Sub-fragmentation of structural reactive material casings under explosion

Zhang, Fan; Gauthier, Maxime; Cojocaru, Cristian

Publisher's version / Version de l'éditeur:
https://doi.org/10.1063/1.4971532
Shock compression of condensed matter - 2015 : proceedings of the Conference of the American Physical Society Topical Group on Shock Compression of Condensed Matter : 14-19 June 2015, Tampa Bay, Florida, USA, 2017-01

Sub-fragmentation of structural reactive material casings under explosion

Fan Zhang, Maxime Gauthier, and Cristian Cojocaru

Citation: AIP Conference Proceedings **1793**, 040038 (2017); doi: 10.1063/1.4971532
View online: https://doi.org/10.1063/1.4971532
View Table of Contents: http://aip.scitation.org/toc/apc/1793/1
Published by the American Institute of Physics

Sub-Fragmentation of Structural Reactive Material Casings under Explosion

Fan Zhang[1, a)], Maxime Gauthier[2] and Cristian Cojocaru[2]

[1]*Defence Research and Development Canada, P.O. Box 4000, Stn. Main, Medicine Hat, AB, T1A 8K6 Canada*
[2]*National Research Council Canada, 75, de Mortagne, Boucherville, QC, J4B 6Y4 Canada*

[a)]Corresponding author: fan.zhang@drdc-rddc.gc.ca

Abstract. A concept of reactive hot spots intruded in a thick, structural reactive material casing was investigated to generate fine fragments for efficient energy release from casing material under explosive loading. This was achieved through distributing micro MoO_3 particles into a granular Al casing, made by hot isostatic pressing, in a fuel-rich ratio of $10Al+MoO_3$. Reaction of Al and MoO_3 during casing primary or secondary fragmentation creates heat and gas products to form micro-scale hot spots, whose expansion initiates local fractures leading to fine fragments of the rest of Al. Explosion experiments, using a 4.4 cm diameter cased charge with a casing-to-explosive mass ratio of 1.78 in a 2.1 m^3 cylindrical chamber, demonstrated the presence of fine fragments and more efficient fragment combustion to augment air blast, as compared to a baseline pure Al-cased charge, thus indicating the feasibility of the concept.

INTRODUCTION

A structural reactive material (SRM) is defined to possess both high energy density and structural strength, made of grain-scale metals to bear both bulk and meso-scale properties. SRM can be used for explosive charge casings to contribute additional energy to air blast through its fragment reaction either promptly after charge detonation or upon impact with nearby structure [1-3]. Prompt reaction of fragments from thick casings will need mechanisms to generate fine fragments. The reactive hot spot concept has been introduced through distributing micro reactive material particles into base SRM in a fuel-rich equivalence ratio [3]. Reaction of these particles during SRM fragmentation creates heat and gas products to form micro-scale hot spots, whose expansion initiates local fractures leading to fine fragments of the rest of SRM. Aluminum (Al) and copper oxide (CuO) particles were previously used as the hot spot material distributed into base Al through cold gas dynamic spray deposition. In the present study, micro Al and molybdenum oxide (MoO_3) are investigated as the hot spot material.

EXPERIMENTAL PROCEDURE

The SRM comprises a fuel-rich micro-composite $10Al+MoO_3$. Local diffusion-dominant reactions of Al around the distributed MoO_3 particles are near stoichiometric in an atomic ratio of $N_{Al}/N_{MoO3} = 2$ and serve as hot spots. This results in a heat of reaction of 4.703 kJ/g within the hot spot volume and gas products O, O_2, AlO, Al_2O, MoO, MoO_2 etc. at 4600 K from an equilibrium constant volume explosion calculation with all phase changes. Ignition temperature is another key parameter for hot spot material reaction. For arrested-reactive-milled nanocomposites $2Al{\cdot}3CuO$, $4Al{\cdot}Fe_2O_3$, $8Al{\cdot}MoO_3$ and $2.35Al{\cdot}Bi_2O_3$ in vacuum, ignition temperatures were found to be similar in a range of 800–950 K [4]. Under charge detonation conditions, the bulk shocked temperature in the casing may not reach the thermite ignition temperature. However, dissimilar impedance materials and local structure discontinuities within the casing could enhance shock dissipation, resulting in high temperatures beyond the ignition threshold.

Powders selected were atomized Al with a purity of 99.7% (Valimet H30, $d_{50} = 35$ μm) and MoO_3 with a purity of 99.9% (Atlantic Equipment Engineers, ≤ 44 μm). SEM images of powder morphology are illustrated in Fig. 1,

Shock Compression of Condensed Matter - 2015
AIP Conf. Proc. 1793, 040038-1–040038-5; doi: 10.1063/1.4971532
Published by AIP Publishing. 978-0-7354-1457-0/$30.00

where the MoO_3 particles are seen to be agglomerates of very fine particles. The mixture was mechanically premixed and production of a 10Al + MoO_3 thick-walled tube was tried through both cold spray deposition and hot isostatic pressing (HIP). The former failed in building an Al-MoO_3 coating due to the MoO_3 hardness and high-concentration feedstock. The HIP process was successful in manufacturing the Al-MoO_3 cylinder at a bulk density of 3.19 g/cm^3, practically reaching 100% theoretical-maximum-density (TMD). The porosity was evaluated to be 1.46 vol%, from a Clemex image analysis of the polished cross-sections depicted in Fig. 2 using a Hitachi S-4700 Field-Emission-Gun Scanning Electron Microscope (FEGSEM). It can be seen that the MoO_3 is well distributed within the volume, presenting in deformed agglomerates or fine layers between the Al grain boundaries; both inherit from the initial fine MoO_3 particles and their porous agglomerates. The chemical composition (Al, MoO_3) were clearly identified from X-Ray Diffraction analysis using a Bruker AXS D8 Discover Diffractometer, where some MoO_2 was present likely due to a partial reduction of MoO_3 by Al during a degassing treatment at 823 K prior to the HIP processing.

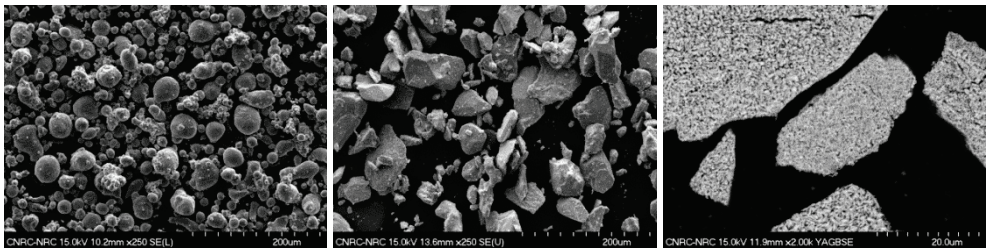

FIGURE 1. SEM in secondary electron imaging mode (SEI) for Al (left), MoO_3 (middle) and its higher magnification (right).

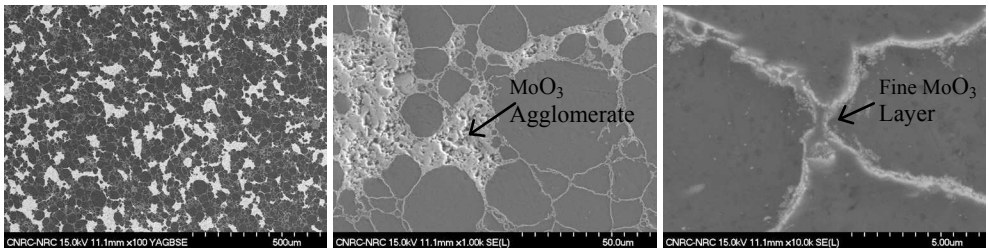

FIGURE 2. FEGSEM for polished cross-section of HIPed 10Al + MoO_3 (left in backscattered electron image: Al in dark grey and MoO_3 in light grey) and its higher magnifications (middle & right in secondary electron image).

A cylindrical casing was assembled from the machined HIP tube, 3.35 cm in ID, 4.36 cm in OD and 140 g in weight, covered with two Al 6061-T6 lids (Fig. 3). A 100 g C-4 explosive was contained in the SRM casing, with a cylinder length-to-ID ratio of L/d = 2.15 and a total casing-to-explosive mass ratio of M/C = 1.78.

FIGURE 3. Experimental setup: HIPed 10Al + MoO_3 cylinder casing assembly (left); 2.1 m^3 cylindrical explosion chamber (middle); cylindrical symmetry test configuration (right).

Explosion experiments were conducted in a 1.18 m diameter and 2.1 m^3 closed steel chamber using a cylindrically axi-symmetrical configuration (Fig. 3), where the cylindrical charge is suspended horizontally in the same axis and at the center of the horizontally cylindrical chamber. Detonation was initiated using an RP83 detonator and propagated along the charge axis, while the expansion of SRM fragments took place in the radial direction towards the chamber cylindrical wall. A Phantom 16.10 high speed camera was set in front of the chamber

window. Four Endevco piezo-resistive pressure transducers A, B, C & D were mounted on the chamber cylindrical wall, with B and C facing the charge center for a normal reflection measurement. An Endevco transducer E was set on an in-house designed mount at a radius of R = 39 cm from the charge center to measure a near-field incident blast pressure. The chamber was sealed at a local atmospheric air pressure of 92.3-93.7 kPa and temperature of 11-20 °C. The residue fragments and explosion solid products were recovered after each test.

RESULTS AND DISCUSSION

Figures 4 and 5 show the reaction process of fragments from the pure Al and 10Al+MoO_3 casing, respectively, obtained from 13.15 µs frame-rate high speed photographs. While more incipient reaction appears in Fig. 5, both casings show limited fine fragments reacting promptly after detonation (the four jets at a 90° interval originate from the four screw connections of lids to the casing as seen in Fig. 3). Upon fragment impact on the chamber cylindrical wall, significant, rapid reaction of fragments from both casings takes place. The reaction radiation pattern from the 10Al + MoO_3 casing, however, appears dominant by much finer secondary fragments than that from the Al casing.

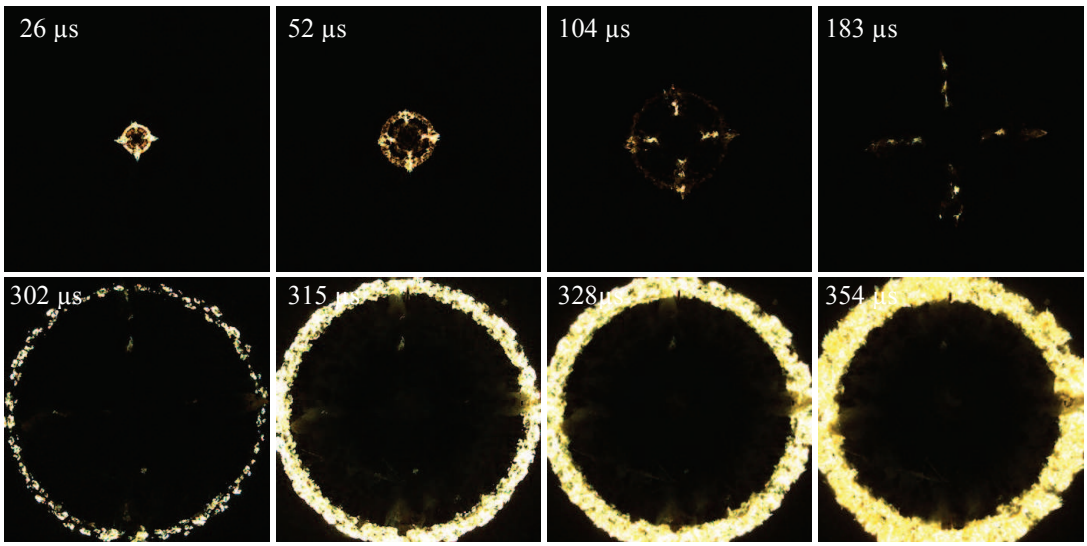

FIGURE 4. Reaction of Al casing fragments after detonation and upon wall impact (U15085A).

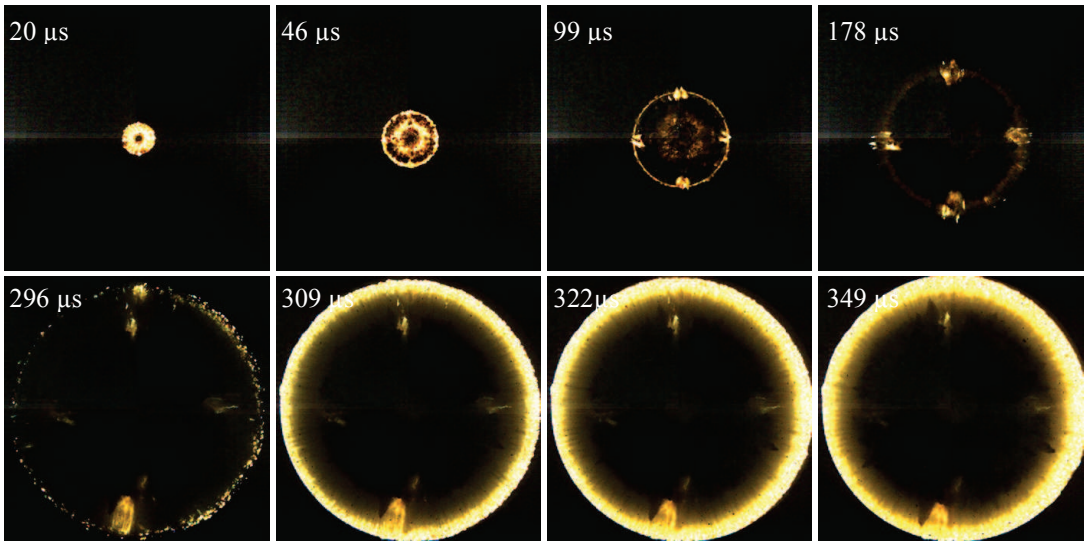

FIGURE 5. Reaction of 10Al + MoO_3 casing fragments after detonation and upon wall impact (U15126A).

Pressure results from two tests for each type of casings, as given in Fig. 6, show that the Al-MoO_3 cased charges, with respect to the Al cased charges, provide a 15% increase in primary shock peak at incident gauge E and a 50% increase in normal-reflected shock peak at wall gauge B. A precursor and primary two-shock front structure, typical for an SRM-cased charge explosion [1], appears on gauge B at R = 59 cm but not yet at gauge E at R = 39 cm. This indicates that the frontal primary fragments overtake the primary blast shock between 39 cm and 59 cm. The significant enhancement of both reflected precursor and reflected primary shock at R = 59 cm suggests the combustion of more fine fragments from the Al-MoO_3 than the Al casing upon impact on the wall. In late times, the same quasi-static overpressure (QSP = 430-440 kPa) reaches for both Al and Al-MoO_3 casings, as shown in Fig. 7. The same QSP also indicates the same energy amount released. A significant increase in < 1mm fragments or products powder for 10Al+MoO_3 over Al casings was evident from the recovered solid residue after test. X-ray diffraction (XRD) analysis, conducted on the post-explosion residues of <1 mm powder, shows new compounds of $Al_2(MoO_4)_3$ and Al_5Mo (Fig. 8), clear evidences for the Al-MoO_3 hot spot thermite reaction.

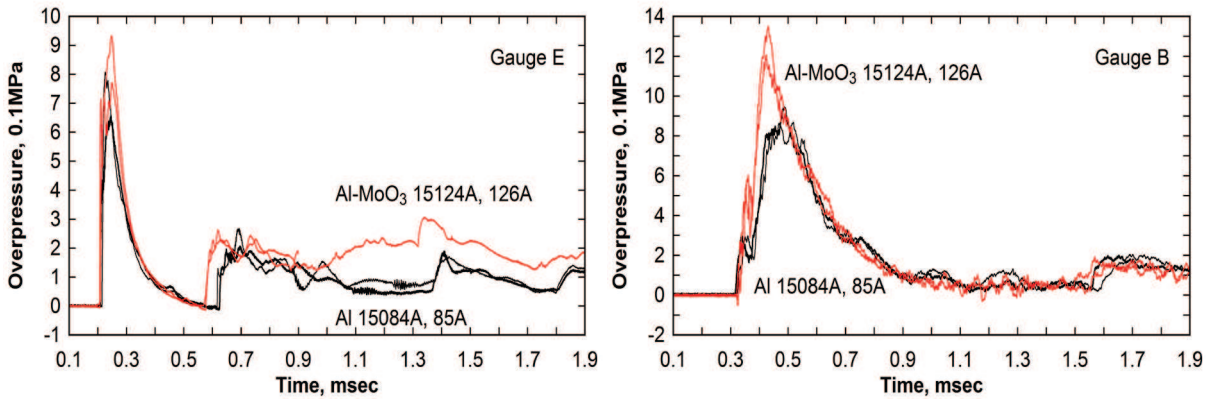

FIGURE 6. Four test pressures at incident gauge E (left) and wall-reflected gauge B (right) for 10Al + MoO_3 and Al casings.

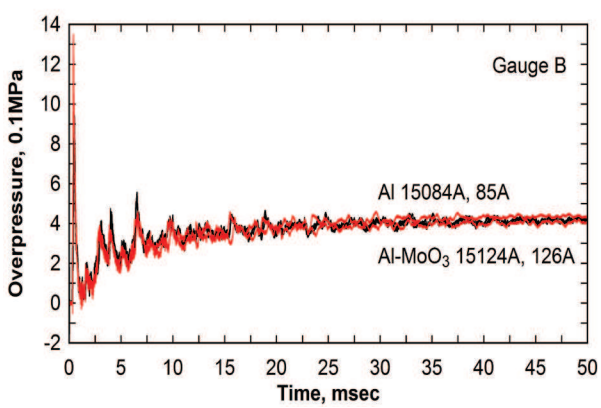

FIGURE 7. Long time pressures for four tests at gauge B.

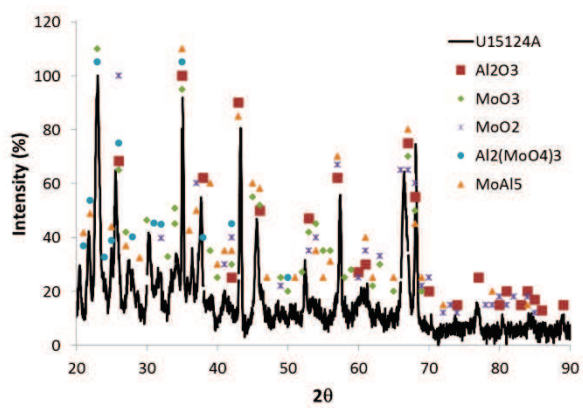

FIGURE 8. XRD pattern of <1 mm residue powder after test.

Both high-speed photographs and pressure results are consistent and indicate that the reactive hot spots within the 10Al + MoO_3 casing lead to significant sub-fragmentation of the secondary fragments generated upon wall impact but are less effective during the primary fragmentation upon charge detonation. These results are consistent with previous results from a 6Al + CuO casing [3]. The fact of a mild enhancement in incident blast front suggests that a more powerful explosive would be necessary to generate a stronger detonation shock for prompt initiation of a large number of the thermite hot spots within the casing, in order for casing sub-fragmentation into more fine primary fragments upon detonation. In addition, shock initiation studies are necessary to understand ignition threshold of hot spot materials under explosive loading.

ACKNOWLEDGMENTS

The significant effort and support of Brain Eichelbaum, Kiril Mudri, Ryen Stallmann, Robin Laing, Karl Baker and the technical staff from the Suffield Field Operations Section in conducting the experiments are gratefully acknowledged. This work was jointly funded by Defence Research and Development Canada and the Advanced Energetics Program of Defense Threat Reduction Agency (Dr. William H. Wilson).

REFERENCES

1. F. Zhang, L., Donahue and W. H. Wilson, "The effect of charge structural-reactive-metal cases on air blast", in *Proc. 14th Detonation Symposium* (Coeur d'Alene, IH, ONR-351-10-185, 2010), pp. 2-11.
2. K. Kim, W. Wilson, J. Quintana, J. Roybal, J. Rocco, C. Watry, M. Brown, T. Zahrah, N. Glumac and M. Clemenson, "Detonation initiated chemical reactions in structural energetic materials", in *Proc. 15th Detonation Symposium* (San Francisco, CA, 2014), in press.
3. F. Zhang, A. Bacciochini, B. Jodoin, M. Radulescu and R. Ripley, "A hot spot concept to enhance fragmentation of structural-reactive-material casings", in *Proc. 15th Detonation Symposium* (San Francisco, CA, 2014), in press.
4. R. A. Williams, J. V. Patel, A. Ermoline, M. Schoenitz and E. I. Dreizin, Combust Flame 160, 734–741 (2013).