Influence of channel aspect ratio on the failure of detonation in a two-dimensional porous-walled channel

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In general, all detonations waves are cellular. However, it was found that mixtures with significant argon dilution are characterized by very regular cellular structures, while undiluted mixtures in general display an intricate structure of interacting transverse waves, forming an irregular cellular structure. There is now a growing amount of evidence that the irregular structure mixtures rely on transverse waves interactions for their propagation, while the regular mixtures are more stable, approach the ZND model, and rely mainly on leading shock compression for their ignition (Moen et al. 1986, Radulescu & Lee, 2002, Radulescu et al., 2002, Lee, 1996). The scope of the present study is to formulate a distinct criterion that could unambiguously discriminate between the two postulated modes of propagation.

The experiments are conducted in rectangular cross-section porous walled channels. Two walls of the channel are porous (stacks of wire screen), separated by a distance d. The other two walls are solid and transparent, separated by a distance w. A schematic is shown in figure 1. In the experiments, a fully developed detonation enters the porous walled section of the channel, where it is either attenuated or fails to low velocities (Radulescu & Lee, 2002). The reaction zone structure and the attenuation process is monitored by schlieren and open shutter photography through the transparent walls, or by smoke foils mounted on the solid walls.

Three mixtures were investigated displaying a wide range of cellular regularity, namely $C_2H_2 + 2.5O_2 +$ 75%Ar, $C_2H_2 + 2.5O_2$ and $C_3H_8 + 5O_2$. The argon-diluted mixture offers the best cellular regularity. Undiluted oxy-acetylene detonations display irregular cellular structures, while the oxy-propane mixtures display highly irregular cells with a significant amount of substructure. The mixture reactivity is monitored through the initial pressure. The critical initial pressure separating detonation failure and successful propagation through the porous walled section was determined for these three mixtures. The cross-sectional aspect ratio of the channels (w / d) was varied over approximately two orders of magnitude. The critical failure limit is expressed as $(d / \lambda)^*$, where λ^* is the characteristic transverse wave spacing, or cell size, corresponding to the critical mixture initial pressure.

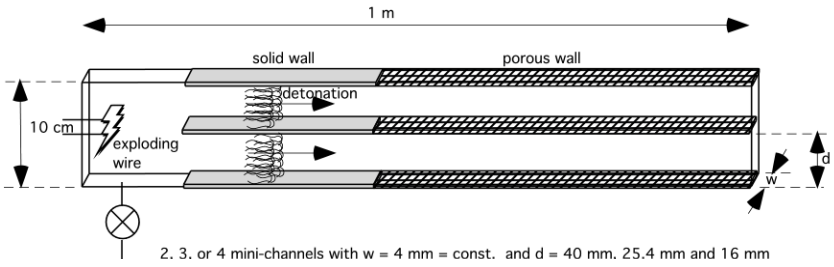

Figure 1 Schematic of experimental set-up

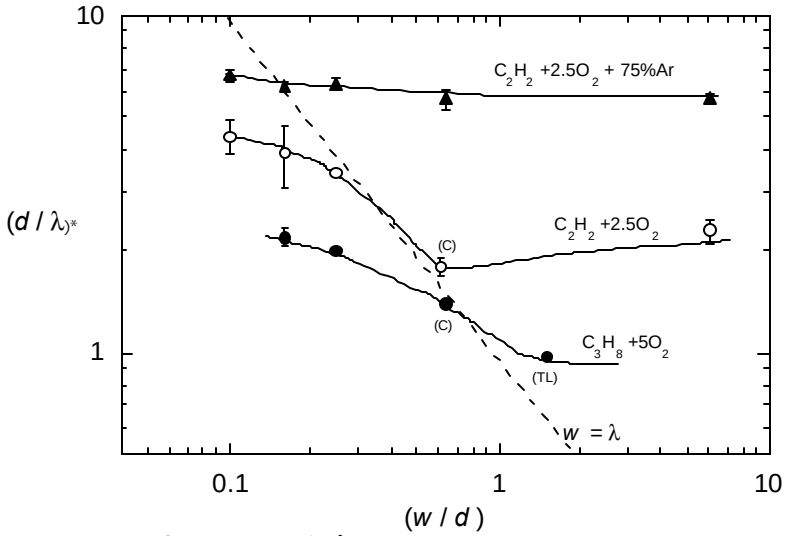

Figure 2 The failure limit $(d / \lambda)^*$ in the three mixtures investigated, as a function of the channel's cross-sectional aspect ratio (w / d)

The failure limits $(d / \lambda)^*$ for these three mixtures are shown graphically in terms of the channel's cross-sectional aspect ratio (w / d) in figure 2. Above this limit (larger values of (d / λ)), detonations propagate successfully throughout the porous wall section. Below this limit, detonations are damped by the porous walls. For the argon diluted mixture, the limit is approximately invariant with channel aspect ratio, yielding $(d / \lambda)^* \sim 6$.

For undiluted oxy-acetylene mixtures, the limit displays a distinctive transition at approximately $w \sim \lambda$. For wide channels, the limit is lower by a factor of two than in the thin channels, suggesting that it is twice more difficult to damp the detonations waves in wide channels. The same trend is observed for the oxy-propane mixture. It is also quite instructive to note that the limits are progressively smaller in the three mixtures investigated, as the detonation regularity is lost. This supports the previous observations that irregular detonations are more robust than regular ones.

These observations were clarified by close inspection of the flow fields observed for each experimental condition. In the oxy-acetylene mixture diluted with argon, the open shutter pictures revealed that for thin channels $(w < \lambda)$, the cellular propagation mode is planar (two-dimensional), with weak transverse waves. For wide channels,

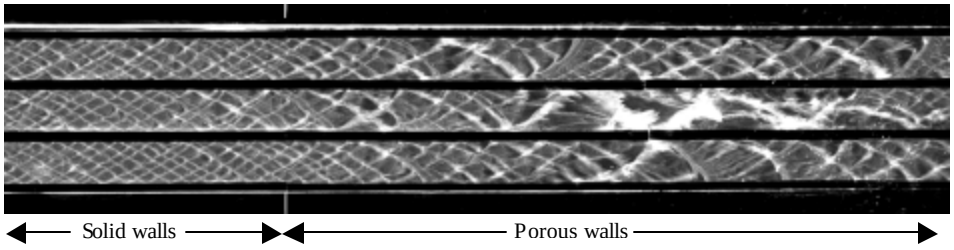

Figure 3 Open-shutter photograph of near limit $C_2H_2 + 2.5O_2$ detonations in the porous walled channels; $(d / \lambda) = 4$, $(w / d) = 0.16$.

the structure of the wave is three-dimensional, with transverse waves oscillating across the *d*-direction (between the porous walls) and in the *w*-direction (reflecting from the solid walls of the channel). The invariance of the failure limit with the channel's aspect ratio suggests that the (weak) transverse waves in this mixture are inconsequential in the failure mechanism in this mixture. The failure mechanism in these detonations could be due to the global mass divergence to the porous walls, which imparts a cylindrical curvature to the front (Radulescu & Lee, 2002). Since the two-dimensional frontal wave curvature, or the amount of mass divergence to the porous walls, does not depend on the channel aspect ratio, these results are consistent with the qualitative and quantitative conclusions of Radulescu & Lee (2002).

In oxy-acetylene detonations, the open-shutter photographs revealed that the transverse waves participate more actively in the ignition process (figure 2). Very bright triple points indicate that a significant amount of chemical activity is achieved near the triple-shock interactions. In the thin channel experiments, the cellular structure was two-dimensional (planar mode) (figure 2). In the wide channels, the detonation structure was three-dimensional. For both two-dimensional and three-dimensional waves, the open shutter photographs indicated an ongoing competition between triple point attenuation at the porous walls and re-amplification of new triple points from weakened transverse waves. Hence the failure mechanism is more closely associated with the attenuation of the transverse waves at the porous wall. The fact that the $(d / \lambda)^*$ limit is lower by a factor of two in wide channels can be attributed to the fact that the transverse wave density doubles in three-dimensional waves and thus it is twice more difficult to damp the detonation's transverse waves. This is also consistent with the fact that the transition operates at approximately $w = \lambda$, where the transition between two and three-dimensional waves occurs.

In oxy-propane mixtures, the open shutter technique was inadequate, due to the high luminosity throughout the reaction zone. Smoke foils were used instead to monitor the detonation wave dynamics in the porous wall section. The smoke-foil records (e.g., figure 4a) indicate the same competition between transverse wave attenuation at the walls and regeneration of new triple points from local instabilities, although the structure is significantly more irregular. Schlieren photographs of the reaction zone structure indicate that the reaction zone structure is spotty and turbulent, with small-scale instabilities on the order of the cellular sub-structure (figure 4b). The rebirth of new transverse waves is associated with the explosion of the fine-scale un-reacted pockets behind the main front, as indicated by the supplementary circular-like compression pulses in figure 2b. The foils also indicate that for thin channels, a planar mode is never really achieved in oxy-propane detonations, due to the coupling between the slapping mode with the fine scale instabilities. This could account for the fact that the limits in this mixture are also lower than for oxy-acetylene detonations, for which no significant sub-structure was observed and the slapping mode contribution was not evident in the photographs.

The conclusions that can be reached are that the failure limit in irregular mixtures is a strong function of the channel aspect ratio. This is a direct consequence of the participation of the detonations' transverse waves in the ignition mechanism, by further gas compression and possibly turbulent mixing. It is important to note that a similar dependence of the failure limit on the channel aspect ratio was also observed by Liu et al. (1984) for detonations diffracting from variable cross-section rectangular slots. It thus appears that transverse wave interactions also play a significant role in the diffractions process, as previously determined by Lee (1986).

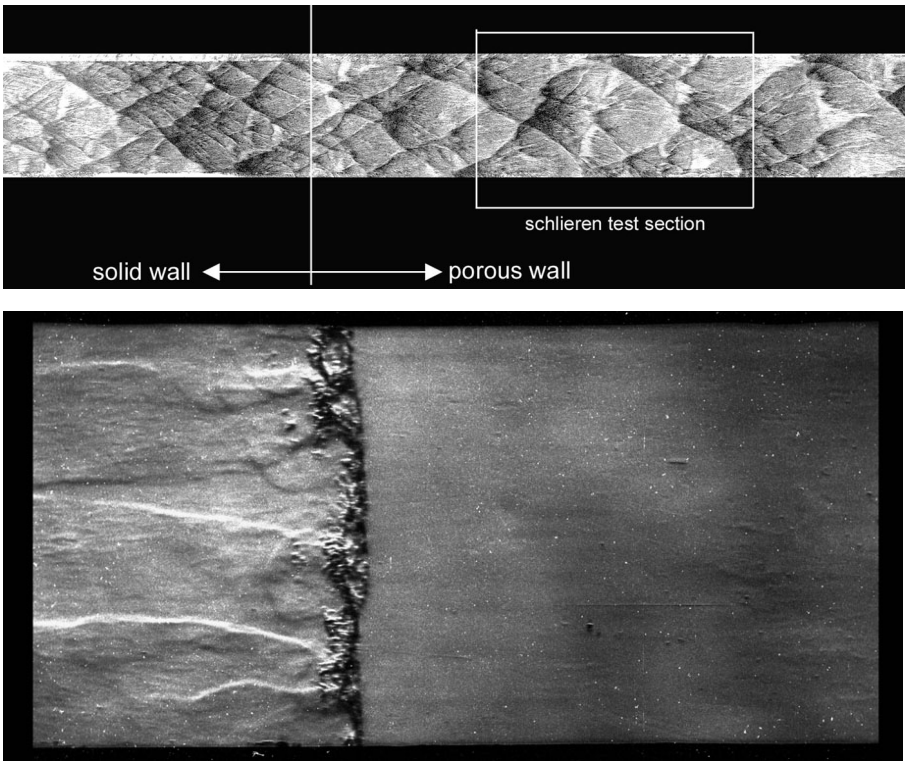

Figure 2 Smoke foil record of the attenuation of the detonation wave cellular structure in porous walled channels (a), and schlieren photograph of the detonation structure in the porous walled section of the channel (b)

For regular structure mixtures, the limits vary very weakly with cross-sectional aspect ratio of the channel. Hence the strength of the transverse waves is weak and they do not participate in the ignition process. By determining the influence of the limits on the channel's aspect ratio, this experimental procedure hence provides a clear framework to determine whether the detonation transverse wave structure plays a role in the detonation's propagation mechanism or not.

In conclusion, it appears that transverse wave interactions are important in irregular structure detonations. Through further gas compression and turbulent interactions, they allow the detonation wave to propagate under more severe conditions, i.e. lower $(d / \lambda)^*$.

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