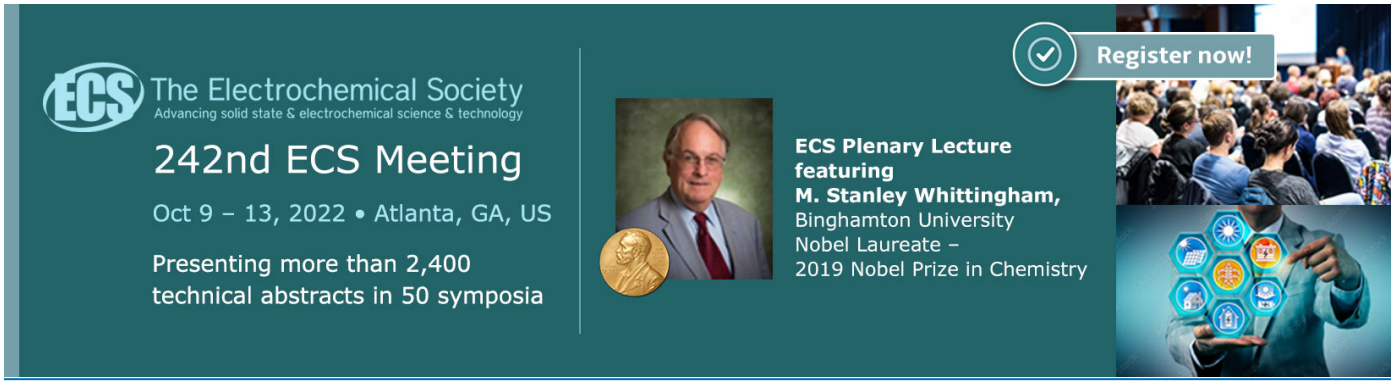
Differences between the detonation behavior of emulsion explosives sensitized with glass or with polymeric micro-balloons



Journal of Physics: Conference Series **500** (2014) 052030 doi:10.1088/1742-6596/500/5/052030

Differences between the detonation behavior of emulsion explosives sensitized with glass or with polymeric micro-balloons

R Mendes, J Ribeiro, I Plaksin, J Campos and B Tavares

ADAI - Associação para o Desenvolvimento da Aerodinâmica Industrial
LEDAP – Laboratório de Energética e Detónica
Department of Mechanical Engineering, University of Coimbra,
3030-788 Coimbra, Portugal

E-mail: ricardo.mendes@dem.uc.pt

Abstract. The differences between the detonation behaviour of ammonium nitrate based emulsion explosives sensitized with polymeric and those sensitized with glass micro-balloons is presented and discussed. Expancel® are hollow polymeric micro-balloons that contain a hydrocarbon gas. The mean particle size of these particles is 30 μm with a wall thickness of about 0.1 μm. The detonation velocity and the failure diameter of the emulsion explosive sensitized with different amounts of these particles have been measured in cylindrical charges by optical fibers. The detonation velocity demonstrates non-linear behaviour in relation to density and reaches the maximum value for a density lower than that of the matrix. The detonation fails when the density approaches that of the matrix. The detonation in the emulsion explosives extinguishes itself at a porosity value that seems to be independent from the nature of the sensitizing agent. For low densities, the detonation velocity is almost independent of the charge diameter, and is close to the values predicted by BKW equation of state.

1. Introduction

Ammonium nitrate (AN) based emulsion explosives (EX) are widely used in the mining explosives industry and are now beginning to be used for other purposes, such as the metal cladding of plates, the explosive forming of metal parts, and the consolidation of ceramic or metal powders [1-2], due to its extraordinary ability to change its own detonation behaviour as a function of the initial density.

The water in oil EX is sensitized to shock initiation through the incorporation of hollow micro balloons. Typically, the EX is classified as a non-ideal explosive because its detonation performance display a significant dependence on the charge diameter and on the inertial confinement. In addition, one of the more interesting features of the detonation behavior of the EX is the variation of the detonation velocity with the density. The detonation velocity increases on a linear scale with the density, reaching a maximum value. From there, an increase in the density provokes an abrupt decrease in the velocity of the detonation that can go up until its extinction [3-6]. This behavior occurs because of the effect of the finite charge diameter and its relation to the increase in the width of the chemical reaction zone with a reduction in the porosity of the explosive [3].

The behavior of the EX described above is very well-known and has been widely reported for EX sensitized with hollow glass micro-balloons (HGMB). However, there are only a few works concerning the detonation behavior of EX sensitized with hollow polymer micro-balloons (HPMB). One of these works was done by Hirozaki *et al.* [6] and reports on the detonation characteristics of EX

as a function of void size and volume of plastic micro-balloons. In order to increase the knowledge of the detonation behavior of EX sensitized with HPMB, this work shall report and analyze the effect of the amount of HPMB used for sensitization on the detonation velocity and on the detonation pressure profile.

2. Experimental Procedure

The composition of the emulsion matrix used in this work was: AN, water, and oil plus emulsifiers, in the mass ratio of 84/10/6. Such a matrix presented a density of 1.38 g/cm^3. The matrix was sensitized with a different amount of HPMB and, for comparison, also with different amounts of HGMB. The final density of the EX sensitised with HPMB ranged from 0.70 to 1.21 g/cm^3, while the final density of the EX sensitized with HGMB ranged from 0.8 to 1.28 g/cm^3. The HPMB used in this study was the Expancel®, whose mean particle size was 30 μm while the HGMB presented a mean particle size of 70 μm.

2.1. Detonation Velocity

The detonation wave velocity was measured at the terminal part of cylindrical explosives charges, with a length of 220 mm and with of 25 mm in diameter. A 4 mm thick wall of PVC tube was used as confinement. The LEDAP standard multi-fiber optical probes (MFOP) [7-8], with sixty-four 250-μm optical fibers connected without any intermediate optics to the electronic streak camera THOMSON TSN 506 N, were used for quasi-continuous measurements of the detonation wave velocity. The MFOP allowed for the evaluation of the DW local velocity with 2-3% error [8]. Figure 1 a) shows an optical fiber band at the end of explosive charge, used to measure the detonation velocity. The evaluation of the detonation velocity was also done, in some experiments, with a set of pairs of optical fibers positioned in the final 70 mm of the explosive charge just as it is presented in figure 1 b). The distance between the two adjacent pins was set to 10 mm.

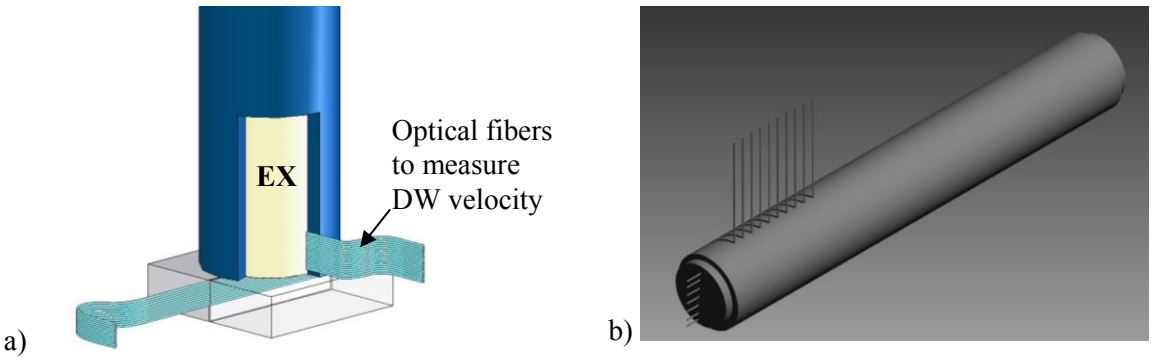


Figure 1. Experimental set-up for measuring detonation velocity with an a) continuous and a b) discrete method.

2.2. Detonation Pressure

The detonation pressure generated by the detonation wave propagation of EX composition was registered by embedding a manganin gauge (MicroMeasurements type LMSS-125CH-048) between 0.4 mm and 25 mm Teflon plates. The two Teflon plates and the manganin gauge, represented in figure 2, were then attached to the end of the cylindrical explosive charge, represented as such in figure 1b).

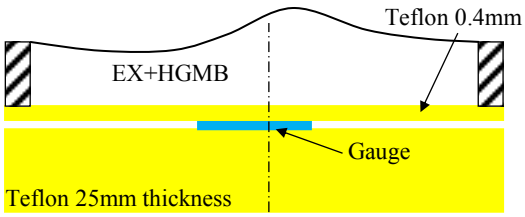


Figure 2. Experimental setup to measure the detonation pressure.

Voltage data was first converted to a resistance variation in the form of $\Delta R/R$ through a calibration procedure, and after that was reduced to pressure using the calibration data from Rosenberg *et al.* [9]. Finally, the pressure profiles in the emulsion explosive $P_{EX}(t)$ were obtained through the application of the Goransson equation [10].

2.3. Theoretical calculation of the detonation velocity

Theoretical calculation of the detonation velocity for the different EX compositions, which were sensitized with HGMB and experimentally tested in this study, was performed using the CHEETAH code [11]. CHEETAH is a physics and chemistry-based computational tool used to predict the performance (e.g. detonation velocity, detonation pressure and the detonation products composition) of explosive formulations. In the version used in this work, CHEETAH calculations have been based on traditional Chapman-Jouguet thermodynamic theory, which assumes that the thermodynamic equilibrium of the detonation products is reached instantaneously and that all reactants are consumed completely.

3. Results and Discussion

3.1. Detonation velocity and pressure

A typical result of the detonation wave (DW) run propagation in the EX obtained with the setup shown in figure 1 a) is presented on figure 3.

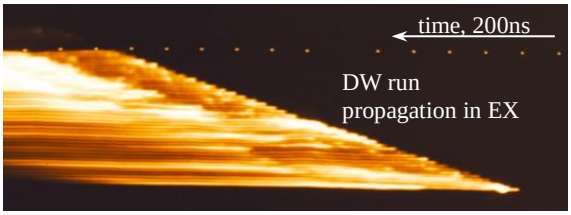


Figure 3. Typical photochronogram for the detonation wave run propagation in continuous mode, with shock wave propagation in a PMMA monitor.

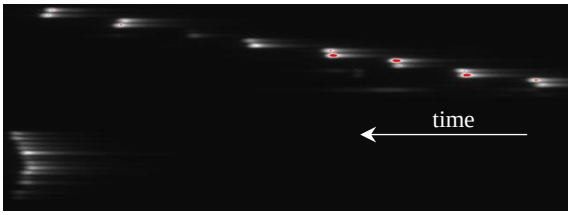


Figure 4. Typical photochronogram for the detonation wave run propagation in discrete mode and DW front curvature.

Figure 4 shows a typical photochronogram obtained with the setup described in figure 1 b). After processing the experimental data, an *x-t* diagram of the DW run propagation can be obtained, and from this slope the mean detonation velocity can be assessed.

The experimental values of the detonation velocity for the tested compositions, with charges 25 mm in diameter, are presented in figure 5. Detonation velocity of both compositions sensitized with HGMB and HPMB exhibit a non-linear behavior as a function of the initial density. The results referring to the detonation velocity of the EX sensitized with HPMB appear to be shifted towards the lower density values when compared to the results of the detonation velocity of the EX sensitized with HGMB. However, in the region where the detonation velocity increases linearly with the density, the EX+HPMB presents a higher detonation velocity than the EX+HGMB. Nevertheless, the critical

density, for which the extinction of detonation is observed, is 1.28 g/cm^3 for the EX+HGMB and is 1.21g/cm^3 for the EX+HPMB. Extinction of detonation at these densities corresponds that the compositions have a very low porosity. Figure 6 shows the application of the model presented in [3] to EX+HGMB for different charge diameters. Such models are based on (D, 1/d) Eyring model, and assume that chemical reaction zone thickness increases as porosity decreases. The fact that the chemical reaction zone increases as the porosity decreases points to the extinction of detonation process as the composition density approaches the matrix density.

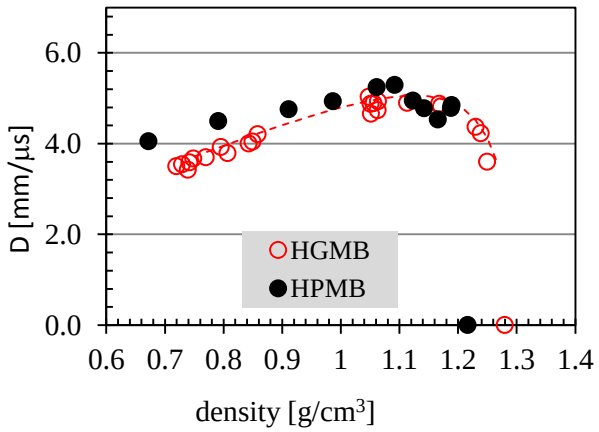


Figure 5. Detonation velocity as a function of density for EX sensitized with HGMB and HPMB.

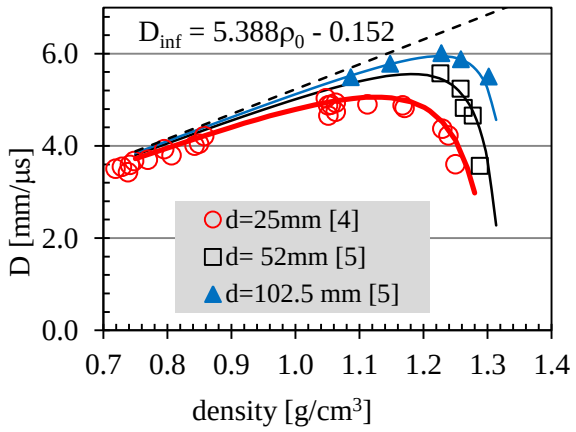


Figure 6. Detonation velocity as a function of density for EX sensitized with HGMB.

Figure 7 shows the detonation velocity of EX sensitized with HGMB and HPMB as a function of the composition porosity ϕ that is defined by the equation (1) where ρ_M is the matrix density, ρ_{MB} is the microballoon density and ρ_0 is the emulsion explosive density.

$$\emptyset = \frac{\rho_M - \rho_0}{\rho_M - \rho_{MB}} \quad (1)$$

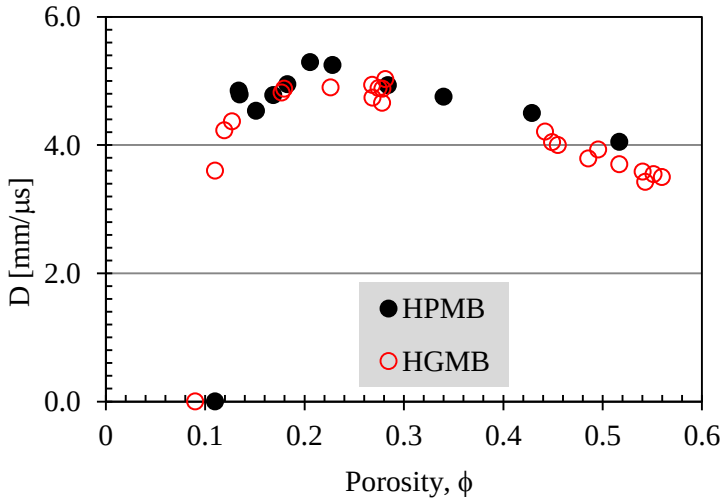


Figure 7. Experimental detonation velocity as a function of porosity for EX sensitized with HGMB and HPMB.

Thus it can easily be observed that the results referring to the detonation velocity of the EX sensitized with both sensitizing agents almost overlap. The critical density above in which the

detonation is extinguished corresponds to a porosity of 0.11 and 0.09 for EX sensitized with HPMB and HGMB respectively. The similarity between the behavior of detonation velocity as a function of the porosity for both EX compositions sensitized with HGMB and with HPMB show the importance of porosity in describing the detonation process of EX. The results also seem to show an ideal porosity for which the energy release from the detonation process is a maximum that corresponds to the maximum detonation velocity. For EX sensitized with hollow micro-balloons less than 70 μm in diameter the experimental results showed that the parameter which characterizes the velocity of the detonation, and is independent of the nature of the sensitizing agent of EX, is the porosity, and is not specific mass.

The detonation pressure profiles $P_{EX}(t)$, in EX for four compositions with different amounts of HGMB, are displayed in figure 8.

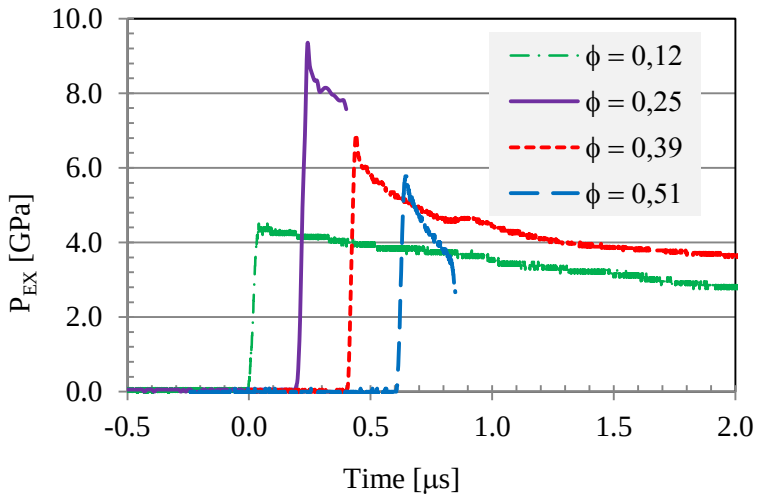


Figure 8. Detonation pressure profile in EX+HGMB compositions. *P(t)* signals were 200 ns offseted from each other to avoid overposition.

Each pressure profile demonstrates an initial, very abrupt, increase in pressure up to a maximum point, after which the pressure declines rapidly, allowing for the identification of the chemical reaction zone. Beyond that first pressure drop, the pressure continues to decay at a different rate which can be associated with the Taylor wave. An EX with very low porosity (ϕ=0.12) poses an exception, as the first peak in this case is absent.

Experimentally it was verified that increments of the HGMB mass fraction up until 20%wt in the EX composition decrease the detonation pressure as well as the detonation velocity. This decrease in the detonation pressure can be explained through the increase of the amount of inert material (glass-dicaperl) from the sensitizing agent present in the composition. In the composition sensitized with HGMB and with ϕ=0.12, a strong reduction in the maximum pressure amplitude was observed, along with an absence of the peak. This can be considered an indicator that the porosity is too low to release the energy content in the explosive to support the DW front propagation. For densities close to the densities of the detonation extinction, as reported in [3], there is a significant increase of the chemical reaction zone from 1-2 mm to 10 mm. It is our understanding that the growth of the chemical reaction zone also manifests in the pressure profile $P_{EX}(t)$ by the lack of the peak pressure.

4. Conclusions

Results comparing the detonation velocity for EX+HGMB and EX+HPMB have been presented as functions of specific mass and composition porosity. The nature of the sensitizing agent does not seem to have had a significant impact on the detonation behavior of the emulsion explosives.

Porosity, rather than initial density, seems to be the key parameter in the detonation behavior of emulsion explosives. For EX sensitized with voids presenting a characteristic diameter smaller than

70 μm, similar values of porosity for both compositions independent of the sensitizing agent (HGMB or HPMB) have been obtained for the extinction of detonation and for the maximum detonation velocity.

The absence of the peak in the pressure profile, along with a composition with very low porosity seems to indicate that the thickness of the chemical reaction zone increases with the decreasing of porosity.

Acknowledgements
Partial funding of this work was provided by the Portuguese Foundation for Science and Technology-FCT under the research contract PDTC/EQU-EPR/114990/2009.

References

[1] Farinha A R, Mendes R, Ribeiro J, Calinas R and Vieira M T 2009 *J. Alloy Compd.* **483** 235-38
[2] Mendes R, Ribeiro J and Loureiro A 2013 *Mater. Design* **51** 182-92
[3] Silvestrov V 2006 *Combust. Explo. Shock+* **42** 4 472–79
[4] Mendes R, Ribeiro J, Plaksin I, Campos J and Farinha R 2010 Non monotonic detonation velocity and pressure behavior of emulsion explosive *13th Int. Seminar NTREM* (Pardubice, Czech Republic) pp 221-28
[5] Lee J, Sandstrom L W, Craig B G and Persson P A 1989 Detonation and shock initiation properties of emulsion explosives *Proc. 9th Symp. Int. on Detonation* USA pp 573-84
[6] Hirosaki Y, Murata K, Kato Y and Itoh S 2002 Detonation characteristics of emulsion as functions of void size and volume *Proc. 12th Symp. Int. on Detonation* USA pp 263-70
[7] Plaksin I, Campos J, Ribeiro J, Mendes R, Gois J C, Portugal A, Simoes P and Pedroso L 2002 Detonation meso-scale tests for energetic materials *AIP Conf. Proc.* **620** pp 922-5
[8] Mendes R 2002 Iniciação e detonação de explosivo plástico de RDX *PhD Thesis* (Coimbra University of Coimbra)
[9] Rosenberg Z, Yaziv D and Partom Y 1980 *J. Appl. Phys.* **51** 3702-05
[10] Al'tshuler L V, Doronin G S and Zhuchenko V S 1989 *Fizika Goreniya I Vzryva* **25 N2** 84-103
[11] Fried L E 1996 Cheetah V1.40 User's manual *report No UCRL-MA-117541*