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Investigation on the influence of the initial RDX crystal size on the performance of shaped charge warheads

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ABSTRACT

Copper lined wave shaped shaped charges of particular design and liner metallurgy were used to investigate the effect of explosive crystal size on the resultant shaped charge jet parameters. Composition A3 with RDX of three different average crystal sizes, i.e. 30 μm, 100 μm and 300 μm were used in the investigation. All other parameters in the charge were kept constant and in particular, care was given to obtain consistent dimensional quality and liner microstructure, in order to prohibit the variation of other parameters. Specific flash-X-ray diagnostics were used in field tests to obtain the jet parameters from multiple firings of similar charges. It is found that the varying crystal size of the RDX has a marginal influence in the total jet length of the jets. However, it is also found that there is less variation between firings in the jet parameters for jets from the charges loaded with the crystal size of 100 μm.

1. Introduction

Warhead designers are continually in pursuit of improving the performance of their products. For decades, shaped charge designers have focused on liner material [1–5], the microstructure of the liner material, initiation systems and different explosive materials. Few researchers have quantified the influence of the explosive microstructure or the initial energetic material crystal size on the performance of shaped charges. Generally, a qualified explosive is used to quantify various parameters of shaped charge jets. This paper aims at providing experimental data demonstrating the influence of the explosive crystal size on the cumulative lengths generated in precision shaped charge jets.

Rheinmetall Denel Munition is in the fortunate position of manufacturing small batches of explosives within pilot plants whilst pressing explosives and manufacturing liners all at one site. This provided the opportunity to conduct this investigation with full control of all the relevant manufacturing parameters.

An 80 mm diameter concept warhead design was selected containing a 60° copper cone with an average liner grain size of 30 μm with a variation of 10 μm, Comp A3 – RDX91:WAX9 main and relay charge with a combined mass of approximately 580 g, wave shaper for peripheral initiation, as shown in Fig. 1. No housing/confinement was used for this evaluation.

The trending motion of the explosive community has moved from TNT based explosives onto plastic bonded explosives and now even more modern binder materials for more insensitive explosives. Optimizing an explosive material for the improvement of its sensitivity/insensitivity involves an optimization process in terms of explosive crystal size. Some formulations make use of mono-modal, bi-modal and even tri-modal explosive mixtures. A few decades ago, shaped charges were typically cast with a mixture of TNT and other explosives. Early attempts were made to measure the roughness of the detonation front resulting from inhomogeneity's of the explosive and the detonation front. The question was raised if this roughness has an impact on the performance of a shaped charge jet (SCJ). However, experiments were difficult to perform due to the many other parameters in the charge that could vary and results were either inconclusive, or showed that the influence was only marginal [6]. This question re-emerged when the classical cast, or pressed-cast, TNT based explosives were replaced by plastic bonded explosives (PBX) to make the charges more insensitive [7]. While the TNT in previous compositions (effectively a castable binder the explosive mixture) was detonable and the detonation front could propagate with closely similar velocity in the explosive and in the ‘binder’, this is not the case with the inert plastic binders. Consequently, the use of PBX should increase the roughness of the

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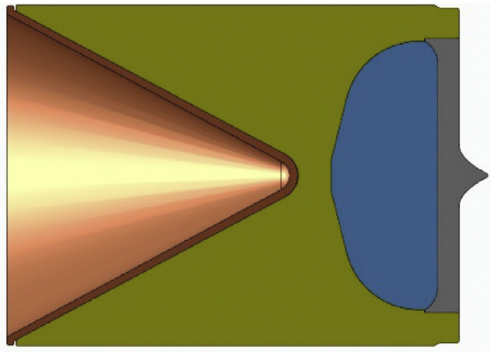

Fig. 1. Concept warhead design for evaluation.

detonation front [8].

The characterisation of the crystal structure in the explosive is well established process and has been used as a tool for correlating parameters such as explosive sensitivity, efficiency of different binders [9], the formation of hotspots with in a granulated pressed PBX [5,6], evaluation of pressing quality [7,8] and evaluating fractal networks of intergranular voids [14].

Table 1
Various lots of Comp A3 manufactured with different RDX grades/crystal sizes.

RDX Grading	Coarse	Medium	Fine
Lot	003	005	006
RDX Name	107	105	104
RDX Grain Size/μm	300–400	100	20–30

Crystal sizes of 30 μm, 100 μm and 300 μm were selected for this investigation. The fine crystal size was selected to be comparable to the average grain size of the copper liners. The larger crystals were selected three and ten times larger to ensure good variation in the three the explosive batches.

This particular project made use of Comp A3: RDX 91% - Wax 9%. Three batches of RDX were manufactured with different crystal sizes at RDM's pilot plants. These three batches of explosives were placed behind OFHC copper liners with a fixed average grain size of 30 μm. These liners form part of another investigation, where the emphasis is on strict control of the microstructure and dimensional consistency. The investigation of this paper focusses on quantifying the effects of RDX particle size on the breakup behaviour of the shaped charge jets.

2. Explosive analysis

A detailed analysis of the explosive granular product is shown from RDX selection, to wax coating and then after pressing.

Three batches of the Comp A3 (RDX/WAX 91/9, $\rho = 1.63$ g/cm^3) with the different RDX particle sizes were manufactured within a pilot plant as shown in Table 1. SEM images of the respective RDX types are presented in Fig. 2. Images of the three different Comp A3 batches are shown in Fig. 3. By visual inspection it was already noted that the granular material produced after coating with wax, showed particle size differentiation. Molding powder granules of PBX were prepared using the standard slurry coating process [15–17]. Gravimetric analysis were conducted on the three Comp A3 batches to ensure the RDX/WAX ratio was obtained. The results

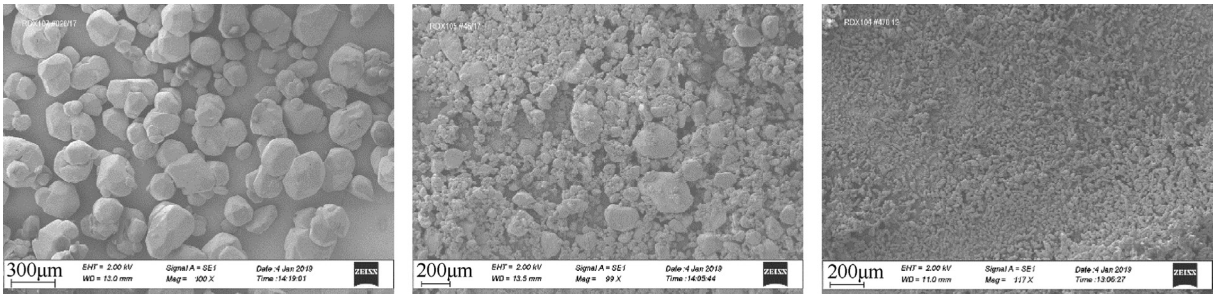

Fig. 2. Scanning electron microscope images of RDX 107, 105 & 104 respectively.

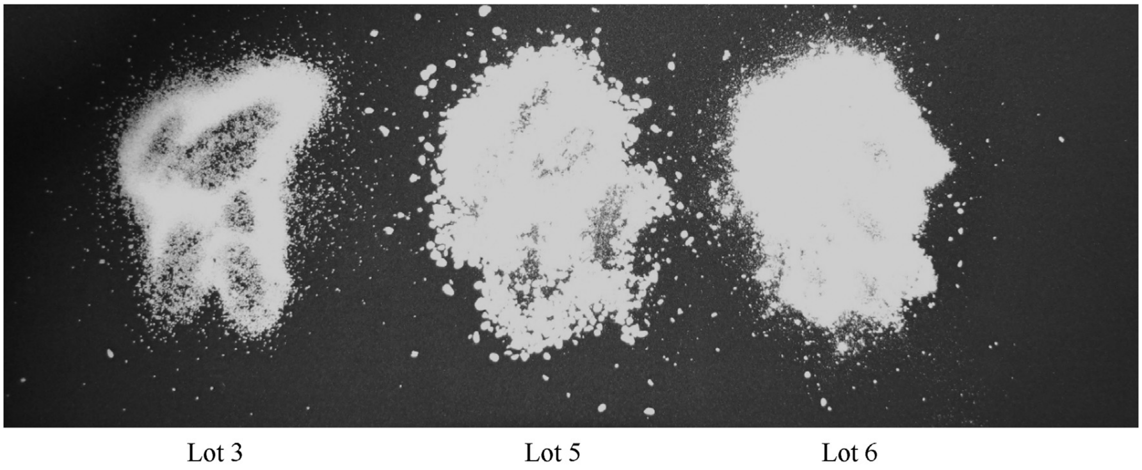

Fig. 3. Three lots of granular Comp A3.

Table 2
Comp A3 – RDX-WAX ratio analysis.

Characteristics	Lot 003	Lot 005	Lot 006
RDX/%	91.5	90.3	90.5
Wax/%	8.5	9.7	9.5

are presented in Table 2, and revealed all three were within specification with a variation of less than 1%.

3. Pressing analysis

All three batches of Comp A3 were used to conduct a pressing analysis. Charges were pressed at room temperature and an elevated temperature of 70 °C at 100 MPa, 150 MPa and 200 MPa effective pressure. The size of the charges pressed for the Comp A3 pressing analysis was 25 mm in diameter and 25 mm long. A summary of the pressing analysis presented in Fig. 4. The densities were calculated by measured the diameters and lengths of each explosive charge.

The pressing analysis shows an increase in density at 21 °C from 94.1% TMD up to 95.67% TMD with an increase in effective pressure from 100 MPa to 200 MPa for batch 6. The densities measured for lots 3 to 5 were uniform at room temperature and at elevated temperatures. The press was heated to 70 °C and new charges were pressed at similar pressures. A more uniform density distribution was measured across a variety of pressures for batch 6 when conditioned at 70 °C. This can be explained due to the binder softening at high temperatures. The density of all charges across batches at elevated temperature was within 0.025 g/cm^3 from 100 MPa to 200 MPa effective pressure.

The densities for the consolidated charges when heated to 70 °C are shown in Fig. 5. Based on the data a single pressure of 150 MPa was selected to press the larger diameter charges. The difference in densities measured for the respective charges at 150 MPa were 0.013 g/cm^3. This change in density should not influence the performance of the shaped charge jets.

The final charges, 85 mm diameter, manufactured were pressed at 150 MPa at 70 °C. The light micrographs shows the difference between the fine and coarse pressed charges shown in Fig. 6. An image of the machined Comp A3 is presented in Fig. 7.

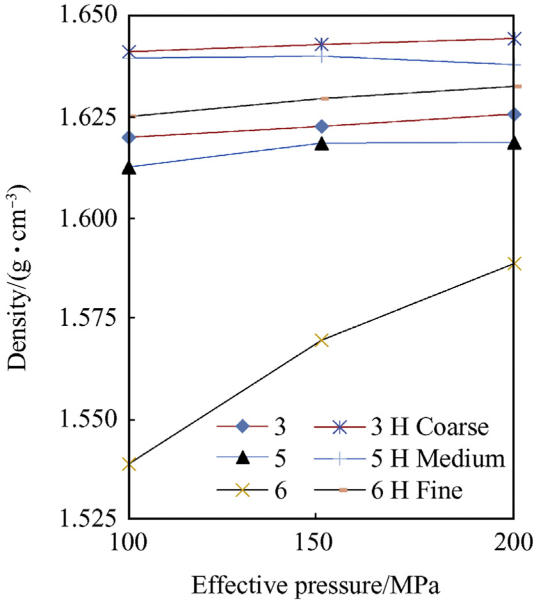

Fig. 4. Density report for consolidated charges.

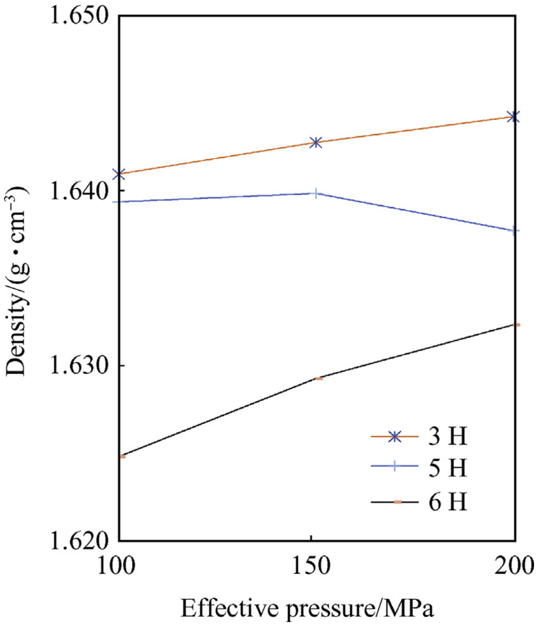

Fig. 5. Density report for the consolidated charges heated to 70 °C only.

4. Warhead manufacture

The 85 mm pressed Comp A3 charges were machined down to a

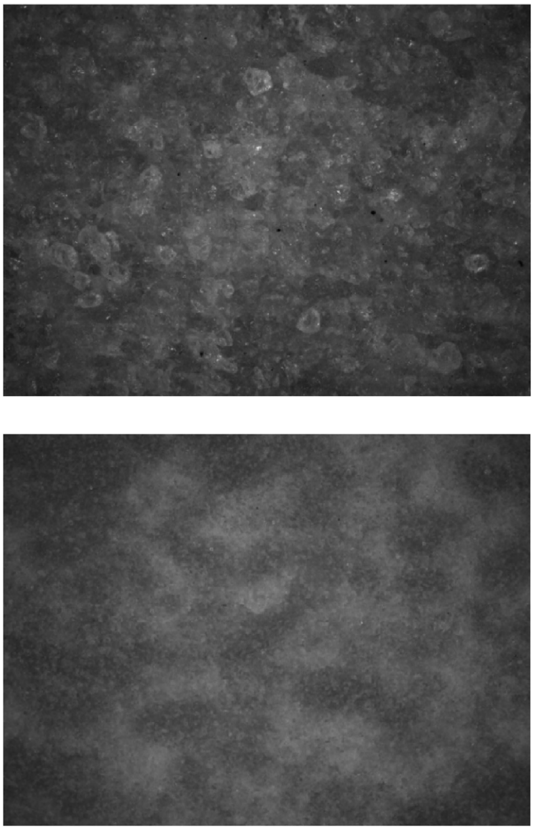

Fig. 6. Light microscopy of the pressed Comp A3, coarse (top) and fine (bottom).

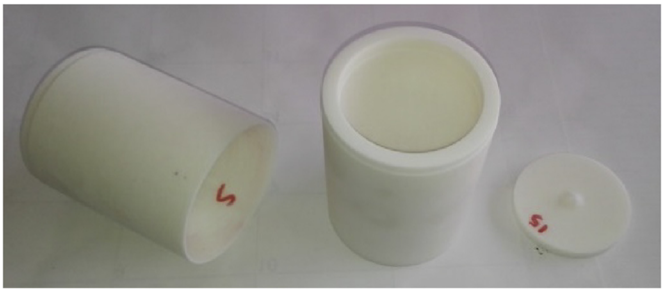

Fig. 7. Machined Comp A3 charges.

final warhead calibre of 80 mm. An image of the machined charges are shown in Fig. 7. A foam wave shaper was used and a copper liner with thickness of 1.7 mm.

5. Flash X-ray analysis

Flash x-ray analysis is the general accepted diagnostic tool used to characterise shaped charge jets [18-21]. A 450 kV double flash X-ray system was used for the firings. An image of the test setup is presented in Fig. 8. The 450 kV system had a beam wide enough to capture the particulated shaped charge jet from tip to slug. Position markers were placed in each firing to ensure accurate allocation to the distance travelled of each particle. The first flash time ensured the jet tip captured at a large standoff to ensure particulation down to 4 mm/μs. The second flash time ensured jet particulation down to the jet tail/slug. Examples of the flash X-ray radiographs presented in Fig. 9 (fine RDX) and Fig. 10 (coarse), respectively. The radiographs are analysed with a locally developed code called JETPMI. The program is a Matlab based image detection software, which write out the most important shaped charge jet properties as output. For the purpose of this paper, reporting of only the jet cumulative lengths is required. A demonstration of the digitised particles shown in Fig. 11. The cumulative lengths of the shaped charge jets presented in Fig. 12. The length of each particle was measured with a matching particle velocity. The cumulative length per velocity segment is the sum of the particles measured up to that particle. The graph on the left presents the cumulative length of the shaped charge jet from tip down to approximately 4 mm/μs. The graph on the right zooms into the 5 mm/μs regime outlining the variation of the duplicate firings. The average breakup times and average length/diameter ratios for particles of the shaped charge jets are presented in Fig. 13.

Fig. 8. Flash X-ray setup.

6. Analysis and discussion

The cumulated length of the jet can be regarded as one of the most important parameters for the SCJ jet performance [5,10–13]. The influence of the explosive crystal size distribution on this parameter is thus of particular importance. The tip velocity measured for each firing was 8.6 ± 0.1 mm/μs. The tip velocities of each jet was measured by double flash X-ray radiographs only. Fig. 12 shows the results for duplicate firings for the cumulative length per jet velocity interval. The graphs depicted show marginal influence of the explosive grain size distribution on the average cumulative jet length of the combined firings. However, there are differences in the variation of the individual jet length of similar firings. Explosive lot 6 (black) had a variation of 20% in cumulative length at 5000 mm/μs. Explosive lot 3 (red) showed a variation of less than 10% in cumulative length at 5 mm/μs. Explosive lot 5 (blue) showed a variation of less than 5% in cumulative length at 5 mm/μs. The data suggests that the explosive microstructure has little influence on the overall shaped charge jet cumulative length. The data rather indicate that an RDX crystal size of 100 μm produces more consistent jets; an initial explosive crystal size of 300–400 μm being too coarse and 20–30 μm being too fine. The physical and chemical explanation for this observation is the topic of a continued investigation. The number of particles from jet tip down to 4 mm/μs were 45 ± 2 for the six firing with an average velocity difference of 100 ± 15 m/s between particles. The average breakup times presented in Fig. 13 (left), shows an average breakup time of 80 μs at the tip and approximately 280 μs at 3 mm/μs; the spread of data also verifies the consistency of the RDX crystal size of 100 μm and the variation in breakup times of the fine and coarse RDX crystals throughout the jet. The break up times were calculated by measuring the inter particle spaces and the velocity difference between those particles. The time was traced back to the point these particles meet. This time is considered the breakup time. The

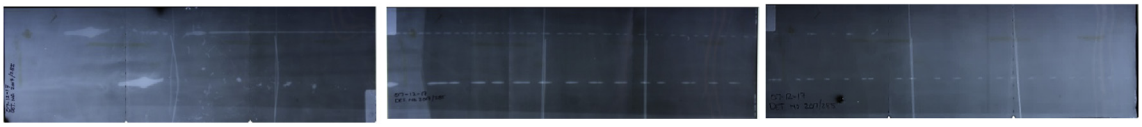

Fig. 9. Lot 6 (fine).

Fig. 10. Lot 3 (coarse).

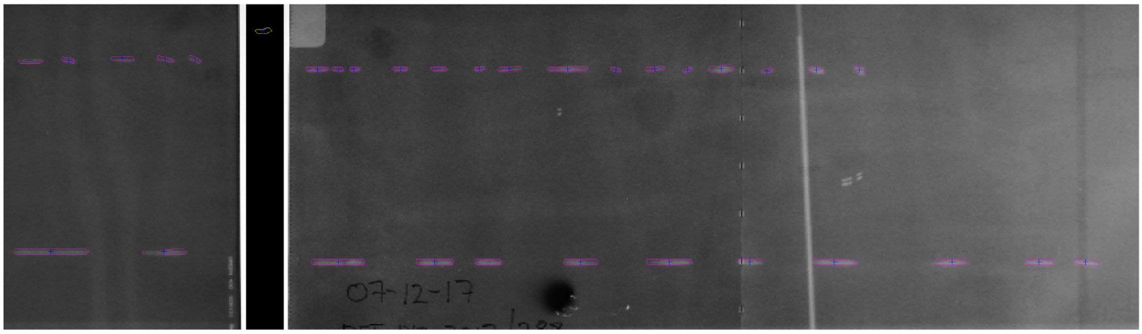

Fig. 11. Image Detection Software used for flash X-ray analysis, JETPMI.

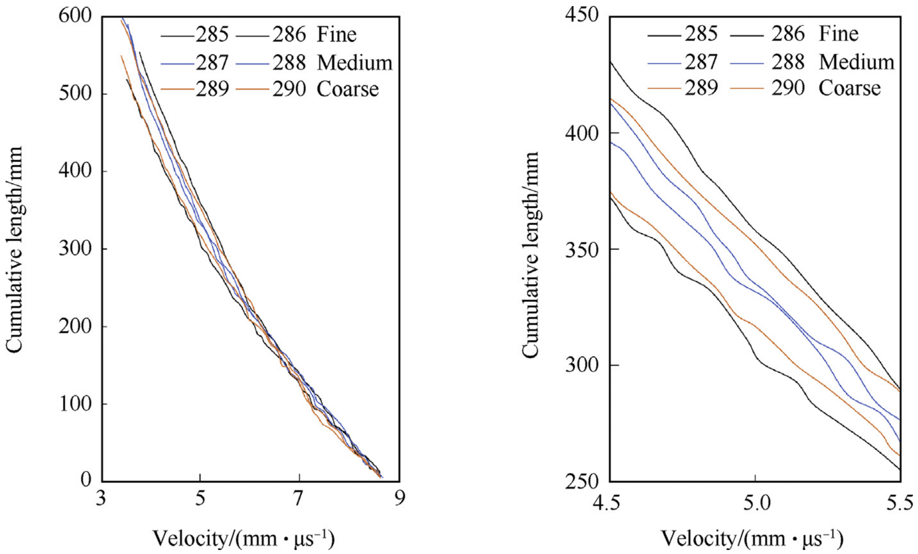

Fig. 12. Flash X-Ray Analysis – Cumulative length of shaped charge jet.

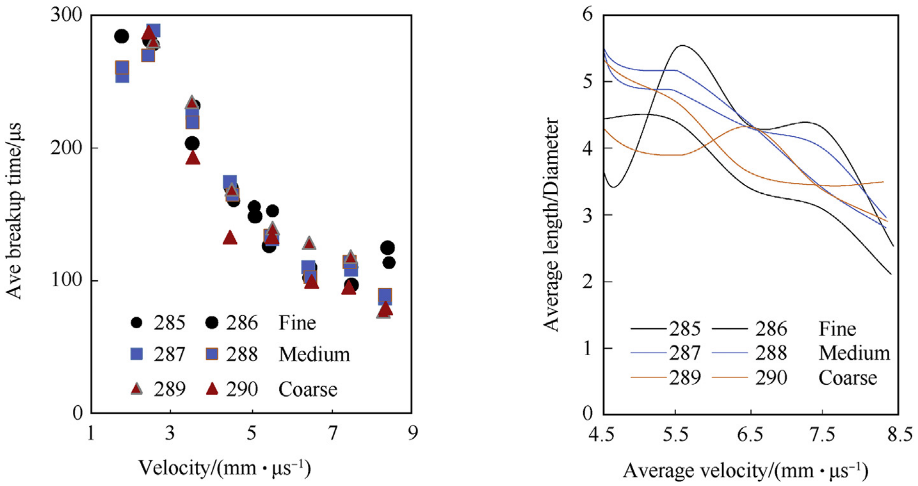

Fig. 13. Flash X-Ray Analysis - Average breakup times (left) and average L/D of particles (right) of shaped charge jets.

average breakup time is the breakup time of all particles in a 1 mm/μs velocity segment. The breakup times are averaged for particles in between 6 km/s and 7 km/s and so on. The L/D ratio presented in Fig. 13 right refers to the length to diameter ratio of each particle digitised for test. The average L/D ratios of the shaped charge jet particles are presented in Fig. 13 (right). The average L/D were also calculated for each 1 mm/μs velocity segment. The graph shows an average L/D of 2.5 at the jet tip increasing up to 5.5 at 4.5 mm/μs. The L/D ratios also confirmed the consistency for the medium sized RDX crystals.

7. Conclusion

Three batches of Comp A3 (RDX:WAX-91:9) were manufactured with different initial RDX crystal sizes. A range of 30 μm, 100 μm and 300 μm was selected for the evaluation. Chemical analysis showed all three batches conformed to the 91:9 RDX:WAX ratio within 1% tolerance. The pressing analysis showed all three press charge densities ($\rho = 1.63$ g/cc) to be comparable within 0.25% g/cm^3. Precision shaped charge warheads were manufactured with copper liners with an average grain size of 30 μm. Six flash X-ray firings were conducted to quantify the influence of the RDX crystal size on the cumulative length of jets produced. The data showed a rather equal trend in terms of break up times and cumulative length for the average of similar firings. The variation of these parameters between the similar firings, however, differed. The conclusion drawn from the data generated is rather that an optimum RDX crystal size exist for such composition that will produce more consistent jet parameters. In the case of this investigation, the 100 μm RDX-105 produced more consistent shaped charge jets over and above that of the RDX 104 (20–30 μm) and RDX 107 (300–400 μm) mixtures.

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