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VOID SIZE DEPENDENCE OF THE STEADY DETONATION PROPERTIES OF EMULSION EXPLOSIVES

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Detonation velocity/cartridge diameter measurements have been made on a series of emulsion explosives containing three size fractions of sieved glass microballoons and at two composition density ranges. The data is analysed using a slightly divergent flow code. The results show the interaction between the kinetics and hydrodynamics of the detonation process.

INTRODUCTION

The sensitisation of explosives by density discontinuities has been recognised since the work of Bowden and Yoffe.[1]

The importance of voids has been described in the classic papers of Campbell, Davis and Travis.[2,3] Evans, Harlow and Meixner[4] and Mader.[5,6]

Most commercial explosives have very large critical diameters for detonation at their theoretical maximum density and in their practical form depend on some form of void for sensitisation i.e. they are of Type II as described by Price.[7] The void may take the form of, for example, gas bubbles, glass microballoons, perlite etc.

In addition to their increasing commercial importance emulsion explosives provide an all liquid system (oil phase + supersaturated droplets) for study and avoid some of the problems which may occur in the analysis of results from compositions containing both liquids and solids. Glass microballoons provide a convenient source of well-defined void size fractions by sieving.

This paper describes the effect of void size and porosity on the steady detonation properties of emulsion explosives. A companion paper[8] discusses the initiation properties of these systems. Since carrying out this work in 1980 and '81 a paper by Japanese workers[9] has appeared which describes a similar study. Our work differs in that a slightly divergent flow code CPEX[10] is used to analyse the results. This allows the process to be discussed in terms of the kinetic and hydrodynamic processes occurring. CPEX was operated in the auto-fit mode i.e. there was no operator adjustment of the parameters to achieve a fit.

EXPERIMENTAL

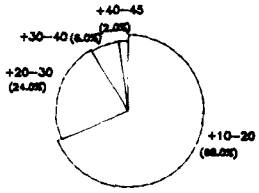
Glass microballoons from the 3M Company were sieved to produce the required fractions then floated on water to remove broken fragments. The two larger fractions were prepared from the C15/250 grade; the smaller fraction from the E22X grade. Size distributions were obtained by optical microscopy. Figure 1.

The emulsion used consisted of:

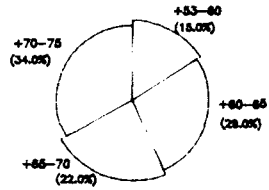
	%
Ammonium nitrate	78.9
Water	15.8
Oil + surfactant	5.3

The number average droplet size was about 1.3 μm with an essentially monodisperse distribution. Emulsions were blended with microballoon fractions to the required porosity. Air bubbles incorporated during the emulsification process were removed by application of vacuum. Detonation measurements at 20^{o}C were made soon after preparation to avoid possible droplet crystallisation effects.

VOD measurements were made with collapsible probes/ microtimer. For critical diameter measurements, it was found that the probe affected the results. All critical diameter results refer therefore to measurements on cartridges without probes. All measurements were made on explosive cartridged in paper.



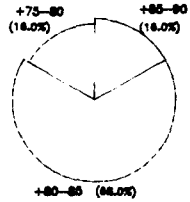
$-45\mu m$



$53-75\mu m$

Figure 1.

Size distribution of the microballoon fraction used in the study.



$75-90\mu m$

VOID SIZE DEPENDENCE OF VOD/DENSITY CURVES

The quantitative results in this paper are derived from VOD/diameter/inverse diameter data. However, as a subsidiary experiment the VOD/density curves were measured for compositions containing the three different microballoons fractions. For any given density there is (because of differing particle density) a difference in the amount of the three fractions required, hence in the total energy of the system (of about 1-2%). The data is shown in Figure 2.

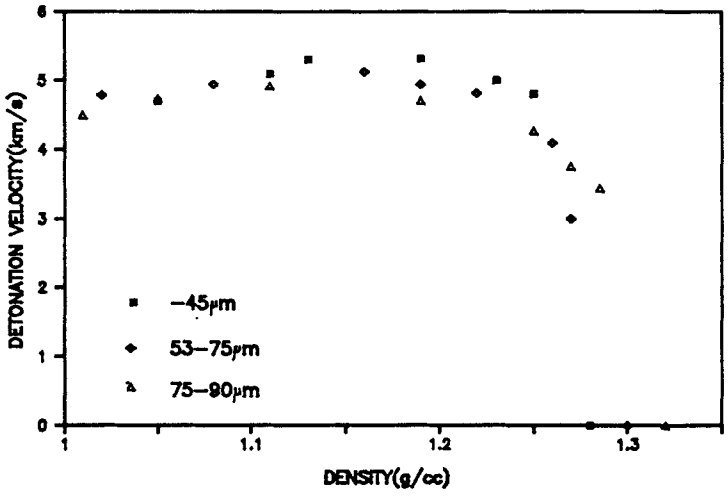


Figure 2. Detonation velocity/density behaviour of emulsion in 30 mm diameter cartridges.

The density at which the VOD is maximum shifts to higher density for smaller voids as reported by Hattori et al[9]. Further observations may be made, however. The failure part of the curve is particularly steep with the small voids. This suggests that as the VOD falls away with decreasing extent of reaction at high density a shock pressure is reached where the hot spots fail to explode. Catastrophic failure then occurs. With larger voids there is a decreased total extent of reaction from hot spot thermal explosion and outward burning at high density but the hot spots continue to explode down to low shock pressures so the curve is less steap. As the system tends

towards an explosive foam at low density the velocity/density curves tend to converge. The above is in total agreement with our previous study of the initiation properties of emulsion explosives.[8]

VOD/DIAMETER MEASUREMENTS

The slope of the VOD against inverse cartridge diameter graphs increased with increasing void size and with increasing density. Small void systems failed at higher velocity in agreement with our consideration of the initiation process.[8]

TABLE I

Microballoon Fraction (μm)	Density ($g.cc^{-1}$)	Failure Velocity ($km.s^{-1}$)
-45	1.06	3.8
-45	1.19	3.8
53-75	1.05	3.12
53-75	1.18	3.2
75-90	1.03	2.5
75-90	1.17	2.95

The data agrees with the concept that the critical point is dominated by the pressure dependence of the hot spot reaction. Applying a CPEX fit to the VOD/diameter data shows the failure point is at a higher extent of reaction the smaller the size of microballoon incorporated and the lower the density. That is, the detonation is tending towards pseudo-homogeneous behaviour.

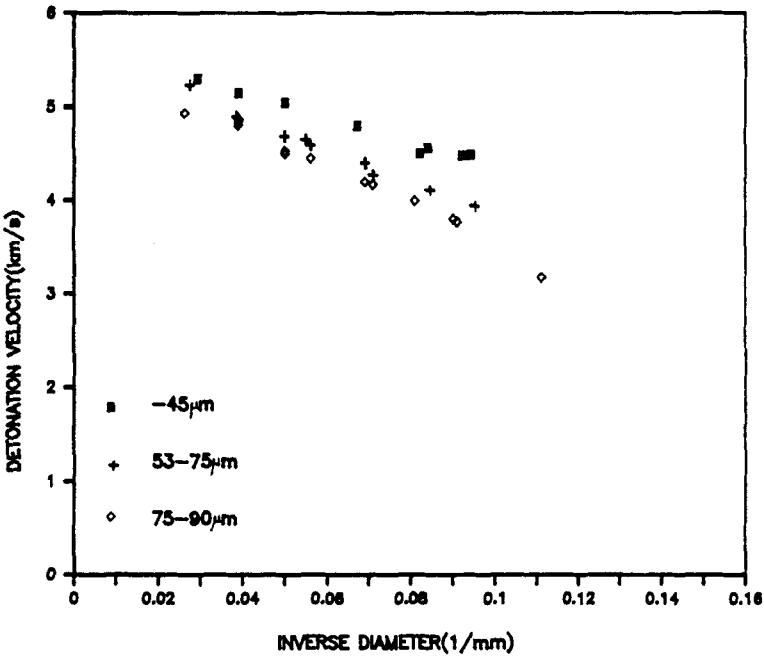


Figure 3. Detonation velocity/inverse cartridge diameter behaviour as a function of microballoon size.

EXTENT OF REACTION AS A FUNCTION OF TIME

Having derived best fits to the experimental VOD/diameter data, the pressure dependent kinetic routines in CPEX can be used to produce extent of reaction/time curves as a function of

void size and density at a fixed pressure. These are shown in Figure 4. for the three void size fractions at densities of 1.06 and 1.16 $g.cc^{-1}$ at 5 GPa pressure.

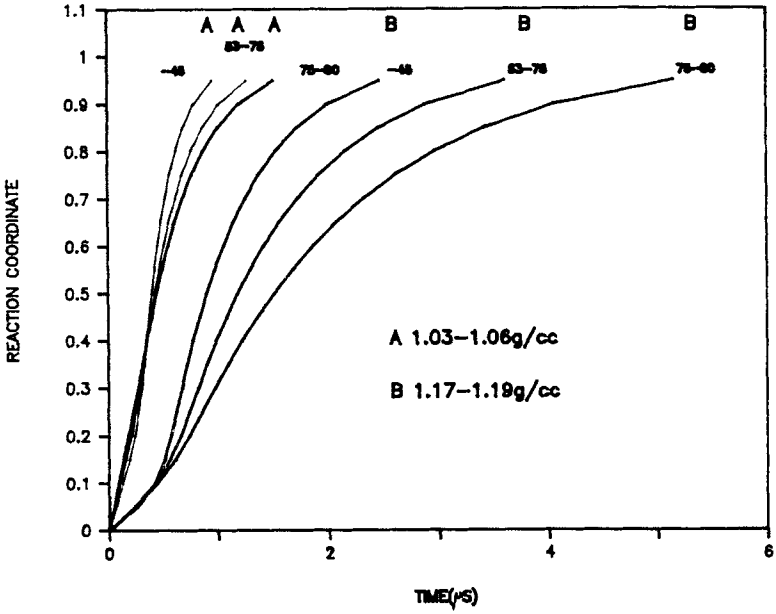


Figure 4. Extent of reaction/time profile as a function of microballoon size and density normalised to 5 GPa.

The total reaction is faster for the small voids. However, it can be seen that the curves cross at about an extent of reaction corresponding to the void (i.e. hot spot) volume.

That is, the proportion of reaction corresponding to hot spot thermal explosion is slower for smaller voids. This is more than compensated for by the high surface area for burning of the small hot spots and the higher temperature of the surrounding matrix caused by thermal conduction from the hot spots and hydrodynamic effects. Hence the total reaction is faster for small voids and the curves cross.

From CPEX the slope of the extent of reaction/time graph i.e. the reaction rate can also be determined. This is shown in Figure 5. again at 5 GPa for the three size fraction in two density ranges. The slower initial phase of reaction but higher peak rate for the small voids is again evident. However it can be seen that the relative reaction rates of the initial phases are rather more pronounced for the low density than for the high density emulsions. We interpret this as evidence that the collapsing voids interact hydrodynamically with each other. Because of this interaction the effective hot spot size is smaller at low density. With smaller voids the effect becomes more pronounced as these are closer together within the emulsion matrix.

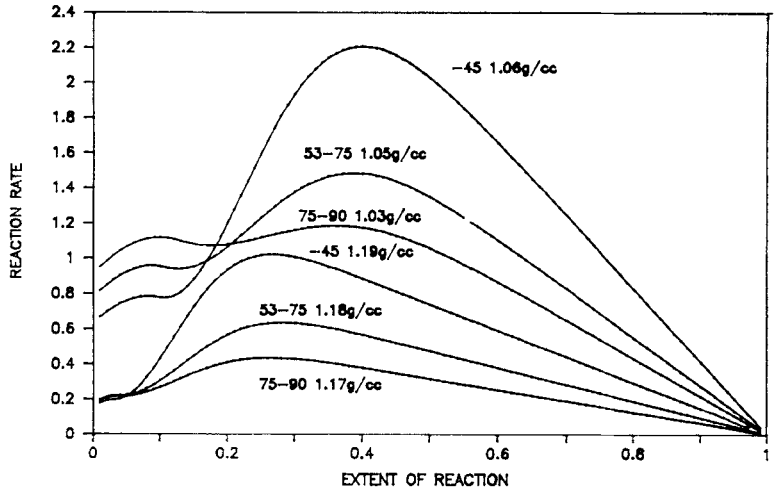


Figure 5. Reaction rate/extent of reaction for an emulsion as a function of microballoon size and density at 5 GPa.

DISCUSSION

A number of mechanisms have been advanced for hot spot formation - adiabatic collapse[1], microjets[5,6], shear banding[11] etc. For a review see Field et al[12]. Void collapse produces both high temperatures and intense mixing in a volume of explosive similar to the original void volume. The hot spots burn outward into the shock heated bulk of the explosive. The detonation velocity as measured is a function of the extent of reaction and the radial divergence of the flow before the CJ plane.

In this paper a steady detonation condition is considered where the shock wave is a detonation wave which has travelled several cartridge diameters in the explosive before a measurement has been made. The steady detonation velocity influences both the hot spot temperature and the shock temperature in the bulk of the emulsion and hence the kinetics of hot spot and burning phases of reaction. In the classical picture there is a size dependent heat flow from the hot spot into the bulk of the explosive. At failure there is an insufficient extent of reaction to maintain a detonation wave sufficient to cause hot spot thermal explosion.

The above may be a rather simplistic picture. In practice we are dealing with a 3-dimensional random assembly of voids in which the average void separation (centre-centre) at 20% v/v voids is 248 micron for 90 micron voids and only 83 micron for 30 micron voids. Thus not only may shear banding from the collapse of one void interact with another placed laterally to it but as the reaction zone is rather longer than the inter void distance the collapse of a void can interfere hydrodynamically with a previously shocked void further back in the reaction zone. The effect of this is to increase the effective thermal diffusivity above that expected for a non-turbulent process and possibily to decrease the effective size

of the hot spots below that of the initial void by interaction of the shear fields of the neighbouring collapsing voids. At lower density there is a general tendency towards a bulk thermal explosion mechanism because of the intense turbulence created by void collapse. This is even more pronounced with small voids because of the small intervoid distance.

In a future paper it will be shown that the intense turbulence and mixing produced by void collapse can have important consequences for the diffusional kinetics of emulsion detonation.

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