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Short communication

Attenuation and recovery of detonation wave after passing through acoustically absorbing section in hydrogen-air mixture at atmospheric pressure

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ABSTRACT

The deceleration and attenuation of a detonation wave in a hydrogen-air mixture were experimentally studied in a cylindrical channel. The inner walls of an extended section of the channel were covered with an acoustically absorbing layer. Experiments were carried out in an undiluted by inert gases mixture at atmospheric pressure and 295 K temperature. Ignition of the hydrogen-air mixture was carried out by a spark gap at a closed end of the detonation tube, and the second end of the tube was opened. A strong detonation wave was formed before entering the section with the acoustically absorbing layer on the walls. The dependence of velocity and pressure at the front of the detonation/shock wave on the thickness of the acoustically absorbing material and mixture composition (equivalence ratio) was presented. The results demonstrate that increasing the thickness of the porous material on the walls lead to further attenuation of the detonation wave to the point where it is not re-initiated at the distance of 15 calibers from the porous section. It was found that the recovery of the detonation wave after the passage of the acoustically absorbing section can happen if the shock wave velocity does not drop below Chapman-Jouguet acoustic velocity.

1. Introduction

Ensuring hydrogen safety at industrial sites is one of the most important goals in the field of hydrogen energy. When analysing the explosion, all the features of hydrogen combustion in closed volumes should be taken into account. The most relevant method of preventing or attenuating a detonation is with chemically active inhibitors (Azatyan et al., 2010) or special elements that can weaken the intensity of the shock or detonation wave like inert particles (Fomin and Chen, 2009; Fedorov and Kratova, 2015) or channel obstacles (Medvedev et al., 2009). Since the detonation wave has a cellular structure, one of the ways to prevent the detonation could be the use of particular forms of coating to diminish the intensity of transverse perturbations. The porous wall effect on detonation was considered by Evans et al. (1955) for the first time. Due to the porous material covering the walls, the DDT distance was doubled. Noticeably later, the effect of the walls on the already formed detonation wave was investigated with the help of high-speed photography, and it showed that the decomposition of the detonation was due to the suppression of the transverse waves in the front of the detonation wave (Dupre et al., 1988). This fact was confirmed in paper of Teodorczyk, and Lee (1995) by analysing the Schlieren images. The effect of porous coatings on the walls was increased in tubes that are of a critical diameter of the stationary detonation propagation (Vasil'ev, 1994). Subsequently, various devices to suppress the detonation were compared by Guo et al. (2002), and it was found that the metal wool is much more effective at suppressing a detonation wave than the perforated plates. However, in work of Radulescu, and Lee (2002), the authors suggested that the weakening of the detonation, due to the disappearance of the transverse wave, occurs only for a detonation mixture with an irregular structure. The detonation weakening in mixtures with a regular cellular structure occurs for other reasons, mostly due to the mass divergence in the porous section. This question was studied in more detail by Mehrjoo et al. (2015), where the authors examined the detonation transition from the tube into the open space. Detonation re-initiation is possible after passing the porous channel (Radulescu and Maxwell, 2011).

In published comparisons of different structures used for detonation suppressing, the diluted by inert gases mixtures of hydrogen

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Nomenclature

ER	equivalence ratio, coefficient of molar excess of hydrogen
DDT	deflagration to detonation transition

or hydrocarbons with oxygen at low pressure were typically used. It does not quite meet the conditions for the possible applications of such structures to prevent or at least mitigate the detonation in hydrogen. Also, the effect of the thickness of the absorbing material at a constant inner diameter of the channel has not been studied.

The goal of this work was to determine the parameters of the hydrogen-air detonation in channels with acoustically-absorbing coatings with open pores. The parameters were determined depending on the hydrogen concentration and the thickness of the absorbing layer. Also, the goal of the investigation was to determine the conditions for recovery of the detonation after the passage of the absorbing section.

2. Experimental setup

Experiments were carried out in a steel tube of circular cross-sections. Fig. 1 shows the scheme of the setup. The inner pipe diameter was 20 mm and the length was 2.9 m. The hydrogen-air mixture was fed to the closed end of the detonation tube. The spark gap was also located at the closed end of the detonation tube, and the second end of the detonation tube was opened. Therefore, the transition from deflagration to detonation took place in the detonation tube.

At a distance of 2000 mm from the closed end of the detonation tube, a steel section with an inner acoustically-absorbing layer on the walls was placed. The absorbing section length was 500 mm. A set of the steel sections with different inner diameters (20, 26, 30, 40 mm) was used. The entire inner surface of the section was covered with acoustically absorbing material. Foam polyurethane with 40 pores per inch and density of 30 kg/m^3 was used as an absorbing material. The coating thickness was selected so that the inner diameter of the channel was 20 mm (no foam, 3 mm, 5 mm and 10 mm, respectively).

To determine the attenuation of the detonation wave, two pairs of pressure sensors by PCB (111A, 113B) were used, installed before and after the acoustically absorbing section. The ranges of the sensors were 20 MPa and 7 MPa, respectively. The rise time for both sensors was less than 1 μs. The location of the pressure sensors is shown in Fig. 1. For registration of the flame front, photodiodes FD-256 were installed, together with pressure sensors. The rise time for the photodiodes was less than 1 μs and the spectrum range was 400–1100 nm. The velocity was measured between two sensors.

The hydrogen-air mixture was held in a vessel of 3 L volume at a maximum pressure of 0.5 MPa. Before each experiment, the detonation tube was filled with three tube volumes of a hydrogen-air mixture at atmospheric pressure and 295 K temperature. Immediately after filling the detonation tube, the mixture was ignited to form the detonation. The energy released in the spark did not exceed 0.1 J, which is significantly less than the energy of the direct initiation of detonation (Guirao et al., 1982).

3. Experimental results and discussion

Experiments were carried out for lean (ER = 0.8), stoichiometric (ER = 1) and rich (ER = 1.5) hydrogen-air mixtures for three thicknesses of the absorbing material: 3 mm, 5 mm and 10 mm. In all three cases, at the entrance of the absorbing section, the sensors detected the strong detonation wave. The velocity of the wave was 2000–2200 m/s, the von Neumann peak pressure was 2.5–4 MPa (*solid line*) and the Chapman-Jouguet pressure was approximately 1.5–2 MPa. The flame front was registered simultaneously with the shock wave (*dashed line*). After passing through the absorbing section, the parameters of the waves were decreased. For all mixtures, the level of attenuation of velocity and pressure corresponded with the absorbing layer thickness. Fig. 2 shows the waveforms of pressure sensors and photodiodes installed before the section with acoustically absorbing material and after the section for ER = 1.

In case of the stoichiometric mixture, the detonation decay happened only using the absorbing layer of 10 mm thickness. When the thickness of the absorbing material was 3 mm, the shock wave intensity was about 0.9 of Chapman-Jouguet pressure, as Fig. 2a shows. The velocity of the shock wave was 2000 m/s. The flame front was detected simultaneously with the shock front.

When the thickness of the absorbing material was 5 mm, the shock wave intensity was about 0.5 of Chapman-Jouguet pressure, as Fig. 2b shows. The velocity of the shock wave was 1450 m/s. At a distance of 100 mm from the absorbing section, the photodiode registered a 50 μs delay between the shock wave and flame front. However, at the last position of the pressure sensor and photodiode (at a distance of 300 mm from the absorbing section), the delay was reduced to 10 μs. Moreover, the intensity of the shock wave was increased up to 0.8 of the Chapman-Jouguet pressure. It can lead to

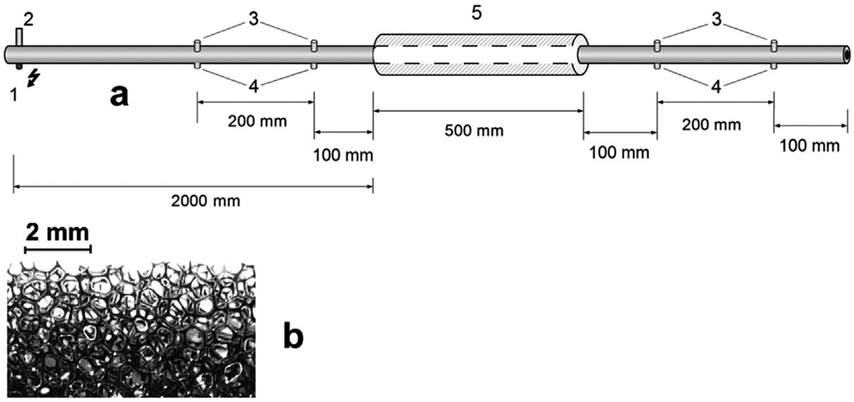

Fig. 1. Scheme of the experimental setup (a): spark gap (1), supply of the combustible mixture (2), pressure sensors (3) and photodiodes (4), cylindrical section with acoustically absorbing layer (5). Photo of acoustically absorbing material (b).