

On the relevance of detonation cell regularity and width

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The width and the regularity of the cells observed on the fronts of detonation waves in gaseous mixtures have been long-time a subject of fundamental studies [1] and used for pre-sizing detonation-based industrial devices and advanced propulsion systems such as Pulsed or Rotating Detonation Engines [2]. However, to our knowledge, no systematic analysis has yet been conducted to discuss the conditions under which these two descriptors are relevant to characterize the cellular structure of detonation fronts.

We address this issue based on head-on and longitudinal soot recordings of detonation cells in detonation tubes with different shapes, namely round (R), square (Q) and triangular (T), but the same area of their cross-sections. We chose the mixture $2H_2+O_2+2Ar$ because its regular cellular pattern in Q tubes at low-enough initial pressures [3] is a convenient reference for comparison with the patterns in R and T tubes. We varied the initial pressure p_0 from 15 to 22.5 kPa.

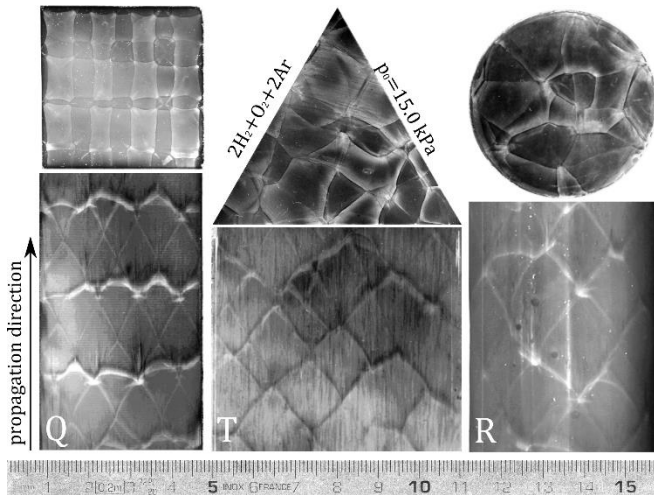


Figure 1. Corresponding head-on and longitudinal soot recordings (area 16 cm^2 , $2H_2+O_2+2Ar$, 15 kPa)

Figure 1 give typical head-on and longitudinal soot recordings. The head-on soot recordings in the Q tube show an evolution with increasing initial pressure p_0 . At lower pressures, up to $p_0 = 17.5\text{ kPa}$, they reaffirm the long-time observed regular arrangement of square and rectangular patterns, e.g., Fig. 1. At intermediate pressures, i.e. $7.5 < p_0 < 70\text{ kPa}$, irregularities emerge stochastically as distorted rectangles and squares. At larger pressures, i.e. $p_0 > 70\text{ kPa}$, all patterns are irregular. In contrast, the head-on recordings in the T and R tubes show irregular patterns regardless of p_0 .

For the same p_0 and the same cross-section area, there are more cells in the Q tube, and in the T tube than in the R tube. Their widths measured on the longitudinal recordings are consistently smaller, as summarized in Figure 2. The relative differences are all the smaller as p_0 is small. Also, the cells are slimmer in the Q tube than in the R and T tubes, which suggests that acoustic-modes locking forces the ratio of the transverse and longitudinal wave velocities.

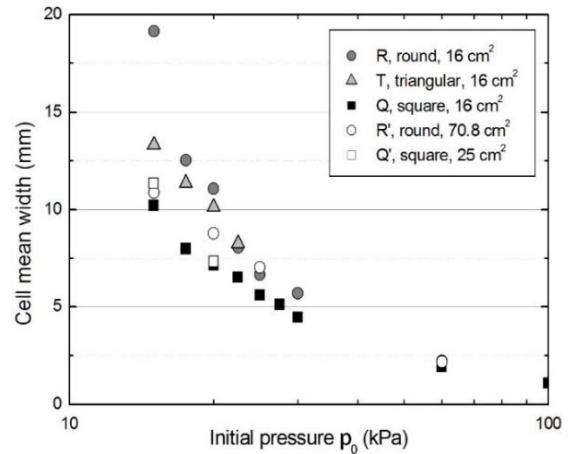


Figure 2. Measured cell sizes against initial pressure

A continuum of regular transverse modes was identified in the Q tubes at low enough initial pressure. The joint analysis of longitudinal and head-on soot recordings unambiguously indicates a continuous modulation of the phase shift of the orthogonal transverse waves - the difference of their impact positions at intersecting walls - as the detonation propagates. Hanana et al. [3] used a similar approach for the one-cell marginal propagation. This suggests that the wave front, although self-sustained, is subjected to long-wave-length low-amplitude instabilities, possibly from the later stage of ignition or small defects at the walls.

The most striking and paradoxical result is the systematic regularity of the longitudinal patterns even in the cases where the head-on patterns are irregular, regardless of the tube. For the considered mixture, this regularity thus appears as a boundary effect and head-on irregularity the rule, particularly close to the CJ conditions of propagation when transverse acoustic is negligible, that is, in tubes with large transverse dimensions.

Therefore, the cell regularity and mean width as usually defined from longitudinal soot recordings may be questionable parameters for calibrating numerical simulations and scaling dynamical behaviors of DDT processes and cellular detonations in gases. Indeed, these behaviors involve at least an acoustic interplay with chemical kinetics with cells larger than in the CJ propagation. Cells on detonation fronts, CJ or not, should be described as three-dimensional objects, which we currently address and hope to share soon.

[1] See the chapters by Vasil'ev, and Desbordes and Presles in Shock Waves Science and Technology Library, vol.6, Detonation Dynamics, Springer, Berlin, Heidelberg
 [2] Shepherd J.E., Kasahara J. (2017). Analytical Models for the Thrust of a Rotating Detonation Engine. Tech. Report FM2017.001, Graduate Aeronautical Laboratories, Caltech.
 [3] Hanana M., Lefebvre M.H., Van Tiggelen P.J. (1998). On Rectangular and Diagonal Three-Dimensional Structures of Detonation Waves, Int. Coll. on Advances in Experimentation & Computation of Detonations