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A Large Scale Study of Blast Effects from a Structural Reactive Material Solid under Explosive Loading

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A structural reactive material (SRM) is made by consolidating a mixture of micro- or nanometric reactive metals and metal compounds to the theoretical maximum density (TMD). A SRM can thus possess a higher energy density, relying on various exothermic reactions, and higher mechanical strength and heat resistance than that of conventional CHNO explosives. Small scale studies of a SRM solid have made progresses specifically to explore it as an energy source for air blast through reaction of fine SRM fragments under explosive loading. These subscale studies comprised a large number of experiments, whereby explosives were encased in a thick-walled SRM solid cylindrical shell with diameters ranging from 40 mm to 100 mm and explosive masses from 100 g to 1.2 kg, using different formulations to provide a variety of detonation pressures and resulting in a SRM casing-to-explosive mass ratio up to $M/C = 1.8$ [1]. These studies laid the foundation for the next stage of developments, including basic SRM solid explosion characterization, material properties of a SRM solid, and its dynamic fine fragmentation mechanisms and fragment reaction mechanisms.

In this paper are discussed the results of large scale experiments involving a SRM cylindrical solid shell scaled up to a diameter ranging from 150 mm to 200 mm with the encased explosive mass from 8 kg to 40 kg, resulting in $M/C = 1.5$ to 4.1. Two SRM formulations are selected from the more than a hundred abovementioned subscale dynamic fragmentation and blast experiments, in which the SRM solid fragmentation size distribution has been retrieved from a snow chamber technique allowing full casing mass recovery. The SRM thick solid shells are machined to final sizes after being consolidated using either hot isostatic pressing or a cold spray deposition technique. The obtained SRM solid reaches full TMD with controlled porosity remaining under 1 vol.% and an ultimate tensile strength of 200 MPa. Tensile strength is more critical than compressive strength in evaluating a SRM solid, whereby the tensile stress-strain curve is obtained using a tensile specimen design following the MPIF (Metal Powder Industries Federation) standard. The large-scale explosion experiments are conducted on a concrete pad 30 m in diameter, covered with a 12.7 mm thick steel plate. Diagnostics include an overhead high speed digital video camera suspended on steel cables 25 m above ground zero between two steel towers, and four high speed digital cameras providing side views of the event; two radial arrays of Endevco piezo-resistive transducers located 90 degrees from one another at the ground level from 3 m to 23 m, mostly at a one meter interval; one radial array of Endevco pressure transducers mounted on lollypop stands from 3 m to 26 m at a height equal to that of the center of the vertically mounted cylindrical charge (height-of-burst); one radial array of thermocouples mounted at the height-of-burst from

4 m to 14 m to measure the temperature within the extended fireball from SRM solid fine fragment combustion. Detonation velocity of the SRM-cased charge is measured using an array of shock pins mounted through the wall along the casing length. In order to understand the dynamic expansion and fracture behavior of the SRM solid shell under explosive loading, two photonic Doppler velocimetry (PDV) probes are employed to measure the expansion of the solid shell surface. The resulting data are used to derive the dynamic tensile stress as a function of strain and strain rate and compared to the static tensile stress-strain curve, and to estimate the maximum expansion velocity corresponding to the initial SRM fragment velocity following case breakout. The latter is also used to evaluate its deviation from the theoretical Gurney velocity. PDV is also further deployed to monitor target flyer plate motion as a measure of the near-field SRM solid fragment momentum flux.

The results are analyzed with the goal to compare them with the findings obtained in the previous subscale experiments and to investigate relevant scaling effects. Numerical simulations are further performed to help understand the scaling on SRM solid fragment dynamics and combustion.

Keywords: Structural reactive material, Reactive material, Intermetallics, Thermite, Metal Combustion, Blast, Reactive fragment

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[1] Zhang, F. Donahue, L., Williams, W.H., The effect of charge reactive-structural-metal cases on air blast. In: Proc. 14th Detonation Symposium, ONR-351-10-185, pp. 2-12, 2010.