Available online at www.sciencedirect.com
ScienceDirect
C. R. Mecanique 337 (2009) 755–760
Comptes Rendus Mecanique

Experimental study of the detonation of technical grade ammonium nitrate

Henri-Noël Presles *, Pierre Vidal, Boris Khasainov

Laboratoire de combustion et de détonique, UPR CNRS 9028, ENSMA, BP 40120, 86210 Futuroscope–Chasseneuil, France

Received 20 July 2009; accepted after revision 19 October 2009

Presented by Sébastien Candel

Abstract

The detonation of technical grade ammonium nitrate at the density $\rho = 0.666$ g/cm^3 confined in PVC and steel tubes was experimentally studied. The results show that the detonation is self-sustained and steady in steel tubes with diameter as small as 12 mm. Critical detonation diameter lies between 8 and 12 mm in 2 mm thick steel tubes and between 55 and 81 mm in PVC tubes. These values testify a strong detonation sensitivity of this product. ***To cite this article: H.-N. Presles et al., C. R. Mecanique 337 (2009).***

Résumé

Étude expérimentale de la détonation du nitrate d'ammonium industriel. La détonation du nitrate d'ammonium industriel à la densité $\rho = 0{,}666$ g/cm^3 confiné dans des tubes en acier et en PVC a été étudiée expérimentalement. Les résultats montrent que sa détonation est autonome et stationnaire en tube acier pour des confinements aussi petits que 12 mm en diamètre. Son diamètre critique de détonation est compris entre 8 et 12 mm en tube acier de 2 mm d'épaisseur de paroi et entre 55 et 81 mm en tube PVC, valeurs qui témoignent d'une forte sensibilité à la détonation de ce produit. ***Pour citer cet article : H.-N. Presles et al., C. R. Mecanique 337 (2009).***

Keywords: Combustion; Ammonium nitrate; Detonation; Detonation velocity; Critical detonation diameter; Detonation sensitivity

Mots-clés : Combustion ; Nitrate d'ammonium ; Détonation ; Vélocité de détonation ; Diamètre critique de détonation ; Sensibilité à la détonation

1. Introduction

Ammonium Nitrate (AN) (NH_4NO_3) is widely used as fertilizer (ammonitrates) but also, thanks to its oxidizing properties, it is used as a component of the composition of certain propellants (propulsion by rocket engines) and commercial blasting explosives. Two varieties of AN are marketed to answer the two types of applications, fertilizer

* Corresponding author.
E-mail address: presles@lcd.ensma.fr (H.-N. Presles).

1631-0721/$ – see front matter
doi:10.1016/j.crme.2009.10.007

AN on the one hand and technical grade AN on the other hand which is distinguished from the former in particular by a strong porosity.

AN is regarded as a weak explosive, not very sensitive to the detonation and, although having been present at the origin of accidents of very great scale (AZF plant explosion, the last one, 21 September 2001), its detonation was not the subject of in-depth studies.

D. Price [1] showed that explosives can be classified in two groups according to the evolution of their detonation characteristics (detonation velocity and critical diameter) with the initial density. For example, the detonation velocity of the group I explosives (such as the TNT) increases with the initial density, simultaneously the critical diameter decreases. On the contrary, the critical diameter of the group II explosives increases with the initial density. On the other hand the detonation velocity passes by a maximum at a value of the initial density noticeably lower than the value of the theoretical maximum density. Cook [2], indeed, showed that with charge diameter given, the detonation velocity of AN decreases for a density higher than 0.95 g/cm^3 (the theoretical maximum density of AN is of about 1.7 g/cm^3). AN belongs to group II although one does not have a complete data set relating to it. To this difficulty the fact is added that in available literature on this subject, the initial state characterization of studied AN is often lacking, which prevents from comparing the results. Consequently, the effects of the initial density on the detonation velocity and the critical diameter of AN are not well known.

The absence of reliable experimental data also prevents the construction of efficient models of hot spot formation and growth aimed to the numerical simulations of various explosion scenarios.

The purpose of the present experimental work is to contribute to the construction of a database for AN.

2. The ammonium nitrate studied

AN used in this work was produced by Grande Paroisse (GP) Company. It is described as porous technical grade AN and its apparent density ranges between 0.64 and 0.83 g/cm^3. The AN concentration is higher than 98% and the percentage of carbon is lower than 0.2%.

It looks like quasi spherical white grains of size ranging mostly between 1 and 2 mm (Fig. 1). Its apparent loose-packed density, measured at the laboratory, is 0.666 g/cm^3 and thus significantly lower than the theoretical maximum density (1.7 g/cm^3), so that the porosity of the porous bed is equal to 60.8%. Fig. 2 testifies to the strong internal porosity of the grains themselves.

3. Experimental study

The detonation velocity measurements were realised in an 800 mm long tube, closed at one end and open at the other (Fig. 3). The tube is mounted vertically and its filling by AN grains is produced via the open top end. The initiation of the charge is obtained by means of the detonation of an explosive booster containing pentrite (FORMEX, detonation velocity $\approx$ 7000 m/s), fixed in top of the tube.

Four optical fibers with a diameter 0.7 mm and length 3 m are mounted to the tube, perpendicular to its axis, forming 3 bases of measurements. The interval between each fiber is of 150 mm, the last fiber is at 20 mm before the closed bottom. The passage of the detonation in front of the optical fiber induces a light signal which is converted into electrical signal by a phototransistor located at the other end of the fiber. This signal is then recorded by a numerical oscilloscope. Run times of the detonation from one fiber to another are deduced from the reading of the signals, from where values of average detonation velocity with an accuracy of 1%.

We studied the effect of the internal diameter Φ_{int} of steel tubes (Φ_{int} (mm): 8; 12; 15; 21; 27; 36; 41 and 52) with a wall thickness of 2 mm and PVC tubes (Φ int./ext. (mm): 55/63.5 and 81/90).

The initial temperature for all the experiments was in the range of 16–18 °C.

4. Results

The results of detonation velocity measurements are represented in Fig. 4 in the form of velocity D versus the reverse of the internal diameter Φ of the steel and PVC tubes.

The results obtained with steel tubes show that velocity $D(\Phi)$ decreases with Φ to $\Phi \approx 15$ mm ($D \approx 1150$ m/s), then slightly increases again. This part of the curve was confirmed by tests in tubes of 2 m length. The values of

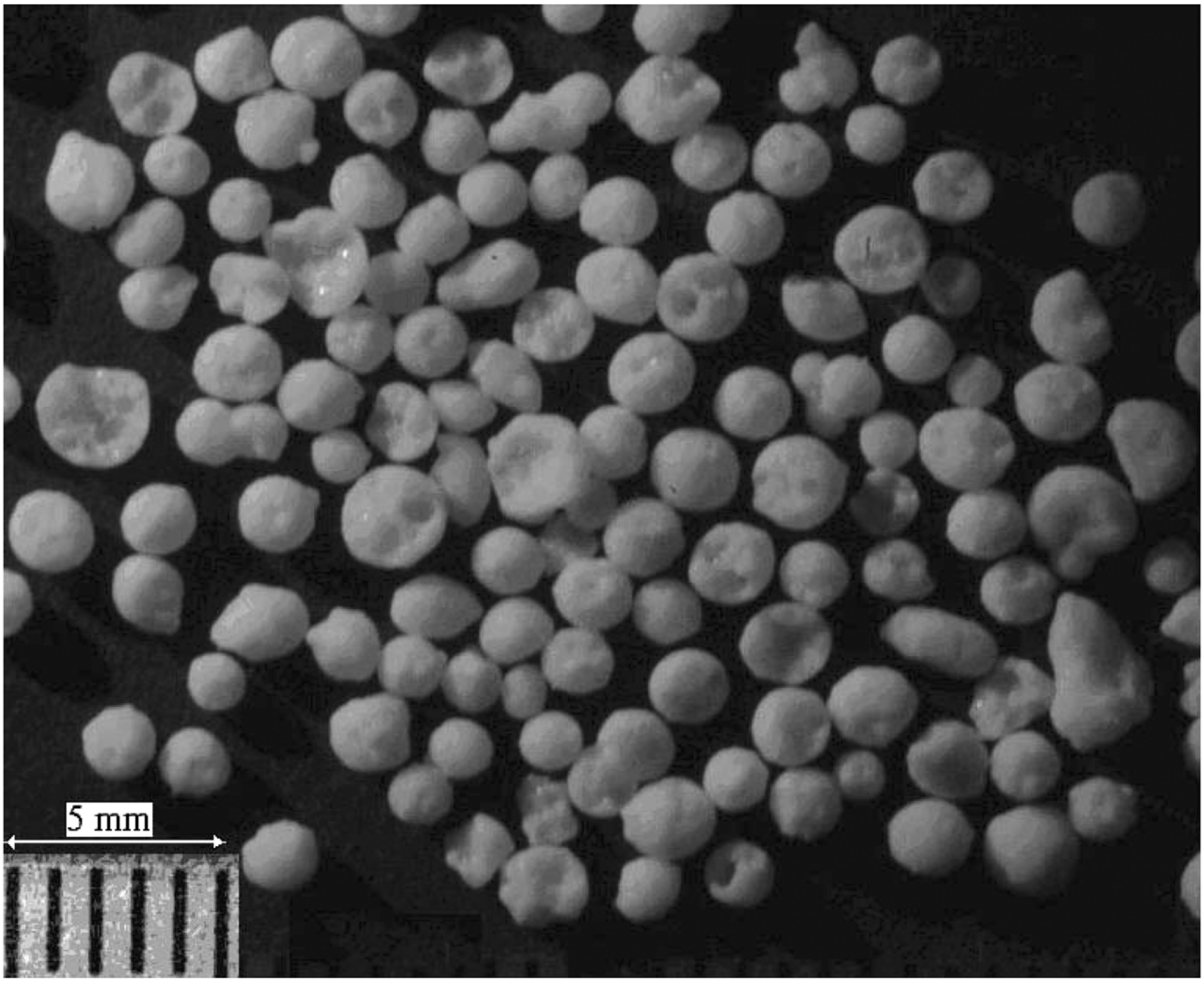


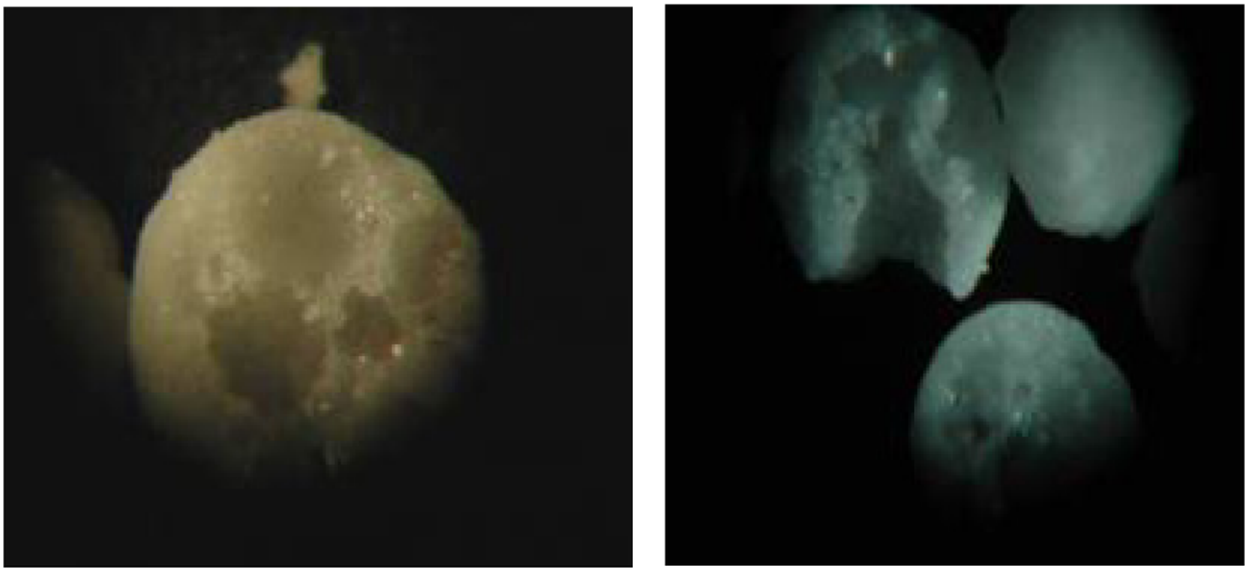
Fig. 1. Technical grade AN grains.

detonation velocity obtained under these conditions are very close to those obtained in 80 cm length tubes. This evolution of the curve $D(\Phi)$ for the small diameters is explained by the fact that the tube is, with constant wall thickness, all the more resistant while its diameter drops. The influence of the wall thickness of a steel confinement on the detonation characteristics of technical grade AN detonation of density 0.85 g/cm^3 had already been highlighted by Miyake et al. [3]. Indeed, this thickness is important for explosives whose detonation presents long reaction zone, which is the case of AN. So low detonation velocities ($D \approx 1150$ m/s) have already been obtained by Cook [2] with unconfined AN charge ($\rho = 1.04$ g/cm^3) of about 16 cm diameter.

In PVC confinement, detonation was obtained only in the 81 mm diameter tube. The detonation was quite stable on the two last bases of measurement with a velocity of 1550 m/s.

Let us note that in all the experiments, the detonation became self-sustained and steady after a propagation distance less than 40 cm.

The values of detonation velocity measured are significantly lower than the theoretical value which, for AN with the density 0.666 g/cm^3, is of approximately 4200 m/s (this value depends on the equation of state used to represent the detonation products). All the characteristics of these detonations known as "low velocity detonation" are of course very distant from those of the "ideal" detonation. The induced pressures are low, about a few kbar. In strong confinement and in particular for the small diameters, these detonations tear the tube wall in long bands or deform the tube (increase its diameter), but in any case do not produce small fragments.



(a) (b)

Fig. 2. The same grain (of approximately 2 mm) whole (a), then broken (b).

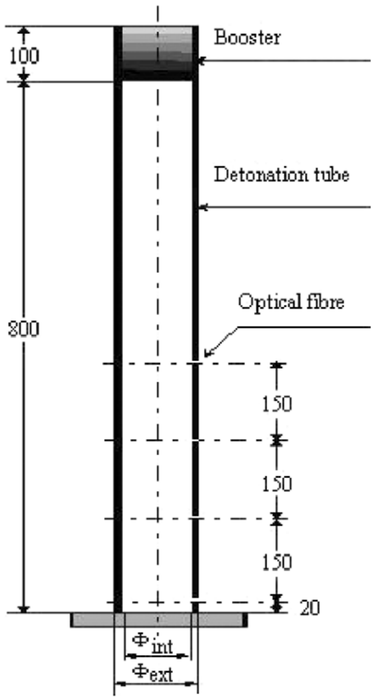


Fig. 3. Diagram of the detonation tube.

The values of critical diameter (Table 1) are not absolute, they depend not only on the nature of confinement (steel, PVC) but also thickness of the tube wall. Nevertheless, the values obtained testify to a high detonation sensitivity of studied AN.

Experiments [4] on grinded technical grade AN manufactured by Grande Paroisse confined in paperboard tubes (density 0.683 g/cm^3) show that at a density of 0.93 g/cm^3 it detonates in a 100 mm diameter tube at a velocity of

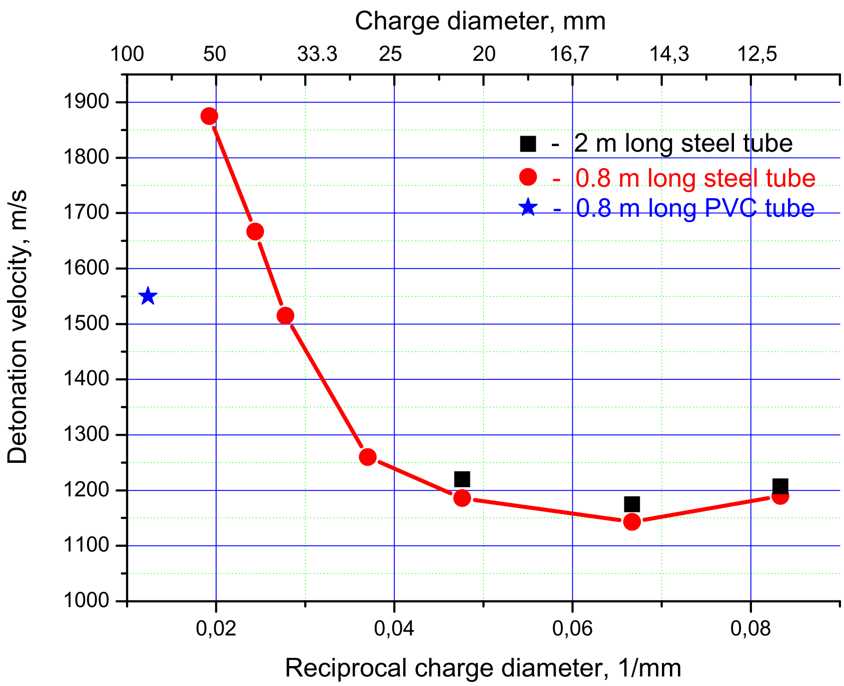


Fig. 4. Detonation velocity D of AN versus the internal diameter Φ of steel and PVC tubes.

Table 1
Critical diameter Φ_C of AN ($\rho = 0.666$ g/cm^3) in steel and PVC confinements.

Confinement material	Steel	PVC
Critical diameter Φ_C (mm)	$8 < \Phi_C < 12$	$55 < \Phi_C < 81$

2420 m/s. This result proves that under these very weak confinements, the critical diameter of technical grade AN (for this density) is lower than 100 mm. That confirms our result which shows that the critical diameter of technical grade AN (density of 0.666 g/cm^3) in weak confinement (PVC) is lower than 81 mm.

5. Conclusions

The experimental results obtained in this study show that detonation in porous technical grade AN with the density 0.666 g/cm^3 confined in steel tubes can propagate in tubes of very small diameters, up to 12 mm. So, under certain conditions, technical grade AN can have a high detonation sensitivity. They also constitute a new database which it would be useful to extend to establish the reliable curves of variation of the velocity and the critical diameter of detonation versus the initial density. This experimental work is indeed essential for the development of physicochemical models of hot spot formation and growth needed for reliable numerical simulations of explosions of ammonium nitrate.

Acknowledgements

The authors thank Grande Paroisse Company which supported this work and provided the AN.

References

[1] D. Price, Contrasting patterns in the behaviour of high explosives, in: Fourth International Symposium on Detonation, 1964, pp. 693–702.
[2] M.A. Cook, The Science of High Explosives, Reinhold Publishing Corporation, New York, 1958, p. 50.

[3] A. Miyake, A.C. van der Steen, H.H. Kodde, Detonation velocity and pressure of the non-ideal explosive ammonium nitrate, in: Ninth International Symposium on Detonation, 1989, pp. 560–565.
[4] H.R. James, B.D. Lambourn, C.A. Handley, N.J. Whitworth, H.N. Angseesing, P.J. Haskins, M.D. Cook, A.D. Wood, R.J. Briggs, P.R. Ottley, An investigation of the detonation characteristics of some non-ideal explosive compositions based upon ammonium nitrate, in: Thirteenth International Symposium on Detonation, 2006, pp. 110–120.