DOUBLE CELLULAR DETONATION STRUCTURE

D. Desbordes, V. Guilly, B. Khasainov, J. Luche, and H. N. Presles

Laboratoire de Combustion et de Détonique (UPR 9028 CNRS),
ENSMA, 1 Avenue Clément ADER – BP 40109
86961- Futuroscope-Chasseneuil Cedex – France

Recent experimental works on detonation in gaseous nitromethane (CH_3 NO_2) [1,2] and in gaseous reactive mixtures, using NO_2 as the main oxidizer of fuels [3], have revealed the existence of a new double cellular structure (Fig. 1) on large range of equivalence ratio ϕ of the mixture. Numerical studies have shown that this is the consequence of a reaction heat release in two successive exothermic steps.

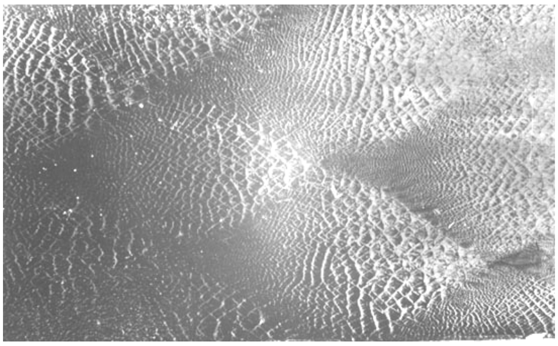

Fig 1. Example of double detonation cellular structure in H2-NO2/N2O4 mixture at p0 = 0.5 bar and T0 = 293 K, for equivalence ratio ϕ = 1.1

The specific chemical kinetics of oxidation of a fuel by NO_2 is responsible of that phenomenon. This kinetics lies on two different time steps of NO_2 conversion, i.e.:

- the first very fast step of consumption of O_2, when NO_2 is being transformed completely into NO and,
- the second delayed and slower step of transformation of NO into N_2 by a subsequent O_2 consumption and/or into N_2 and O_2 by NO decomposition, depending on the equivalence ratio ϕ.

The characteristic chemical time of the first step , of the order of 10 ns (maximum of heat release rate) is always defined, while the existence of the second one depends on whether this reaction step can be characterized by the existence or not of a second local maximum reaction rate. Then, the existence of one or two chemical characteristic times explains respectively the existence of a single or a double cellular detonation structure.

Experimental and numerical one-dimensional studies of detonation in H_2- NO_2/N_2O_4 mixture at ambient conditions illustrate this behaviour [3,4].

For $\phi > 0.8$ and $\phi < 0.4$, two distinct reactions steps (with their own chemical length) appear in 1D steady ZND calculations using a detailed chemical mechanism of oxidation of H_2 by NO_2/N_2O_4. These results explain the existence:

- of a double net of cellular structure of very different sizes for $\phi > 0.9$: a large cell of size λ_2 including a smaller cell of size λ_1 (at least one order of magnitude exists between λ_2 and λ_1) and,
- of a single cellular net of size λ_1 for $0.5 < \phi < 0.9$.

Two-dimensional numerical simulations of detonation cell structure with two successive exothermic reaction steps display either single or double detonation cell structure [5] depending on the rate of the second reaction step relative to the first one.

Propagation of such a double cellular detonation in a tube of internal diameter d shows the possible bifurcation of detonation propagation regime [4,6], depending on the relative characteristic sizes λ_2 and d, i.e.:

- when $\lambda_2 < d$, a quasi-CJ detonation regime (high detonation velocity) with a double cellular structure propagates in the tube,
- when $\lambda_2 > d$, a low velocity, “non-ideal” detonation regime, supported only by the heat release of the first step with the single cellular net of characteristic size λ_1 is observed in the tube.

References

[1] Presles H. -N., Desbordes D., Guirard M., Guerraud C. Gaseous nitromethane and nitromethane-oxygen mixture, a new detonation structure. Shock Waves 6 (1996) 111-114.

[2] Sturtzer M. -O., Lamoureux N., Matignon C., Desbordes D., Presles H. -N. On the Origin of the Double Cellular Structure of the Detonation in Gaseous Nitromethane and its Mixtures with Oxygen, Shock Waves14 (2005) 45-51.

[3] Joubert F., Desbordes D., Presles H. -N. Structure cellulaire de la détonation des mélanges H2-NO2/N2O4, C. R. Mécanique 331 (2003)365-372.

[4] Desbordes D., Presles H. -N., Joubert F., Gbagdo Douala C. Etude de la détonation de mélanges pauvres H2-NO2/N2O4, C. R. Mécanique 332 (2004) 993-999.

[5] Guilly V., Khasainov B., Presles H.-N., Desbordes D., Vidal P. Numerical Study of Detonation Cells Under Non-Monotonous Heat Release. Proceedings of the 20th ICDERS, Montreal (2005).

[6] Luche J., Presles H. N., and Desbordes D. Influence of Ar Dilution on Detonation Regime in H2-NO2/N2O4 Mixtures, Proceedings of the 20th ICDERS, Montreal (2005).