Experimental investigation on flame propagation characteristics in Kelvin-type ordered porous media

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1. Introduction

Porous media combustion (PMC) has the characteristics of higher flame speeds, extended flammability limits, lower pollutants emissions, and enhanced heat exchange[1]. Foamed porous ceramics manufactured by traditional methods have nonuniform pore size and closed cells, which has an adverse effect on combustion performance. Pore-scale simulation shows that the nonuniform size and distribution of pores cause the inhomogeneity of the local reaction zone, flow field, and temperature distributions[2]. Chen et al.[3] found that the inhomogeneous preheating temperature distribution would cause the inclination of flame front in the packed bed. In recent years, the additive manufacturing technology of ceramic materials has developed rapidly, which can realize the forward design of porous structures and improve the uniformity of porous ceramics. However, the accurate flame dynamics in porous media have not been revealed, which are critical for understanding the flame stabilization mechanism. In this work, the flame propagation characteristics in the ordered porous media are investigated and the temperature of the solid matrix is measured by shortwave infrared thermometry (SWIR). The Kelvin-type structure is chosen in order to use a similar structure to the foamed material and facilitate experimental measurements.

2. Experiment setup

The porous media temperature in a meso-scale burner is measured by a commercial SWIR thermography (Optris, PI 1M) during the flame propagation process. The device measures the temperature of the object based on infrared radiation, and the response spectral is in the 0.85-1.10 μm band. By comparing with the results measured by thermocouples, it was determined that the relative error of SWIR thermography caused by quartz glass with a thickness of 1-4mm was less than 3%. A 3D-printed porous media with regular tetradecahedron cells is used, as shown in Fig. 1. The material of the porous media is nickel-based superalloy (GH3625), and the total length is 52.0 mm. The porosity of porous media is 0.759, and the length and diameter of the strut are 3.0 mm and 1.8 mm, respectively. The cross-section of the burner is square, with an inner side length of 18.0 mm and a wall thickness of 2.0 mm. The wall is made of quartz glass to facilitate the observation of flame and measurement of porous media temperature. Air and methane enter the burner after being fully premixed. The origin of the coordinates and the positive

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direction are shown in Fig. 1. The photographs of flame are taken by a digital camera, and seven K-type sheathed thermocouples are used to monitor the temperature of porous media.

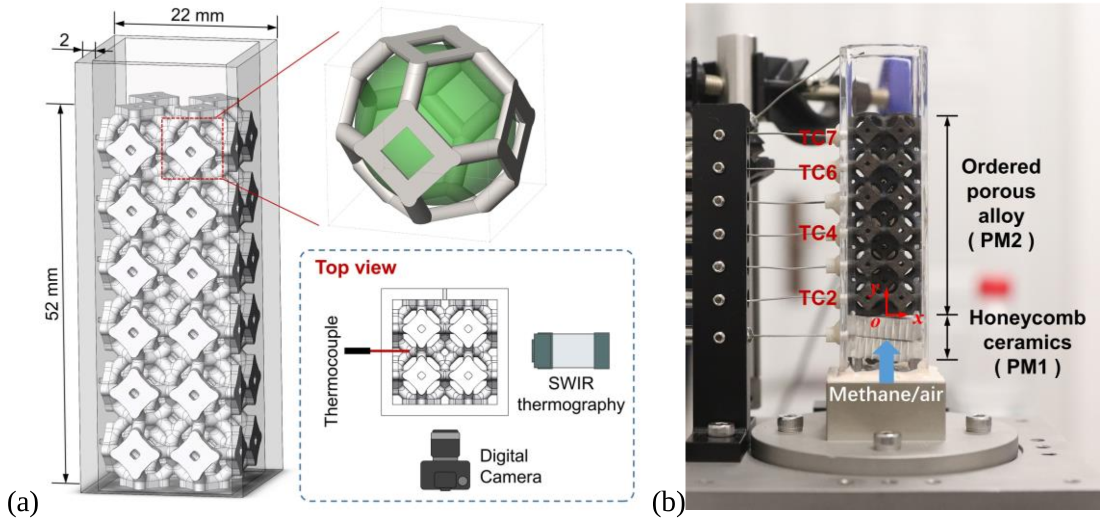

Fig. 1 (a) Schematic of the experimental system, (b) Photograph of the meso-scale porous burner.

3. Results and discussion

As shown in Fig. 2, four flame propagation modes are found under different inlet conditions, which are static flame at exit, static flame in PM, slow flame, and fast flame, respectively. Both the equivalent ratio and the flow rate can affect the flame propagation mode. When the flow rate remains at 40 cm/s and the equivalent ratio increases from 0.7 to 0.8, the flame mode changed from the static flame at exit to the fast flame, as shown in Fig. 2(b).

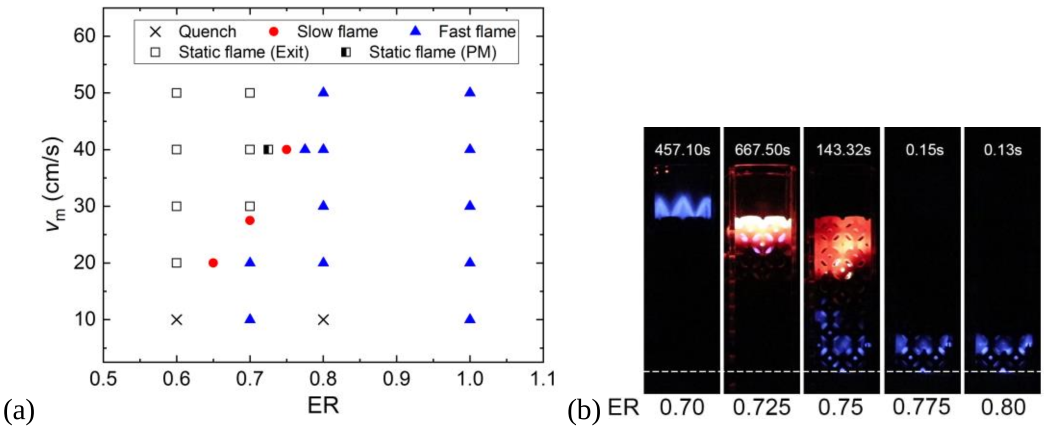

Fig. 2 (a) Flame propagation modes under different inlet conditions, (b) Flame photographs at v_m = 40 cm/s.

Temporal temperature curves of TC7 at v_m = 40 cm/s are shown in Fig. 3(a). In fast flame mode, the flame speed is 38.3 to 102 cm/s and the PM temperature is lower than 90 ºC, which indicates the heat exchange between the flame and the porous media is very weak. While in slow flame mode, flame propagation is pulsed in the porous media, as shown in Fig. 3(b), similar to the mode observed in the nickel foam[4].

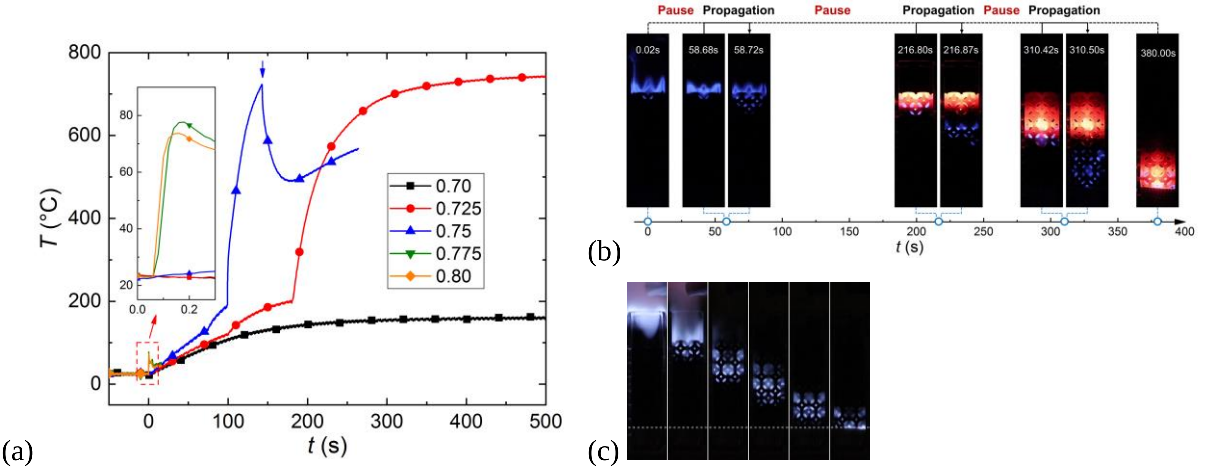

Fig. 3 (a) Temporal temperature curves of TC7 at v_m = 40 cm/s. (b) Propagation process of slow flame at ER = 0.70 and v_m = 27.5 cm/s. (c) Propagation process of fast flame at ER = 1.00 and v_m = 30.0 cm/s.

Then the relationship between the flame propagation and the high-temperature zone is analyzed at slow flame mode. An averaged temperature distribution is obtained by averaging the values of 51 pixels near the central axis, as shown in Fig. 4(a). Then the temperature distributions within 100-380 s are summarized in Fig. 4 (b) to analyze the evolution process of the high-temperature zone. The positions of the flame front and the maximum temperature are also plotted. The area of the high-temperature zone gradually expands when the flame temporarily stops moving. During this process, the maximum temperature value rises slowly to 834 °C, and the relative position of the maximum temperature is almost constant, about 10 mm downstream of the flame front.

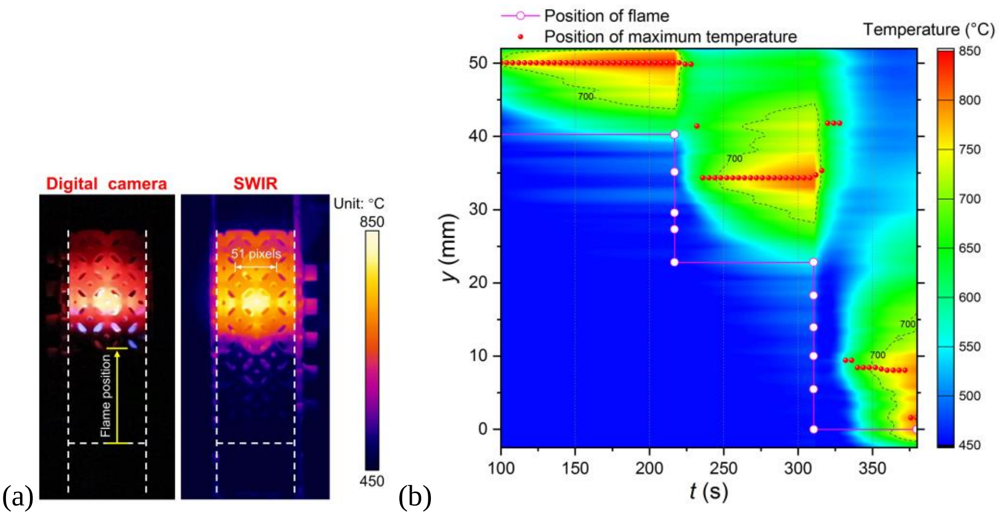

Fig. 4 (a) Slow flame position and temperature distribution at t = 300s; (b) Temporal evolution of the flame position and the temperature distribution.

4. Conclusions

In this study, four flame propagation modes are found in the Kelvin-type ordered porous media. Both the equivalent ratio and the flow rate can affect the flame propagation mode. In slow flame mode, the flame is pulsatingly propagated in the porous media. The area of the high-temperature zone gradually expands when the flame temporarily stops moving. The distance between the positions of maximum temperature and flame front is almost constant at the same condition.

References

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