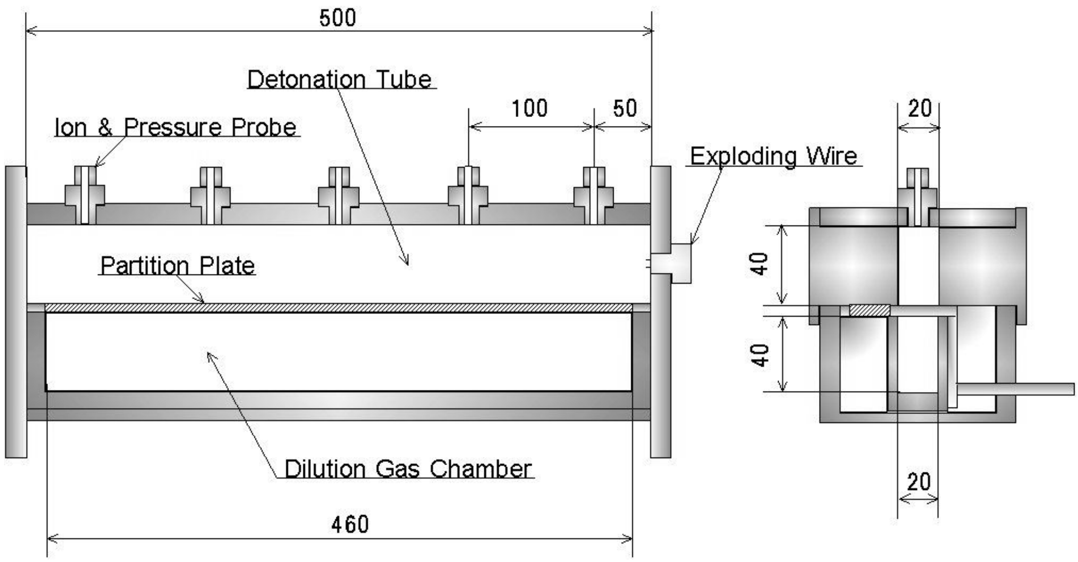

Fig. 1. Schematic of the detonation tube for formation of mixtures with concentration gradients.

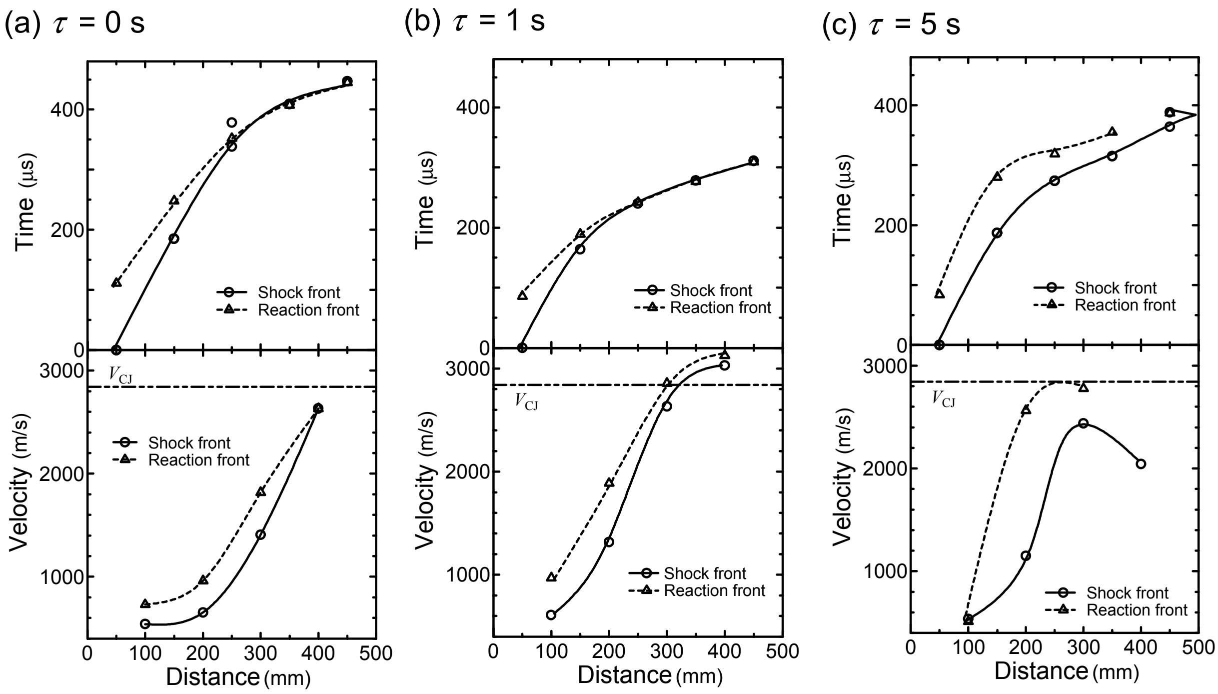

Fig.2. *x-t* diagrams and velocity profiles for various opening duration of the gas dilution chamber, τ.

Changing the opening duration of the plate forms mixtures with various concentration gradients in the detonation tube.

To detect a shock and a reaction front individually at one measuring point, the combination probe(3) which consists of a pressure and an ion probe is placed at each 100 mm in the upper wall of the detonation tube. A smoked aluminum foil of 0.1 mm in thickness is also fixed to the side wall to record variation of cellular structure. Ignition of the mixture is made with an exploding wire. An initial pressure is 0.1 MPa both in the detonation tube and the dilution gas chamber.

3. Results

Figure 2 shows effects of the opening duration of the gas dilution chamber, τ, on the velocity profiles of shock and reaction fronts, where τ of 0 s denotes the condition that sliding of the plate was not done. In Fig. 2 (a) and (b), there can be seen acceleration of shock and reaction fronts and subsequent formation of detonation waves. In the present work, an energy of 4.7 J supplied to the exploding wire was not enough for direct initiation of detonation. In the case τ of 5 s, no detonation initiation was observed.

Smoked foil records corresponding to Fig. 2 are shown in Fig. 3. In Fig. 3 (a) and (b), very fine cells appear at about 270 mm and 250 mm from the end wall, respectively. This indicates that detonation initiation for τ of 1 s occurs at almost the same location as with no

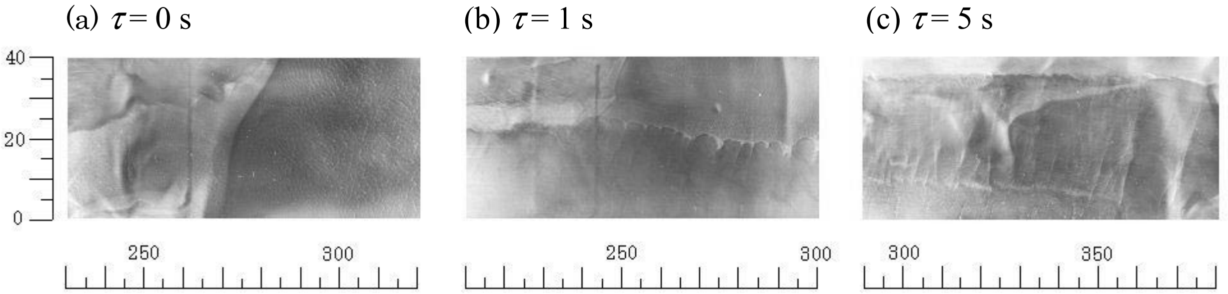

Fig.3. Smoked foil records for various opening duration of the gas dilution chamber, τ.

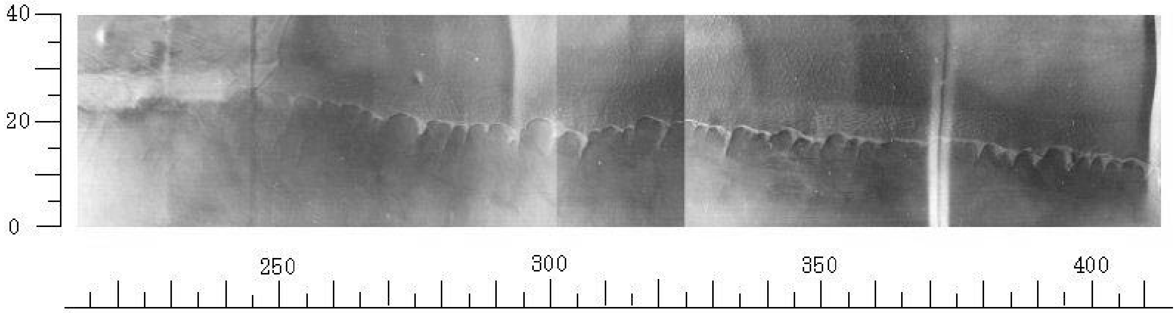

Fig.4. Smoked foil record of detonation propagation in a mixture with a concentration gradient for τ of 1 s.

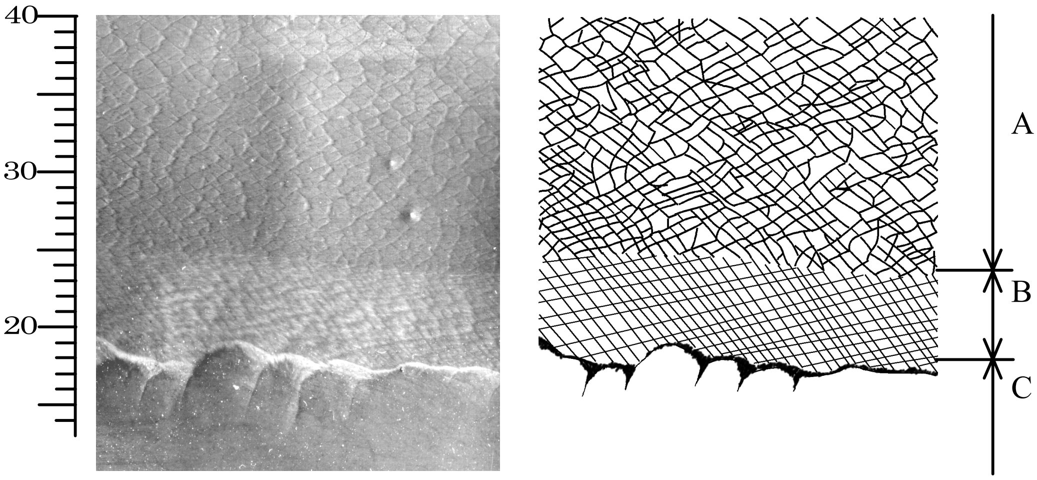

Fig.5. Smoked foil record and corresponding sketch showing the cellular and the diamond-shaped pattern for τ of 1 s.

concentration gradient. Since diffused oxygen does not reach the upper wall of the detonation tube in 1 s, the detonation initiation is governed by properties of the most detonable mixture. For τ of 5 s, no cell structure can be seen on the smoked foil record.

Figure 4 shows cellular structure after the detonation initiation for τ of 1 s. From the fact that no cellular structure is observed in the lower part of the smoked foil (region C), the scratch-line is related to the boundary of detonation propagation. The cell size near the upper wall is about 1.2 mm and this size corresponds to an equivalence ratio of unity. As shown in Fig. 5, the diamond-shaped pattern with width of about 5 mm (region B) is observed between the scratch-line and the cellular pattern in the upper part. The size of this pattern is about 0.5 mm and is too small for a cell size of steady detonation waves, because at an initial pressure of 0.1 MPa the minimum cell size of hydrogen-oxygen mixtures is about 1.0 mm for an equivalence ratio of 0.7(4). In addition the diamond-shaped pattern is much regularly traced on the smoked foil in comparison with the cellular pattern shown in the upper part. Consequently they do not indicate detonation propagation and are formed by triple points originating from the cellular structure (region A). Then these triple points reflect at some density boundary surface and cause the diamond-shaped pattern. From these results it is deduced that the boundary between the region A and B shows a detonation propagation limit owing to the concentration gradient.

4. Conclusion

A study is made on detonation waves propagating in mixtures with concentration gradients in the direction normal to the propagation direction. From observation of the smoked foil record, the boundary between the cellular and the diamond-shaped pattern, which is formed by triple points originating from the cellular structure, shows the propagation limit owing to the concentration.

References

(1) Tonello, N. A., Sichel, M. and Kauffman, C. W., Mechanism of detonation transmission in layered H_2-O_2 mixtures, Shock Waves **5**: 225-238 (1995).

(2) Oran, E. S., Jones, D. A. and Sichel, M., Numerical simulations of detonation transmission, Proc. R. Soc. Lond. A **436**: 267-297 (1992).

(3) Ishii, K. and Grönig, H., Behavior of detonation waves at low pressures, Shock Waves **8**: 55-61 (1998).

(4) Ooyagi, S., Ochiai, T., Yoshihashi, T. and Harigaya, Y., Relation between cell size, induction zone length and critical initiation energy in oxyhydrogen detonations, Trans. Jpn. Soc. Mech. Eng. **54**: 3559-3564 (1988).