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THE EFFECT OF CHARGE REACTIVE METAL CASES ON AIR BLAST

Fan Zhang[1], **and William H. Wilson**[2]

[1]*Defence R&D Canada-Suffield, P.O. Box 4000, Stn. Main, Medicine Hat, AB, Canada T1A 8K6*
[2]*Defense Threat Reduction Agency, 8725 John J. Kingman Rd., Fort Belvoir, VA, U.S.A. 22060-6201*

Abstract. Experiments were conducted in a 23 m^3 closed chamber using a charge encased in a cylindrical reactive metal case to study the effect on air blast from the case fragments. Parameters varied included case/charge mass ratio, charge diameter and charge type (i.e., detonation energy and pressure). The pressure histories measured on the chamber wall showed a double-shock front structure with an accelerating precursor shock followed by the primary shock, suggesting the early-time reaction of small case fragments. During the early reflections on the chamber wall, significant pressure rises versus the steel-cased and bare charges indicated combustion of a large amount of small case particles generated by secondary fragmentation. The analysis of explosion pressures and recovered fragments and solid products gave an expression for burnt casing mass as a function of Gurney velocity and charge diameter. The equivalent bare charge mass that yields the same explosion pressure as the cased charge increased with case/charge mass ratio and reached 2.5 times charge mass at the ratio of 1.75.

Keywords: Reactive case, reactive structural material, fragmentation, air blast.
PACS: 44.05.+e, 62.20.mm, 47.40.-x.

INTRODUCTION

As a steel cased explosive charge detonates, high-speed fragments of the case deliver lethal kinetic energy pieces that also enhance momentum loading to the near-field structure. Alternatively, fragments from a reactive structural metal case can introduce both the kinetic energy effect and a secondary energy release through fragment combustion to enhance blast loading [1]. Fragments whose combustion is completely or partially controlled by diffusion-limited rates provide a high rate of energy release only if they are small [2]. Whether combustion of reactive fragments can effectively contribute to air blast depends on the reaction mechanism of the fragment material and size distribution with sufficient concentration. The effort has been made in previous work to give the effect of reactive metal cases on air blast in dependence on detonation energy and pressure through closed chamber experiments [1]. The current work is aimed at a more general expression for air blast enhancement in terms of case/charge mass ratio, charge diameter and detonation energy and pressure.

EXPERIMENTAL PROCEDURES

Experiments were conducted in a 3 m internal diameter, 23 m^3 cylindrical steel chamber [1]. A 12.3 mm thick replaceable layer of steel was clad on the internal surface of the chamber wall to prevent its damage from high-speed case fragments. Three Endevco piezo-resistive pressure transducers were installed on the chamber cylinder wall indicated by B, C and D, where the C was located at the middle with an interval of 0.7 m between the gauges. High-speed video photographs were taken from a window located at the center of the right end plate of the chamber. The charge was suspended in the center of the chamber and the chamber was then closed with a local atmospheric air pressure of 91.8-92.8 kPa and temperature of -6 to 9 °C. The residue fragments and solid products of explosion are recovered after each test.

A C4 explosive and a RDX/IPN/Al thermobaric explosive (TBX) were chosen. According to the Cheetah code 2.0 (Lawrence Livermore National Laboratory) with the BKWS EOS, the detonation mechanical energy, pressure and velocity were 5.74 kJ/g, 25 GPa, 8.0 km/s and 3.43 kJ/g 14 GPa, 6.6 km/s, respectively, assuming Al in TBX to be inert during the detonation due to large particle sizes. The charge was contained in a reactive metal case, a baseline steel case or a reactive metal-steel bimetallic case, where the case comprised a 16.25 cm long cylindrical tube and two end plates. Bare charges contained in a 2 mm thin polyethylene case were used as reference charges. Table 1 summarizes all the parameters studied including a range of case/charge mass ratios, charge diameters, explosive types (detonation energy and pressure) as well as case materials.

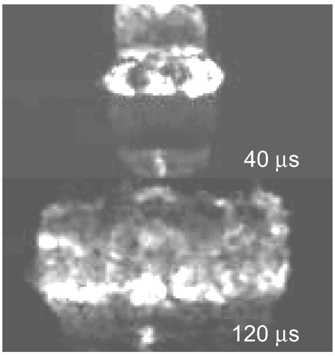

Figure 1. Case fragmentation in early explosion of a 7.62 cm I.D. reactive metal case/C4 charge (#9167C).

RESULTS AND DISCUSSION

Figures 1 and 2 show the reactive case expansion and fragmentation and the subsequent fireball in early explosion of a 7.62 cm inner diameter (I.D.) C4 charge, based on 50 frames/ms high speed photographs. Detonation is initiated from the top by an RP83 detonator. The cylindrical case fracture and fragmentation occur at a failure radius $R_f \approx 2R_0$ at 40 µs (R_0 - initial case outside radius), and fragments can be seen later in Fig. 1.

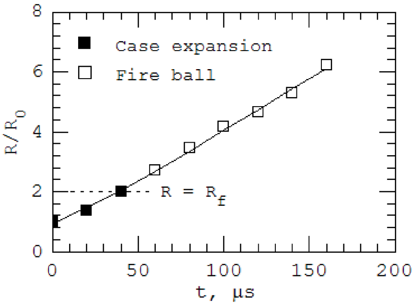

Figure 2. Case and fireball radial expansion for the charge in Fig. 1 (#9167C).

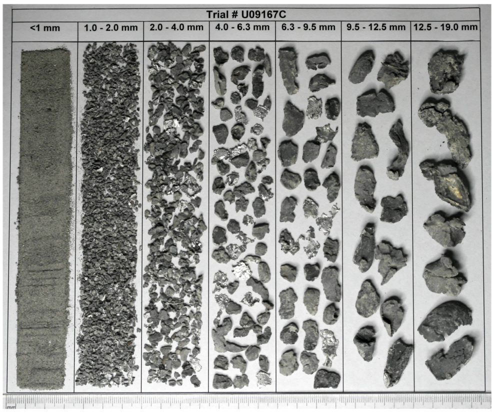

Figure 3. Recovered fragments and < 1 mm powder including fine fragments and oxide products (#9167C).

After the explosion, the detonation and afterburning products were clad on the chamber walls but mostly found on the floor of the chamber. An example of the recovered residue fragments and solid products from a reactive case/C4 charge is shown in Fig. 3. Figure 4 plots the measured fragment distribution for the 10.16 cm I.D. reactive case/C4 charges at various ratios of case mass, *M*, and charge mass, *C*. An increase in case/charge mass ratio (*M/C*) results in a shift of the size distribution towards the larger fragments.

The shock front of the reactive-cased charges (both C4 and TBX) exhibits a two-shock structure, as displayed in Fig. 5. A precursor shock is followed by the primary shock generated from the detonation transmission. When compared with the shock front structure of the bare and the steel-cased charge, the appearance and enhancement of the precursor shock suggests the combustion of small reactive fragments in the early time before the wave reaches the chamber wall. An increase in *M/C* results in an enhancement in precursor shock. Similar two-front structure was also observed for charge configurations of a TNT core surrounded by reactive particles [3].

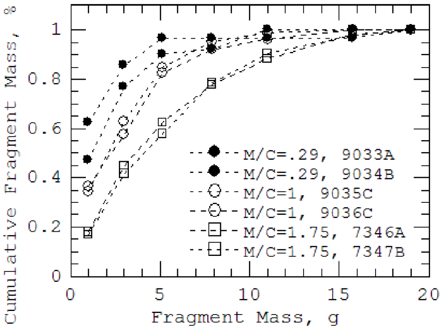

FIGURE 4. Fragment distributions of 10.16 cm I.D. reactive case/C4 charges at various *M/C*.

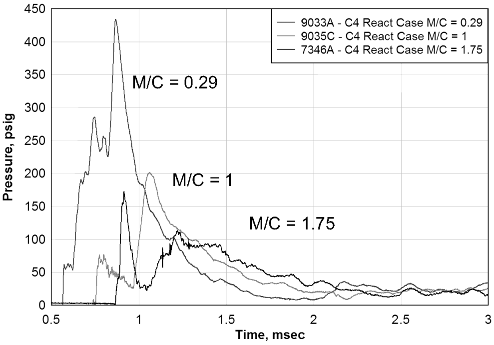

FIGURE 5. Front pressure structure at gauge B for 10.16 cm I.D. reactive case/C4 charges at various *M/C*.

Figure 6 gives the long time reverberating pressure wave histories approaching quasi-static pressures (QSP). An increase in *M/C* results in a decrease in the initial explosion pressure but an increase in the follow-on pressure. Within the first 10 ms between the first and fourth reflections on the chamber wall, the pressure rise for reactive case charges achieves a factor of 1.6 (at *M/C* = 1.75) versus the bare charge, based on an average of the pressures at the three gauge locations. This indicates rapid combustion of a considerable amount of small case fragments that are further generated by secondary fragmentation through wall impact fracturing and molten fragment aerodynamic breakup (stripping and shattering). The final QSP for the reactive case charges tested reaches a factor of 1.84 versus the bare charge.

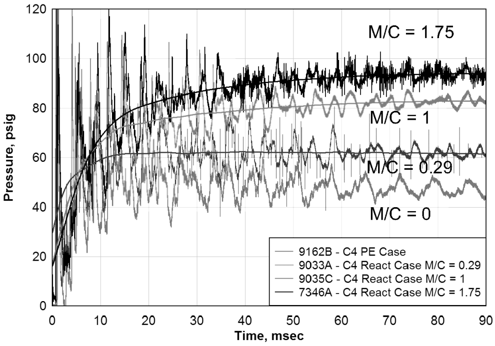

FIGURE 6. Long time pressure histories at gauges B for 10.16 cm I.D. reactive case/C4 charges at various *M/C*.

Table 1 gives the QSP averaged from the three gauges and the mass of recovered case fragments and powder including fine fragments and solid products. Using equilibrium constant volume explosion calculations (Cheetah 2.0) that produce the measured QSP at an afterburning efficiency of $\eta = 0.85$ from previous chamber tests, the burnt mass of the reactive case can be derived and is in agreement with the experimental data from recovered fragments and solid products. Figures 7 plots the obtained burnt case mass (averaged over repeated tests) versus case/charge mass ratio, explosive type (detonation energy) and charge internal radius: $M_B/M = f(M/C, E_0, R_I)$. A significant mass of the reactive case can be burned to enhance air blast depending on these parameters. The burnt case mass ratio increases as the case/charge mass ratio decreases, or detonation energy or charge diameter increases.

Since the fragment size from reactive cases can be related to the expansion rate, it is reasonable to consider a correlation of the burnt case mass with a maximum casing expansion velocity – the Gurney velocity in terms of M/C and E_0:

$$M_B/M = f(V_G(M/C, E_0), R_I) = \sigma V_G R_I^n \qquad (1)$$

where

$$V_G = \sqrt{2E_G}\left(\frac{M}{C}+\frac{1}{2}\right)^{-1/2}$$

TABLE 1. Experimental Results

Test#	*M/C* kg/kg	I.D. cm	QSP[a] kPa	Rcvd Frags g	Rcvd Pwdr g
Reactive case / C4 (E_0 = 5.74 kJ/g, p_{CJ} = 25 GPa)[b]					
9160B	0/2.0[c]	10.16	332	0	
9162B	0/2.0	10.16	331	0	
9033A	0.578/2.0	10.16	416	256	TBD
9034B	0.578/2.0	10.16	419	258	438
9035C	2.02/2.0	10.16	525	479	1226
9036C	2.02/2.0	10.16	534	474	1289
7346A	3.54/2.0	10.16	609	1172	1707
7347B	3.54/2.0	10.16	610	872	1469
9049A	2.10/1.19	7.62	368	783	1149
9078A	2.10/1.19	7.62	361	911	1098
9167C	2.10/1.19	7.62	359	778	TBD
9082A	5.89/3.3	12.7	816		
9083A	5.89/3.3	12.7	833	2021	2945
Reactive-Steel case / C4 (E_0 = 5.74 kJ/g, p_{CJ} = 25 GPa):					
9085A	3.54/2.0	10.16	417	TBD	TBD
9091A	3.54/2.0	10.16	437	TBD	TBD
Reactive case / TBX (E_0 = 3.43 kJ/g, p_{CJ} = 14 GPa)[b]:					
7347A	0/2.0[c]	10.16	454	0	
7345B	3.54/2.0	10.16	631	1484	1678
7346B	3.54/2.0	10.16	610	1635	1961
Steel case / TBX (E_0 = 3.43 kJ/g, p_{CJ} = 14 GPa):					
7345A	3.63/2.0	10.16	392	3628	

a. Overpressure w.r.t. the 91.8-92.8 kPa local atmosphere.

b. Cheetah 2.0 results, E_0: detonation mechanical energy, p_{CJ}: CJ pressure. For TBX, inert Al was assumed during detonation.

c. Bare charge contained in a 2 mm polyethylene case.

The simple expression (1) gives remarkable agreement with complex experimental results as indicated in Fig. 7 (coefficients $\sigma = 0.013\ s/m^{(n+1)}$ and $n = 1.5$ assuming $E_G \approx E_0$). Refinement of eq. (1) can be made when further considering a relation of E_G with E_0.

Finally, an equivalent bare charge mass, C_{EB}, for cased charges (w.r.t. the bare charge of the same explosive) was calculated using the equilibrium explosion (Cheetah 2.0) that yields the measured QSP. As plotted in Fig. 8, an increase in M/C results in an increase in C_{EB}/C that reaches 2.5 at a case/charge mass ratio of 1.75.

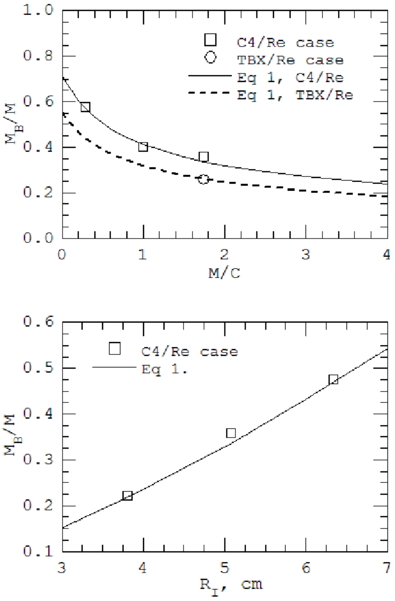

FIGURE 7. Burnt case mass fraction versus *M/C* and E_0 at R_I = 5.08 cm (upper), and versus R_I for C4 charges at *M/C* = 1.75 (lower).

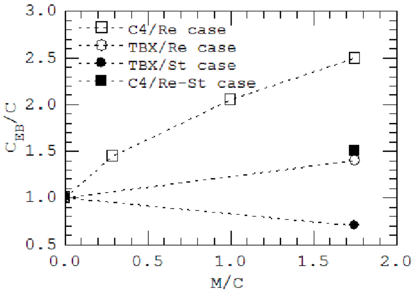

FIGURE 8. Equivalent bare charge mass for blast effect of R_I = 5.08 cm charges.

REFERENCES

1. Zhang, F. Williams W.H. "Reaction of fragments from cased explosive charges", *20th MABS*, Oslo, Norway, 2008.
2. Zhang, F., Yoshinaka A., Frost D., Ripley R.C., Kim K., Wilson W., Proc. *13th Int. Det. Sym.*, 2006, pp 233-244.
3. Zhang, F., Anderson, J., Yoshinaka A., *Shock Compression of Condensed Matter – 2007*, pp 885-888.