Journal of Engineering and Applied Sciences 12 (4): 950-953, 2017
ISSN: 1816-949X

An Interrelationship Between Reaction Zone Thickness and Explosives Column Length Derived Using a Polymer Bonded Explosives Formulation

Henco Bezuidenhout and Samir Mukhopadhyay
Department of Chemical Engineering, Faculty of Engineering,
Cape Peninsula Universit of Technology, Cape Town, South Africa

Abstract: Published literature suggests that the reaction zone length is related to the charge diameter in an explosives detonation. The research presented in this study made an effort to establish a possible interrelationship between reaction zone thickness and explosive column length as opposed to charge diameter. For the purpose of experimental validation, explosive charges of different length were prepared keeping the density and diameter unchanged. All charges were fired against aluminium witness blocks and the dimensional elements of the indentations were measured. The results obtained from the study had shown that the reaction zone thickness was related to charge length. An equation was proposed for the detonation velocity prediction relating to explosive height.

Key words: Explosives height, reaction zone, aluminium block, indentation diameter, explosives diameter

INTRODUCTION

In an explosive charge, the relationship between the detonation velocity, diameter of the charge and reaction zone length can be defined by Eq. 1 (Eyring *et al*., 1980). Reaction zone length refers to the length or thickness of the layer in which the chemical reaction takes place. Eyring *et al*. (1980) suggested the reaction zone length be obtained by plotting detonation velocity of unconfined explosives charges (D_u) against the explosive cylinders inverse radius ($y = 1/R_0$) in mm^{-1}. Further to this Souers (1999) stated that data reported in the before mentioned way evolved to become the standard display of the size effects with specific reference to diameter (Eyring *et al*., 1980) used the constant which they believed to be the reaction zone length. Souers *et al*. (2004) later interpret this constant to be the skin thickness where no energy release occurs. For the purpose of this study Eyring's interpretation of being the reaction zone length is adopted. Cooper highlighted that the detonation velocity asymptotically approached a constant value as the diameter of the explosives charge became larger (Cooper, 1996). This could continue until an ideal detonation velocity or infinite diameter detonation velocity (D_∞) was obtained:

$$\frac{Du}{D\infty} = 1 - a\frac{1}{d} \qquad (1)$$

Determining the reaction zone thickness can be invaluable in understanding the effect of confinement on the velocity of detonation in an explosive charge. It is, however challenging to determine the reaction zone thickness from experimental data obtained by the diameter relation because manufacturing of explosive pellets having large variations in dimensional parameters. Explosives pellets were manufactured by pouring explosives powder into a cylindrical hole in a steel mould. A top and a bottom punches were placed into the cylindrical cavity in the mould so that the explosives powder was between the punches. The explosives powder was then compressed by moving the punches towards each other. This produce a solid, cylindrical explosives charge with the same diameter as the inner diameter of the cylindrical hole in the mould. By keeping the explosives mass constant and varying the travel distances of the punches the length of the solid explosives charge changed and inadvertently also the density of the charge. An explosives charge manufactured in the described manner is known as an explosives pellet. The challenge being that for each explosives pellet with different diameter a specific tooling is required. Hence, an alternative approach is needed to determine the reaction zone thickness where such manufacturing constraints do not exist. From the published literature, alternative methods for determining (with specific reference to explosives column height) is yet to be established.

Corresponding Author: Henco Bezuidenhout, Department of Chemical Engineering, Faculty of Engineering,
Cape Peninsula Universit of Technology, Cape Town, South Africa

This study reports on the investigation conducted in an effort to replace (a_h) determined from diameter with (a_h) determined from explosives column Height (H_e). Throughout this study a Polymer Bonded explosives (PBX) formulation containing 95% cyclo-trimethylene trinitramine (RDX) and 5% Kel-F (in this study RXKF 9501) was used. Explosive columns of similar diameter (7.88 mm) and density (ρ) (1.66 g/cm^3) were used but the length of the explosive charges was varied. The witness blocks were cylindrically shaped with a diameter of 50 mm and height of 20 mm in all experimental research.

MATERIALS AND METHODS

In this study, the witness block material was kept constant in all experimental research. Hence, the profiles obtained were assumed to be influenced by the energy fluctuations of the explosives column only. For the experimental work explosive pellets with a diameter of 7.88 mm were used. This diameter was chosen as this was sufficiently above the critical diameter of the explosives formulation (4.0 mm <critical diameter >5.0 mm) identified for this study (Dobratz, 1985). Although, the critical diameter was not known, pre-work towards this study had shown reliable detonation in column thicknesses as low as 2 mm, hence the proposed literature value of 4-5 mm was considered within acceptable range. Furthermore this diameter range could be achieved from existing tooling and was compatible with the available manufacturing capability.

To determine the influence of explosive column length on the indentation profile of the aluminium witness block, seven different charge lengths were prepared and tested. Identifying the optimal means of initiating the explosives pellets was crucial as this would influence run-up distance to optimal detonation velocity at a specific explosive column length (D_h) in the defined geometry. When working in small diameters with length over diameter ratio's <1, it was important to ensure that the initiator used did not contribute to the indentation obtained in the witness block.

Research done by Johansson and Persson (1970) showed that when an initiator transfers energy to an acceptor charge, acceptor charge does not start to react from the axial plane at the exact interface. Rather that the acceptor charge starts to react (pick-up) a certain distance from the axial interface. This distance then contains a region of unreacted explosives. The distance is a function of the magnitude of the donor or initiator charge and the thickness of a barrier between the donor initiator and the acceptor. In these tests the barrier is the bottom of the aluminium initiator shell. If the donor charge is large, unreacted explosives increase. When working with thin layer explosives this is a crucial parameter to control. Methods of initiation should be such that that he region of unreacted explosives is as small as possible. Exploratory work conducted by the researchers of this study identified a detonator with low explosives content and would be an optimal initiator for this evaluation. The detonator contained 0.03 g of Penta-Erythritol-Tetranitrate (PETN) and 0.160 g of lead azide.

Table 1: Indentation profile of explosives charges with different lengths

Sample	H_e (mm)	d (mm)	M_e (g)	ρ (g cm^{-3})	H_e/d	I_d (mm)	d_i (mm)
A	1.99	7.88	0.16	1.66	0.25	1.34	10.27
B	3.01	7.88	0.24	1.66	0.38	1.39	10.74
C	4.25	7.88	0.34	1.66	0.54	1.81	12.14
D	7.51	7.88	0.61	1.66	0.95	2.42	13.34
E	15.02	7.88	1.22	1.66	1.91	2.92	14.21
F	22.59	7.88	1.83	1.66	2.87	3.06	14.26
G	30.03	7.88	2.43	1.66	3.81	3.06	14.64

The experimental set-up entailed cylindrical RXKF 9501 explosives charges, varying in length from 1.99-30.03 mm being tested on aluminium witness blocks. Each charge was placed vertically in the centre of an aluminium block. A detonator was placed on top of the explosives charge. Post-test, the indentation diameters (d_i) and indentation depths (I_d) of the profiles were measured. Results obtained from the above tests are given in Table 1. Additional tests were conducted in an attempt to measure (D_u). Break wires connected to an oscilloscope were secured to the explosive charges at selected distances. The oscilloscope recorded the time when each of the break wires open the electrical circuit (the wires break). The distance/time relationship is then used to calculate the detonation velocity of the reaction.

RESULTS AND DISCUSSION

Witness blocks had shown a trend in change in profiles after tests were conducted progressively. As the explosives mass increased, the indentation profile also changed dimensionally. Table 1 show the detailed result obtained on indentation profile of explosive charges varying length.

Table 2 shows the detonation velocities measured against explosive column lengths. Table 2 also highlights that when the explosives column height increases, detonation velocity increases too. Equally Table 2 shows that the indentation diameter increases as the explosives column height goes higher. The aforementioned dimensional changes relate to the power of the explosives which in turn arise from the detonation velocity of the explosives. It can be postulated that the detonation

Table 2: Detonation velocity related to explosives height and indentation diameter

D_h measured (km sec^{-1})	ρ (g cm^{-3})	H_e (mm)
7.393	1.66	3.400
7.551	1.66	4.650
8.161	1.67	7.780
8.210	1.66	15.710
8.249	1.67	23.450
8.401	1.67	31.200

velocity asymptotically approaches a constant value as the height of the explosives column becomes longer. As the indentation depth and diameter approach a plateaued region, it is indicative of constant power output of the explosives even with an increase of explosive height. From a constant power output, a constant detonation velocity can be assumed. This explanation addresses detonation velocity related to infinite Diameter (D_∞).

The observations from this study can relate to the same argument applicable to detonation velocity at infinite explosive column height. From Table 1, it is seen that indentation diameter and indentation depth approach a constant value at H_e/d ratio that is >1. A plot of d_i/H_e (Fig. 1) shows that indentation diameter approaches a plateaued region over a certain height of explosives.

In this plateaued region the detonation velocity is almost constant reaching an optimum and it can therefore be accepted that the reaction zone thickness is approaching to a constant value. The slope of the linear section of the indentation vs explosives column height plot can not be accepted as a function of the reaction zone thickness (as this is purely indentation data). Detonation velocity vs. $1/(H_e/d_i)$ plot (Fig. 2) also show a linear section (where the detonation velocity approaches steady state) and the slope of this section is deemed as a function of the reaction zone length. The new value for (a), now (a_h) is determined to be 0.2395. Souers (1999) reported a reaction zone thickness of 0.22 mm for RDX at a density of 1.67 g cm^{-3} (Sours *et al*., 2004).

The D_∞ represent infinite diameter detonation velocity and in this approach this is considered to be equal to the detonation velocity at theoretical maximum Density (D_{TMD}). This has been verified by cross calculating detonation velocities using data from the literature. The D_{TMD} for the explosives composition used in this evaluation (RXKF 9501) is 8.635 km sec^{-1} with a corresponding theoretical maximum density (ρ_{TMD}) of 1.82 g/cm^3. Using the Urizer Eq. 2, 1.66 g/cm^3 as used in this study:

$$D_u = 5050 + \rho\left(\frac{D_\infty - 5.50}{\rho TMD}\right) \qquad (2)$$

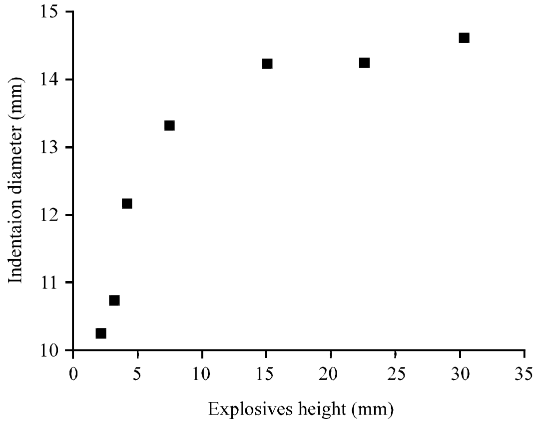

Fig. 1: Indentation diameter (d_i) as a function of explosives height

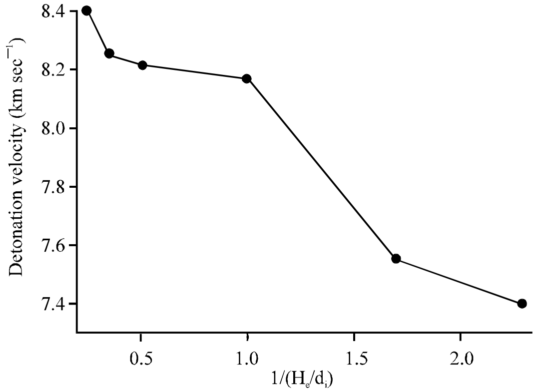

Fig. 2: Detonation velocity as a function of $1/(He/d_i)$ (D_u)

This correlates well with actual measured detonation velocity average of 8.373 km sec^{-1}. With the diameter of the explosives charge known and a measured detonation velocity being available, equation 1 was used to calculate (a). Equation 1 rendered a value of 0.2391 for (a) that compared closely with (a_h), established earlier as being 0.2395. It must be noted here that (a) is different for different explosives (Cooper, 1996) similarly will (a_h) be different for different explosives.

From Eq. 1 using (a), the detonation velocity for other diameters can be plotted. When (a_h) is used and values in Eq. 1 are replaced with height instead of diameter a marginal shift in the values is observed as these values being slightly higher. However corresponding data with the new reaction zone thickness can be considered comparable to the reaction zone thickness determined from explosive column diameter values. Equation 1 can not be used for values with $H_e/d_i<1$. Using the data from Table 1 an interrelationship has then been derived describing (D_h) to indentation depth (Eq. 3):

Table 3: Indentation data compared to detonation velocity data

Indentation diameter determination			Detonation vlocity determination			
H_e (mm)	d_i (mm)	D_hC^* (km sec^{-1})	D_h M^{**} (km sec^{-1})	D_hC^* (mm)	d_i (mm)	H_e (mm)
1.990	10.27	7.019	-	-	-	-
3.010	10.74	7.127	7.393	7.326	11.19	3.40
4.250	12.14	7.865	7.551	7.874	12.23	4.65
7.510	13.34	8.317	8.161	8.322	13.38	7.78
15.02	14.21	8.471	8.210	8.429	14.18	15.71
22.59	14.26	8.287	8.249	8.291	14.30	23.45
30.30	14.65	8.362	8.401	8.369	14.69	31.20

C^* = Calculated result; M^{**} = Measured result

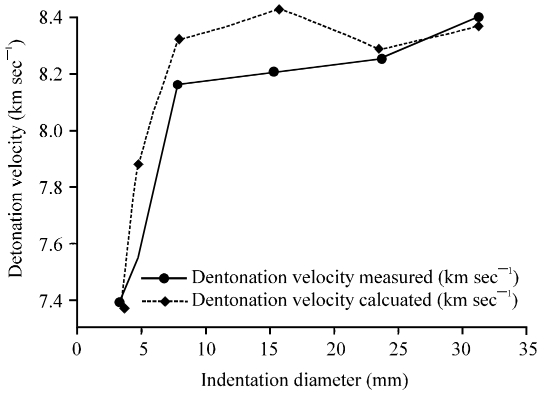

Fig. 3: Calculated and measured detonation velocity as a function indentation diameter

$$\left[\frac{D_h}{d_i}\right]^{-1} = 0.1061\times\left(\mathrm{In}H_e\right)+1.3901 \tag{3}$$

This interrelationship describes the detonation velocity at column lengths that give a $H_e/d_i<1$ and also for $H_e/d_i>1$. In this interrelationship, the following variables are catered for: the detonation velocity at height, the explosives height and the indentation diameter obtained from experimental data. Results obtained from Eq. 3 are shown in Table 3 and compared to measured data in Fig. 3.

CONCLUSION

Reaction zone thickness can be determined from explosives height. Indentation profiles show a distinct region where the indentation diameter and indentation depth stabilize. It has been shown that the detonation velocity asymptotically approaches a constant value as the height of the explosives column goes higher. An equation is proposed for the detonation velocity prediction relating to explosives height. This equation has been developed and validated using indentation data derived experimentally. The new equation provides comparable results to experimental data.

ACKNOWLEDGEMENT

AEL mining services for the use of their laboratories and financial assistance.

REFERENCES

Cooper, P.W., 1996. Explosives Engineering. Wiley, New York, USA., ISBN:9780471186366, Pages: 460.

Dobratz, B.M., 1985. LLNL Explosives Handbook: Properties of Chemical Explosives and Explosive Simulants. University of California, ?Oakland, California?, USA.,.

Eyring, H., F.E. Walker, S.M. Ma and N. Coon, 1980. Similarity and differences between conditions for initiation and failure of detonation. Proc. National Acad. Sci., 77: 2358-2361.

Johansson, C.H. and P. Persson, 1970. Detonics of High Explosives. Academic Press, Cambridge, Massachusetts, Pages: 330.

Souers, P.C., 1999. Measuring explosives non-ideality. Lawrence Livermore National Laboratory, Livermore, California, USA.

Souers, P.C., P. Vitello, S. Esen, J. Kruttschnitt and H.A. Bilgin, 2004. The effects of confinement on detonation velocity. Propellants, Explos. Pyrotech., 29: 19-26.