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VELOCITY OF DETONATION AND CHARGE DIAMETER IN SOME RDX-DRIVEN HETEROGENOUS EXPLOSIVES: PBXW-115, PBXN-111, COMPOSITION H-6 AND COMPOSITION B

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ABSTRACT

Experimental data on the dependence of velocity of detonation on charge diameter, V(d), of unconfined cylindrical charges of the underwater explosives, PBXW-115 (Aust.), PBXN-111 and Composition H-6 and of Composition B are given. The data is analysed in terms of a previously-reported empirical relationship between the V(d), the detonation velocity at infinite charge diameter (D*) and a reaction zone length parameter, (a*).

1. INTRODUCTION

Whelan and Bocksteiner [1,2] have recently reviewed the status of the various mathematical relationships between the experimentally-observed steady state velocity of detonation (V of D or V(d)) and charge diameter (d) for

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cylindrically-shaped, unconfined RDX-driven composite explosives. They have suggested that, for many of these formulations, the relationship between V of D and charge diameter (d) follows not the familiar linear, Eyring equation [3],

$$V(d) = D\,(1 - [a/d]) \qquad \text{(Eq. 1)},$$

where D and a are curve fitting constants,

or linear variations of it [4], but rather an elliptical dependence of the form

$$V(d)^2 = (D^*)^2\,(1 - [a^*/d]^2) \qquad \text{(Eq. 2)},$$

where D* and a* are also curve fitting constants.

This conclusion was reached not only by considering the linear least squares analyses of experimentally-determined data from several formulations [1,2], but also, in almost every case, by noting that the experimental values of V(d) for larger diameter charges were appreciably less than those expected on the basis of Eq. 1. It was also observed that there appears to be a simple connection between the critical diameter, d_c, and a*, viz.,

$$d_c = 2.208\,a^* \qquad \text{(Eq. 3)}.$$

Here, a* could be regarded as a reaction zone length parameter characteristic of the formulation in the same way that Wood and Kirkwood [5] have related the CJ-point of a detonation, ξ^*, to the radius of curvature, S, of the detonation wave front .

Those formulations whose V(d) profiles appeared to follow Eq. 2 all appeared to have a significant component of coarser (perhaps > 150 μm) particle sized RDX in their formulation, whereas those which appeared to follow Eq. 1

more closely, behaved more like typical monomolecular explosives and contained considerable fine (perhaps < 40 μm) RDX [1,2,6].

In this paper, the authors present a selection of the actual experimental data upon which this relationship was arrived at, for the underwater explosives, PBXW-115 (Aust.) [1,2], its US counterpart, PBXN-111 [1,2,7], and the High Blast Explosive, Composition H-6 [8], and the widely-used explosive, Composition B [4,9].

Most of these data were summarised in the earlier report [1], without the supporting experimental data.

2. FORMULATIONS

PBXW-115 (Aust.) and PBXN-111 are described in detail elsewhere [1,2,7]. They are both cast-cured PBXs, made from bimodal RDX 20%, ammonium perchlorate (AP) 43%, Al 25% in a plasticised HTPB-based polyurethane binder. The principal differences between the two are in the coarser RDX component: Woolwich (Nitric Acid Process) Type I RDX [10], which is HMX-free [2], makes up the coarser RDX component in PBXW-115 (Aust.); Bachman (Acetic Anhydride Process) or Type II RDX [11], which can contain up to 14% HMX, makes up the coarser RDX component in the bimodal mix used for PBXN-111.

The formulation, Composition H-6, upon which the reported experimental data were based, was made at AMRL [12a] to US Military Specification MIL-E-22267A [12b] using RDX [Type I, Grade 1 of Australian manufacture [10]; colloquially called Grade A]. It analysed within specification to TNT 27.7%, RDX 43.1%, Al 22.7%, $CaCl_2$ 0.4%, Wax 6.1%.

In the following discussion, the authors will be referring to V (d) data on Composition B, tabulated by Gibbs and Popolato [9]. It is assumed that the formulation of this Composition B was made to US Military Specification MIL-C-401E (13 Mar 1974), from RDX [Type II, Class 1] [11] 63%, TNT 36 %, Wax 1%.

RDX (Class 1) produced to US specifications [11] has the following particle size distribution: particle size greater than 300 μm - 10 % (max.), particle size between 300 and 75 μm - at least 65 %, and particle size less than 75 μm - 25 % (max.). RDX (Grade 1) produced to Australian specifications [10] has a slightly different particle size distribution: particle size greater than 300 μm - 25 % (max.), particle size between 300 and 75 μm - not less than 67 %, and particle size less than 75 μm - 12 % (max.).

3. EXPERIMENTAL RESULTS

In Tables 1-4, the V(d) data for unconfined cylindrical charges of PBXW-115 (Aust.) [2], PBXN-111 (also known as PBXW-115, from the US Naval Surface Warfare Center) [7], Composition H-6 [8] and Composition B [4,9] (for values of d somewhat greater than d_c) are listed, while in Table 5, an analysis of these data is given. The data for Composition B, perhaps the most surprising in these analyses, are also produced graphically in Figures 1 and 2. Similar plots can be drawn for the other compositions. From these plots for Composition B it is apparent that,

overall, there is less scatter in Figure 2 than in Figure 1 and that at larger diameters, the data fit Eq. 2 more closely than they fit Eq. 1 (see also Table 4).

Table 1. The Dependence of Velocity of Detonation on Charge Diameter in Unconfined Charges of PBXW-115 (Aust.), density 1.79 Mg m^{-3} [Ref. 2].

Diameter, mm	V(d), m s^{-1}	Diameter, mm	V(d), m s^{-1}
200	5557	110	5306
170	5525	110	5372
140	5476	80	5072
140	5445	80	Fail

Table 2. The Dependence of Velocity of Detonation on Charge Diameter in Unconfined PBXN-111, formerly PBXW-115, density 1.79 Mg m^{-3} [Ref. 7].

d, mm	V(d), m s^{-1}	d, mm	V(d), m s^{-1}
69.1	5540	49.6	5421
49.9	5315	41.1	5190
49.7	5331	38.7	5036
49.6	5365	35.5	Fail

Table 3. The Dependence of Velocity of Detonation on Charge Diameter in Unconfined Charges of Composition H-6, density 1.74 Mg m^{-3} [Refs. 8,12].

d, mm	V(d), m s^{-1}	d, mm	V(d), m s^{-1}
38	7355	13.47	7294
22.75	7348	13.47	7290
22.75	7325	9.4	7238
15.7	7283	9.4	7147
15.7	7330		

Table 4. The Dependence of Velocity of Detonation on Charge Diameter in Unconfined Charges of Composition B, density 1.70 Mg. m^{-3} [Ref. 4,9].

d, mm	V(d), m s^{-1}	d, mm	V(d), m s^{-1}	d, mm	V(d), m s^{-1}
25.5	7868	12.7	7819	7.95	7738
25.5	7889	10.0	7787	7.95	7725
24.8	7869	10.0	7792	7.96	7746
24.8	7864	10.0	7755	6.36	7648
24.8	7847	8.48	7738	6.35	7650
12.7	7816	8.47	7742	5.61	7572

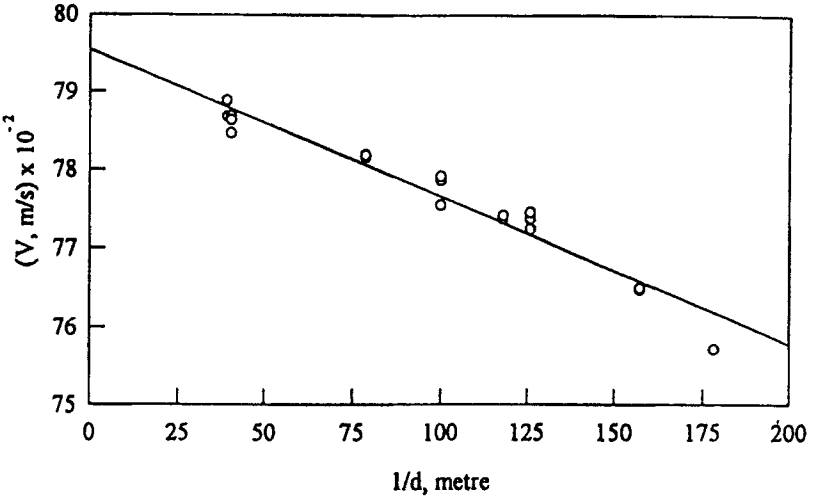

Fig.1 The plot of (V of D) vs (1/d) for unconfined charges (cylindrical) of Composition B.

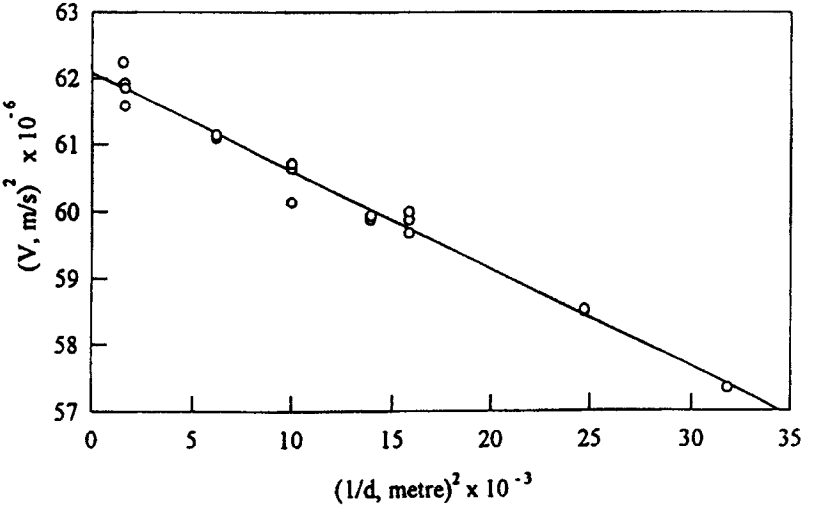

Fig. 2. The plot of $(V \text{ of } D)^2$ vs $(1/d)^2$ for unconfined charges (cylindrical) of Composition B.

Table 5. Analytical Description of the Relationship between the observed V of D and Charge Diameter for Unconfined Cylindrical Charges of PBXW-115 (Aust.), PBXN-111, Composition H-6 and Composition B.

PBXW-115 (Aust.) : Unconfined Charges, Charge Diameters: 80 mm to 200 mm.

Critical diameter: 80 mm (1x Go, 1x No-Go)

$$[V, m\ s^{-1}] = 5913.37\{1 - (11.048 / [d, mm])\}$$

LLSQ Coefficient of Determination = 0.9680

$$[V, m\ s^{-1}]^2 = (5641.77)^2 \{1 - (35.254 / [d, mm])^2\}$$

LLSQ Coefficient of Determination = 0.9833

PBXN-111 : Unconfined Charges, Charge Diameters: 38.7 mm to 69.1 mm

Critical diameter: 37.6 ± 1.6 mm (exptl.)

$$[V, m\ s^{-1}] = 6193.4\{1 - (6.849 / [d, mm])\}$$

LLSQ Coefficient of Determination = 0.9076

$$[V, m\ s^{-1}]^2 = (5760.0)^2 \{1 - (18.325 / [d, mm])^2\}$$

LLSQ Coefficient of Determination = 0.9364

Composition H-6: Unconfined Charges, Charge Diameters 9.4 mm to 38 mm.

Critical diameter: < 7 mm (exptl.)

$$[V, m\ s^{-1}] = 7431.4\{1 - (0.284 / [d, mm])\}$$

LLSQ Coefficient of Determination = 0.7873

$$[V, m\ s^{-1}]^2 = (7368.3)^2 \{1 - (2.023 / [d, mm])^2\}$$

LLSQ Coefficient of Determination = 0.8330

Calculated Critical Diameter = 4.4 mm (based on Reference 1)

Composition B: Unconfined Cylindrical Charges, Charge Diameters 5.6 to 25.5 mm. Critical diameter: 4.3 mm

$$[V, m\ s^{-1}] = 8023.5 \{1 - (0.340 / [d, mm])\}$$

LLSQ Coefficient of Determination = 0.8885

$$[V, m\ s^{-1}]^2 = (7895.1)^2 \{1 - (1.673 / [d, mm])^2\}$$

LLSQ Coefficient of Determination = 0.9805.

Calculated Critical Diameter = 3.7 mm (based on Reference 1)

5. DISCUSSION

Using standard spreadsheet techniques, one can readily see that over a large range of diameters, the experimental data for the RDX-driven component of the overall detonation reactions [1,2,13] of PBXW-115 (Aust.), PBXN-111, Composition H-6 and Composition B fit Eq. 2 rather more satisfactorily than Eq. 1. This becomes more apparent if one plots the same relationships using averaged V of D data for a particular value of d.

The significance of the results for PBXW-115 (Aust.) and PBXN-111 has already been discussed [2]. In as far as Composition B and Composition H-6 are concerned, Composition H-6 can be regarded as an aluminised form of Composition B. However, from the results presented in Table 5 and summarised in

Table 6, one can see both that the experimentally-determined limiting values of the detonation velocity at infinite charge diameter and the (elliptical) reaction zone

Table 6. The Limiting Value of the Velocity of Detonation and the Reaction Zone Length Parameters in PBXW-115 (Aust.), PBXN-111, Composition H-6 and Composition B, calculated from Eq. 2.

Formulation	D^*, m s^{-1}	a^*, mm
PBXW-115 (Aust.)	5642	35.3
PBXN-111	5760	18.3
Composition H-6	7368	2.02
Composition B	7895	1.67

length parameter, described by D^* and a^* from Eq. 2, are different for these two compopsitions, reflecting the modifying role of aluminium in the RDX-driven detonation reaction in Composition H-6 at these charge diameters. The reaction zone length parameter in Composition B is more compact [2,5] than that in Composition H-6, but not greatly so; on the other hand, the value of D^* for Composition B is much greater than that of Composition H-6. While, overall, there are much more exothermic reactions taking place in Composition H-6 [Table 7, calculated from a program developed by Cichra and Doherty [14] based on

Table 7. The Calculated Heats of Detonation for Composition B and Composition H-6, for Possible Reaction Pathways, following Cichra and Doherty [14]

Formulation	**Calculated Heat of Detonation (kJ / kg)**			
	Reaction Pathway, as defined by Cichra and Doherty [14]			
	MO - CO - CO_2 - H_2O	MO - CO - H_2O - CO_2	MO - H_2O - CO - CO_2	CO - MO - MN
	(where MO = Al_2O_3 and MN = AlN, where applicable)			
Comp. B	3930	3700	4690	not applicable
	Products: principally H_2O, CO, CO_2, N_2, $C_{(s)}$ [Ref.15]			
Comp. H-6	7700	7700	8530	4155
Compare:				
RDX	5600	5050	5050	not applicable
ρ 1.80 Mg m^{-3}, V(∞) 8700 m s^{-1}				
PBXW-115	7725	7725	8550	6250
ρ 1.80 Mg m^{-3}, V(∞) 5642 m s^{-1}				
TNT	(Ref. 11, 14), ρ 1.64 Mg m^{-3}, V(∞) 6900 m s^{-1}, ΔH (exptl.) 4500 kJ / kg			
	Products: principally H_2O, CO, CO_2, N_2, $C_{(s)}$ [Ref.15]			
	2650	2650	4100	not applicable

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thermochemical inputs and the Kamlet-Jacobs methodology], the reactions in Composition B are generating more energy at the detonation front and depositing more energy before the CJ-plane, in the various charge sizes under investigation here [13,15,16].

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REFERENCES

1. D. J. Whelan and G. Bocksteiner, J. Energetic Materials, 13 15-34 (1995).

2. G. Bocksteiner, M. G. Wolfson and D. J. Whelan, *"The Critical Diameter, Detonation Velocity and Shock Sensitivity of Australian-made PBXW-115 (Aust.)"*, Aeronautical and Maritime Research Laboratory (AMRL) Report, DSTO-TR-94-0076 (1994).

3. H. Eyring, R.E. Powell, G.H. Duffey and R.B. Parlin, Chem. Rev., 45 69-181 (1949).

4. A.W. Campbell and R. Engelke, Proc. Sixth Symp. (Internatl.) on Detonation, San Diego, CA, USA, 642-652 (1976).

5. W. W. Wood and J.G. Kirkwood, *"Diameter Effect in Condensed Explosives. The Relation between Velocity and Radius of Curvature of the*

Detonation Wave", in J. G. Kirkwood, Shock and Detonation Waves (Gordon and Breach, New York) 1960, pp. 101-109.

6. K. Kim, *"Particle-Size-Dependent Reaction Rate in Shocked Explosives"*, in S. C. Schmidt & N.C. Holmes (Editors), Shock Waves in Condensed Matter 1987 (Elsevier, New York) 1988, pp. 531-534.

7. J. W. Forbes, E. R Lemar and R. N. Baker, Proc. Ninth Symp. (Internatl.) on Detonation, Portland, ORE., USA, 806-815 (1989).

8. M. C. Chick, T. Bussell and L. McVay, AMRL (formerly Materials Research Laboratory), Maribyrnong, Victoria, Australia. Unpublished work, 1987.

9. T. R. Gibbs and A. Popolato (Editors), *"LASL Explosive Property Data"*, University of California Press, Berkeley, CA, USA (1980), pp. 11-12, 239.

10. RDX, Australian Defence Standard, DEF (Aust.) No. 5382 (October 1974)

11. RDX, US Military Specification MIL-R-398C (Amendment 5, 1 May 1978).

12. a) L. McVay and T. Bussell, *"Some Properties of Australian-produced Explosive Composition H-6"*, Materials Research Laboratories Technical Report, MRL-TN-525 (1987).

b) T. S. Costain and R. V. Motto, *"The Sensitivity, Performance and Material Properties of Some High Explosive Formulations"*, Picatinny Arsenal Technical Report (Dover, NJ, USA), No. 4587 (1973).

13. a) D. A. Jones and D. L. Kennedy, *"Application of the CPEX Non-ideal Explosive Model to PBXW-115"*, Materials Research Laboratory Technical Report, MRL-TR-91-40 (1991).

b) D. L. Kennedy and D. A. Jones, *"Modelling Shock Initiation and Detonation in the Non-ideal Explosive PBXW-115 / PBXN-111"*, presented to the Tenth Symp. (Internatl.) on Detonation, Boston, Mass., USA, 12-16 July 1993, Paper 102 (1993).

14. D. A. Cichra and R. M. Doherty, *"Estimation of Performance of Underwater Explosives"*, Proc. Ninth Symp. (Internatl.) on Detonation, Portland, Oregon, USA, pp 633-639.

15. F. Volk, *"Analysis of the detonation Products of Insensitive High Explosives"*, Proc. 25th. Internl. Annual Conf. of ICT, 28 June-1 July 1994 (Karlsruhe, Germany), Paper 4, esp. Tables 1 and 2.

16. G. A. Leiper, Phil. Trans. Royal Soc. (London) A **339** 419-429, esp. pp 423-425, (1992), and references cited therein.