A Critical Diameter Study of the Australian Manufactured Underwater Explosive Composition H6

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ABSTRACT

Composition H6 is a widely used main charge filling for underwater blast weapons such as mines, depth charges, torpedoes and mine disposal charges. In weapon applications, computational models require experimental data to determine certain specific output parameters of H6 to predict various underwater blast scenarios. To this end, the critical diameter d_c , which is the minimum diameter which will sustain a stable detonation , and the limiting value of the velocity of detonation at infinite charge diameter D_∞ , were determined for unconfined cylinders of H6. An ionization probe technique was used to measure the velocity of detonation (V of D) of the H6 over a range of charge diameters (d).

The data thus obtained was fitted to an elliptical V (d) relationship to obtain the critical detonation parameters below:

PARAMETER	SYMBOL	RESULT
V of D at infinite charge diameter	V_∞	7367 m/s
cut-off-velocity	$V(d_c)$	6571 m/s
reaction zone length	a*	2.0 mm
critical diameter	d_c	4.4 mm

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Executive Summary

Computational models for predicting underwater weapon performance require input data for detonation parameters of the explosive filling , and one of these is the widely used underwater charge filling Composition H6. This explosive is often used in underwater blast weapon such as mines, depth charges, torpedoes and mine disposal charges. Australian manufactured H6 has the same percentage composition of ingredients as its US counterpart but the RDX component is made by a different process and has undergone a final milling and boiling process in its formulation. Thus Australian H6 is expected to exhibit different values for it`s explosive properties .

One of the important parameters needing resolution for model predictions is the critical diameter , which is the minimum diameter of a charge that will sustain a stable detonation. This parameter is determined by a series of experiments , using ionization probe techniques to measure the velocity of detonation (V of D) of the H6, over a range of charge diameters (d).

The data thus obtained was fitted to a V(d) vs (1/d) elliptical relationship, to obtain the reaction zone length parameter a*, from which the minimum diameter to sustain stable detonation , d_c , was calculated.

Other data determined from the experiments included:

(i) the V of D at infinite charge diameter D_∞ , and
(ii) the cut-off or threshold detonation velocity V(d_c).

As a consequence of the investigation the computational predicting models have a set of validated parameters to evaluate the performance of Australian H6 filled underwater warheads , rather than using estimates from related explosives.

The validated underwater blast prediction models will assist the ADF in modelling the terminal effects of underwater weapons on maritime targets , the smart purchase of effective weaponry and Australian Defence Industries in the development of Australian manufactured underwater weapons .

Contents

1. Introduction

Australian manufactured H6 differs from its US counterpart in that the RDX component is made by a different process (the direct nitration of hexamine) and has undergone a final milling and boiling process before it is added to the other ingredients. For this reason it is expected that the Australian H6 will have some different detonation parameters than those published for the American Composition H6.

Following on from an earlier evaluation [1] of some of the physical properties of H6 this technical note describes the use of an ionization probe (IP) technique to evaluate the V of D of H6 over a range of charge diameters. By applying Whelan's [2] recently published elliptical relationship between the experimentally determined V of D of unconfined cylindrical charges of the high explosives (HE) and the charge diameter (d), a curve fitting constant a* could be calculated. This allowed the critical diameter (d_c) of the HE, its maximum V of D at infinite charge diameter (D_∞), and its minimum cut-off or threshold velocity V(d_c) to be determined.

Further tests were conducted using a high speed photographic (HSP) technique [3] for charges, of 5 and 3 mm diameter. At these small diameters the ionization probes had been cumbersome and unreliable. By using the HSP technique it was anticipated that V of D data could be obtained at charge diameters nearer the predicted failure diameter.

2. Composition H6 , Designation and Background

Composition H-6 is a widely used main charge filling for underwater blast weapons such as mines, depth charges, torpedoes and mine disposal charges. It was first developed in the USA as an enhanced blast filling based on RDX/TNT [4]. Current Australian supplies of H-6 were manufactured at St Marys Munitions Factory (MFF) New South Wales and its main use to date has been as fillling for the Mk 82 and Mk 84 bombs.

The RDX component of Australian H6 was manufactured at Albion Explosives Factory (AEF) by the Woolwich process (direct nitration of hexamine) and, unlike its American counterpart, Woolwich type RDX is free of HMX [5]. The manufacturing process included, at the penultimate stage of production, a milling and boiling step, which was designed to break down crystlaline aggregates and remove traces of residual acid [6]. **This RDX was designated Grade B, Class 1.**

The composition of Australian H6 and it`s specification limits are listed in Table 1.

Table 1:Chemical Composition of H-6

Component	*Nominal Composition % by weight*	*Specification Limits % by weight*
TNT	29.5	29.2 ± 3.0
Aluminium	21.0	21.0 ± 3.0
RDX & Nitrocellulose (RDX usually Grade B)	44.0	45.1 ± 0.3
Calcium Chloride	0.5	4.7 ± 1.0
Wax	5.0	4.7 ± 1.0

Further properties of Australian made H-6 can be found in Reference [1].

3. Critical Diameter, Theory

The relationship between the experimentally determined velocity of detonation (V of D) of unconfined cylindrical charges of high explosives and the charge diameter, d, has been extensively examined. From the early work of Eyring et al [7] it became apparent that, for many explosives when tested in this configuration, there was an experimentally validated linear relationship between the V of D and the reciprocal of the charge diameter, 1/d, which took the form

$$V(d) = D[1-(a/d)] \quad (1)$$

where **V(d)** is the V of D of a detonating unconfined cylindrical charge of diameter **d**, and **D** and **a** are curve fitting constants , **D** being the limiting value of the V of D for a charge of infinite diameter and the reaction zone length **a** can be considered a constant characteristic of the explosive formulation.

When the charge diameter approaches the experimentally determined critical diameter, d_c, this equation was quite often seen to fail , especially with high density (>95% TMD) explosives.

Campbell and Engelke [8,9] added a further curve fitting constant d'_c to [Eq 1] which allowed a large amount of V(d) data to be rationalised by a form fitting approach to give :

$$V(d) = D\,(1-[a/d] - [ad'_c/(d-d'_c)] \quad (2)$$

with d'_c being a calculated diameter, as distinct from the experimentally determined critical diameter.

Whelan [2] discovered that the collated experimental results were usually better fitted by an elliptical relationship between V(d) and (1/d), i.e.,

$$V(d)^2 = D^2 (1-[a^*/d]^2) \quad (3)$$

Once again **D** and **a*** are curve fitting constants, whose values are obtained from the linear plot of $V(d)^2$ vs $(1/d)^2$, **D** being the velocity at 1/d = O and the slope = **-Da***. A plot of a* vs d_c from the experimental results obtained a simple line of best fit of the form

$$\mathbf{d_c} = 2.208\ a^* \quad (4)$$

which gave very good agreement between the calculated critical diameters and the experimentally obtained figures.

Combining Eq 3 and 4 the "lower threshold velocity" or "cut-off velocity", $\mathbf{V(d_c)}$ becomes

$$V_{(dc)} = 0.892D \quad (5)$$

By fitting the data to the elliptical relationship $\mathbf{[V_{(d)}]^2}$ versus $\mathbf{[1/d]^2}$ the limiting value for the velocity of detonation **D** could be found. From Eq 3 [2] the curve fitting constant **a***, which is described as being the reaction zone length parameter, was determined . Using Eq 4 the minimum diameter for sustainable stable detonation $\mathbf{d_c}$ (for unconfined cylinders) was calculated , and finally by Eq 5 the cut-off velocity $\mathbf{V_{(dc)}}$ was found.

4. Charge Preparation

The H6 samples used in this investigation were open cast from melted H6 biscuit material , as supplied by Munitions Filling Factory , St.Marys . The samples were melted in steam kettles and poured into preheated moulds. The moulds were allowed to solidify and cool to room temperature before the H6 cylinders were extracted from the mould by pressing. The removal of the casting headers and machining of the samples to size was carried out using a remotely-operated NC lathe .The aluminium component in the H6 castings was found to considerably reduce the service-life of the hardened-steel cutting tools , compared to Composition B .

Charge diameters prepared for testing were : 3 , 5 , 9.4 , 13.5 , 15.7 , 22.75 and 38mm.

Nearing the 5 and 3mm diameter charge sizes the lathe cutting tool had to be kept very sharp , extremely light cuts taken and adroit machining employed to avoid snapping-off the cylindrical samples.

5. Experimental

5.1 Ionisation Probe Technique

Simple and accurate methods of electronically measuring V of D with ionisation switches, also referred to as probes or pins, were described by Campbell et al in 1956 [10]. The updated method used at AMRL in this study involving high speed digital recording and computer techniques [3] was presented by Campanella at the 15th Filling and Assembly Conference MFF St Marys in May 1987.

Using an assembly as shown in Figure 1 the probes were placed at measured intervals between the accurately machined cylinders of cast H-6 . The probes act as open circuit switches which are progressively closed by the passage of the highly ionised detonation front. As each switch closes the electrical pulse that is simultaneously produced was recorded on a digital waveform recorder (Biomation Model 6500) interfaced with a minicomputer (Charles River Data System Model MF211) which processed the digitised data and calculated the mean V of D within seconds of the test being conducted. The minicomputer, via a plotter, also performs an annotated plot of the ionisation probe voltage pulses and calculates the mean of V of D.

A block diagram of the measuring system used is shown in Figure 2.

Figure 3 shows a typical plot of the recorded waveform with results from one of the 22.75 mm charge diameter H-6 tests. Duplicate firings of H-6 unconfined cylinders at five (5) cast diameters (d) were evaluated. The mean V of D was calculated for each diameter , and as per the elliptical relationship formula [2], the linear plot of [V of D] squared versus [1/d] squared was used to find D and a* which in turn gave the d_c.

The high speed photographic (or streak camera) technique was attempted because of the increasing difficulty in assembly of the pin probes for charge diameters under 10 mm. Also, at these diameters, surface discontinuities were more apparent.

As was found by Spear and Wolfson [11] the streak records revealed a variation in image sharpness and a slight variation in magnification across the film from edge to edge. As only two of the four shots detonated a correction factor could not be calculated and it was decided not to use the 5 mm charge diameter V of D results in plotting the d_c.

5.2 Ultra High Speed Streak Photographic (HSP) Technique

Reference [3] gives a complete description of this method of V of D measurement.

Figure 4 shows the H6 pellets in the specially made cardboard jig. The distance between the taut horizontal wires above the detonator and below the end-stop was accurately measured using a Bishop Opto-Scale.

The assembled charge was then set vertically in the firing chamber and the firing leads connected. A Cordin Mod 330 simultaneous streak and framing camera was used in streak mode with the streak slit and the horizontal fiducial wires being focussed by back projection vertically along the charge. Using Kodak T-max P3200 film the camera was first run at slow speed with the charge assembly back illuminated thus exposing the silhouette images of the wires and providing fiducial lines along the full length of the film. The film was then rewound, the lights removed and with the camera run at a known high speed the charge was fired. This exposed a continuous displacement/ time record of the light output from the detonation front on the same film used for exposure of the fiducial lines.

The V of D was determined using a Calcomp Mod.622 digitising tablet, interfaced to a PC, to digitise an enlarged print of the streak record. After allowing for the image magnification and camera writing speed a distance/time plot was obtained. The positions at the start and finish of the streak record which showed the explosive was under or overdriven from the detonator were excluded from the measurement thus leaving the portion of the streak where stable detonation occurred.

A linear regression performed on the stable detonation points determined the best straight line fit, the gradient of which is the V of D.

6. Results

6.1 I P Technique

The results of the V of D measurements obtained by the ionisation probe technique and the plotting data can be seen in Table 2 .

Table 2. V of D vs Charge Diameter

Diameter	Diameter	1/diam, m	VoD	Trend *	$1/d^2$	V^2	Trend *	√(Trend) *
mm	m	m	ms^{-1}		m^{-2}	m^2s^{-2}		
9.4	0.0094	106.4	7147	7206.4	11317	51079609	51770687	7195
9.4	0.0094	106.4	7238	7206.4	11317	52388644	51770687	7195
13.47	0.01347	74.2	7291	7274.3	5511	53158681	53062046	7284
13.47	0.01347	74.2	7290	7274.3	5511	53144100	53062046	7284
15.7	0.0157	63.7	7330	7296.6	4057	53728900	53385554	7307
15.7	0.0157	63.7	7283	7296.6	4057	53042089	53385554	7307
22.75	0.02275	44.0	7348	7338.3	1932	53993104	53858162	7339
22.75	0.02275	44.0	7325	7338.3	1932	53655625	53858162	7339
38	0.038	26.3	7355	7375.6	693	54096025	54133879	7358
38	*0.038*	*26.3*	*7294*	*#N/A*	*693*	*53202436*	*#N/A*	*#N/A*

* *Trend = The linear least squares fit of the $(VofD)^2$ vs $(1/d)^2$ data set .*

The results appear to comply with the [2] linear coefficient in the elliptical $V_{(d)}$ vs d relationship , the exception being the final 38mm diameter charge result (italised). An anomaly may have occurred in the density gradient or a slightly slower transfer from the booster to the main charge , however , the velocity would be expected to quickly pick-up to the V of D of the H6 material and have little effect on the steady state detonation . The inconsistently low value was therefore attributed to experimental variation or instrument error and the V of D reading not used in calculating the mean for the 38 mm diameter charge.

Table 3 shows the averaged IP technique V of D results for the various charge diameters and the relationships 1/d, $[1/d]^2$ and $[V \text{ of } D]^2$.

Table 3. Averaged V of D vs. Charge Diameter

Diameter (d) [mm]	1/d [m]	$[1/d]^2$ [m]	V of D ms^{-1} Averaged	[V of D]^2 $m^2\ s^{-2}$
9.4	106.38	1317	7193	51739249
13.5	74.24	5511	7291	53158681
15.7	63.29	4057	7307	53392249
22.8	43.96	1832	7336	53816896
38.0	26.32	693	* 7355	54096025

* = Not Using Data from shot 10

A plot of the Table 3 data , V versus 1/d, is shown below in Figure 4.

A line-of-best-fit to the data gives the V of D at infinite charge diameter as 7423 m/s, with a linear least squares coefficient of determination of 0.831.

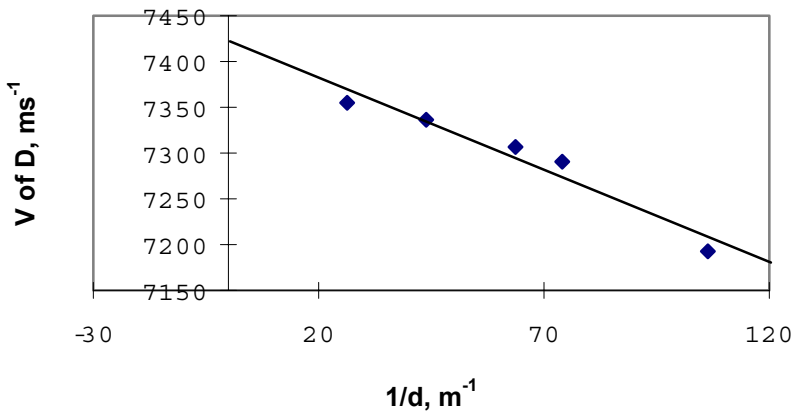

Figure 4 . Plot of [1/d] vs [V] for Composition H6 .

A plot of the Table 3 , V^2 verses $1/d^2$, data is shown below in Figure 5 . A line-of-best-fit from this gives the V of D at infinite charge diameter as 7367 m/s , with a linear least squares coefficient of determination of 0.996 .The curve fitting constant a* , from the slope -221.52 = $-(D^*)^2(a^*)^2]$, is then = 2.02mm.

From Eq 4 $d_c = 2.208\ a^*$
Therefore the Critical Diameter of unconfined H6 = 4.4 mm
The cut-off velocity $V(d_c)$, from Eq. 5 = 6571 m/s.

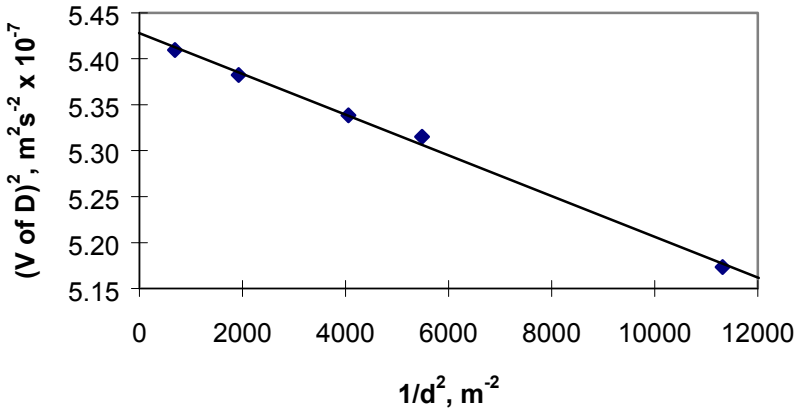

Figure 5 . Plot of [1/d]² vs [V(d)]² for Composition H6.

6.2 HSP Technique

Table 4 shows the HSP technique V of D results for the various charge diameters and the relationships 1/d, $[1/d]^2$ and $[V \text{ of } D]^2$.

Table 4. V of D results obtained from HSP technique

Dia. (d) *mm*	*1/d* *m*	*$[1/d]^2$* *m*	*V of D* *ms^{-1}*	*$[V \text{ of } D]^2$* *$m^2 s^{-2}$*
3	333.33	111111	No detonation	No detonation
3	333.33	111111	No detonation	No detonation
5	200.00	40000	7051	49716601
5	200.00	40000	6855	46991025

The attempt to use the HSP technique for V of D measurement was considered unsatisfactory (see Table 4 above).The ~200 m/s spread of results for the duplicate shots at the 5 mm charge diameter , where detonation did occur , was too large to be acceptable . The variation itself , may be a consequence of being so close to the materials failure diameter .The results , however , did successfully confirm that the d_c of the Australian H6 composition was less than 5 mm and greater than 3 mm .

7. Discussions

When comparing results for the Australian produced H6 with those of the US one must remain aware that each appears to follow its own formulations which all approximate to the generic melt-cast formulation quoted in the US Army Materiel Command Handbook [12] and the US Military Specification [13]:-

RDX	45 ± 3
TNT	29 ± 3
Wax	4.7 ± 1
Aluminium	21 ± 3
$CaCl_2$, etc.	ca 0.5

At NSWC the critical diameter of unconfined H-6 was determined by Stosz [14] to be between 5.1 and 7.6 mm for samples of density 1.72 Mg m^{-3} and by Forbes et al [15] as 6 mm , also at 1.72 Mgm^{-3}. This they noted was fairly similar to their Composition B (60% RDX : 40% TNT with 0.5% wax) which was quoted as 5.0 ± 0.5 mm (for a density of 1.70 Mg m^{-2}).

The expected trend [16] of V of D increasing with increased density of composition was confirmed by comparison with the NSWC data in Table 5 below :

Table 5. Comparison of Australian and US compositions

COMPOSITION	**Density (Mgm^{-3})**	**V of D (m/s)**	**Crit. Dia. (mm)**
AMRL H-6	1.74	7337*	4.4 (Calc.Av.)
NSWC H6 [14]	1.76	7430*	6.3 (Average)

* = Average of two tests for approximately 1 inch diameter cylinders

The RDX used in the manufacture of Australian H6 has primarily been of the smaller particle size M&B Grade B variety . The US RDX is all of the recrystallised variety (therefore larger particle size) , and this would have been used in the NSWC formulations quoted.

A scanning electron micrograph (SEM) of a test piece sample is shown in Figure 5 at x 500 magnification . The irregular RDX Grade B crystals can clearly be seen in the foreground of the polished and etched (bromoform) sample . An identical magnification comparison with SEMs of Composition B samples formulated with recrystalised RDX Grade A and milled and boiled RDX Grade B is shown in Figures 6 & 7 respectfully . These highlight the greater variation in particle size and shape of the Grade B RDX crystals , as used in the Australian manufacturing process of H6 .

In a related study the present authors examined the effect of the two Australian RDX types , on V of D ,when used in Composition B [17]formulations. The results can be seen in Table 6 below:

Table 6. Related V of D data on H6 ingredient Composition B

RDX Type	Formulation	Crit. Dia.	D^*
RDX Type A Class 1	60% RDX, 40% TNT with 1% wax	6.7 mm	7720 m/s
RDX Type B Class 1	55% RDX, 45% TNT with 1% wax	3.6 mm	7658 m/s

The steady state V of Ds between the two was less than the 1% that could be expected from experimental error, however, a significant difference was found in the critical diameters.

A particle size comparison of the two types of RDX manufactured in Australia since 1976 , can be seen below in Table 7.

Table 7. RDX particle size comparison

Type	Final Process	Average Particle Dia.
RDX Grade B Class 1	Boiling and Milling	~ 75×10^{-6} m
RDX Grade A Class 1	Recrystallising	~ 200×10^{-6} m

The results indicate that there appears to be a significant decrease in critical diameter for Composition B with decrease in particle size and therefore Australian H-6 with its significantly smaller average RDX particle size diameter, compared to its US counterpart, could be expected to have a smaller critical diameter.

8. Conclusions

The steady state V of D of Australian manufactured Composition H6 was studied over a number of charge diameters using an Ionisation Probe technique.

The information thus obtained was fitted to an elliptical velocity/charge diameter relatioship which made it possible to predict the detonation parameters, as shown below.These may now be included in the specific hydrocode studies being conducted at AMRL to model underwater blast phenomena.

PARAMETER	SYMBOL	RESULT
V of D at infinite charge diameter	V_∞	7367 m/s
cut-off-velocity	$V(d_c)$	6571 m/s
reaction zone length	a*	2.0 mm
critical diameter	d_c	4.4 mm

It was noted that the reaction zone length parameter (a^*) for the US composition H6 appeared to better compare with the Australian Composition B manufactured using the larger grained R_x RDX than the Australian H6 .The theory that RDX particle size is a controlling factor in determining d_c was further enhanced when a much reduced reaction zone length parameter was found for the smaller grain sized M&B RDX Composition B variant 17].

The experimental results agreed with Whelan`s findings [1] that RDX -driven composite explosives appear to better fit a simple elliptical relationship between V(d) and (1/d) than the linear relationship described by Eyring et al [7] .

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