

Data Capture and Analysis of An OME Item

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Submission date: 30-Dec-2024 02:07PM (UTC+0000)

Submission ID: 246944780

File name: 32477_Adam_Mayo_Data_Capture_and_Analysis_of_An_OME_Item_592935_2097997141.docx
(3.26M)

Word count: 2992

Character count: 16119

University of Wales Trinity Saint David

Ordnance Munitions & Explosives BEng Apprenticeship



Data Capture and Analysis of An OME Item

Data Capture & Evaluation (ACDA 6021)

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12/2024

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Abstract

This report identifies an Ordnance, Munitions and Explosives (OME) item through the analysis of pressure data, fragmentation data and explosive residue collected at the trial site. The study employs a reduced fragmentation arena, including the use of pressure gauges, make foils and strawboard to capture experimental data from the munition. The findings suggest that the quantity of explosives used was low, as indicated by the pressure data. Furthermore, Fourier-transform Infrared (FTIR) spectroscopy of the explosive residue confirmed that trinitrotoluene was the main explosive used. Fragmentation data indicated low velocities, consistent with a naturally fragmenting munition. Thus, the OME item was identified as an RGD-5 grenade. Future research should focus on a more detailed assessment of the fragmentation distribution to enhance the reliability and certainty of conclusions.

1.0 Introduction

1.1 Aims & Objectives

This report's main aim is to determine what Ordnance, Munition and Explosives (OME) item had detonated at COTEC by using the following data to make an informed decision:

- Blast over-pressure data
- Fragmentation data
- Explosive residue swab analysis

1.2 Background

This report uses a fragmentation arena to capture data about the OME item during detonation. Fragmentation arenas are an increasingly important area of OME testing and evaluation that is normally conducted in collaboration with computer models. Traditionally fragmenting munitions produce a large number of high-velocity fragments intended to cause injury or death to personnel [1]. In contrast, shaped charges and explosively formed projectiles are used to create a high-velocity jet capable of penetrating deep into concrete or metals [2]. To aid the investigation a list of possible munitions has been outlined in Appendix A and Table 1 summaries these munitions into the two aforementioned categories.

Table 1 - Types of munitions summary.

Munition	Target effect	NEQ	Explosive	Fragmentation	Fragment Velocity
Mk83 Air dropped munition	Blast	225kg	Comp B	Natural	N/A
M67 Grenade	Fragmentation	0.213kg	Comp B	Preformed	2096ms ⁻¹
RGD5 Grenade	Fragmentation	0.11kg	TNT	Natural	1568ms ⁻¹
81mm Mortar	Fragmentation	0.76kg	TNT	Natural	N/A
RPG PG-7VL	Shaped charge	0.73kg	RDX/TNT 95% - HMX 5%	Natural	N/A
155mm Artillery shell	Fragmentation	1.15kg	Comp B	Natural	N/A

The trial took place at COTEC, located on Salisbury plain training area, which permits fragmenting events to occur due to its large safety area within licenced areas. However, COTEC is subject to constraints as there are residential dwellings 2km away, constraining the noise limits to 130 decibels (dB) at the range boundaries. This limits the surface Net Explosive Quantity (NEQ) to 10kg, excluding the Mk83 Air dropped munition (225kg) from the possible munitions list. COTEC is equipped to conduct the identification trial, with industry-accredited instrumentation that is routinely calibrated and compliant with International Test Operations Procedure (ITOP) 4-2-813 [3].

Experimental blast overpressure from the OME item will be captured, however, an understanding of the expected pressures generated by each munition is required to draw

comparisons. This is achieved using established blast research by Kingery and Bulmash and related calculators online [4] [5]. Table 2 shows the expected pressures at similar distances to the pressure gauges used during the trial. The calculations consider the differing explosive filling of each munition as outlined in Table 1.

Table 2 - Munition pressure predictions.

Munition	Expected Pressure results (kPa) [6]		
	1.003m	2.036m	3.016m
Mk83 Air dropped munition	22941.12	9211.64	5214.43
M67 Grenade	459.91	95.34	45.11
RGD5 Grenade	255.66	57.92	29.39
81mm Mortar	1107.85	221.23	94.62
RPG PG-7VL	1160.37	232.19	98.86
155mm Artillery shell	1597.83	328.37	136.01

Fragmentation of munitions is classified into two categories: preformed and natural. Natural fragmentation results in irregular geometries, which can lead to lower velocities. Whereas, performed fragments have controlled fragment characteristics that have optimised lethality, with higher velocities [7]. Table 1 outlines the type of fragmentation expected from each munition.

The report provides insights into the velocities of the fragments of the OME item. However, for comparisons, theoretical values need to be calculated. Only the velocity of the fragments produced from the grenades are calculated in this report, as their data aligns most closely to the captured pressure data. This is shown in Figure 8 and the calculations are shown in Appendix C.

To calculate fragment velocities this report uses Gurney's equation for centre-initiated spherical charges [8] (Equation 1, Figure 1). Where V is the metal velocity; C is the mass of the charge, M is the mass of the case, $\sqrt{2E}$ the gurney velocity coefficient, which is unique to each explosive [8] [9].

$$\frac{V}{\sqrt{2E}} = \left(\frac{M}{C} + \frac{3}{5}\right)^{-\frac{1}{2}}$$

Equation 1 - Gurney centre-initiated spherical charges [8].

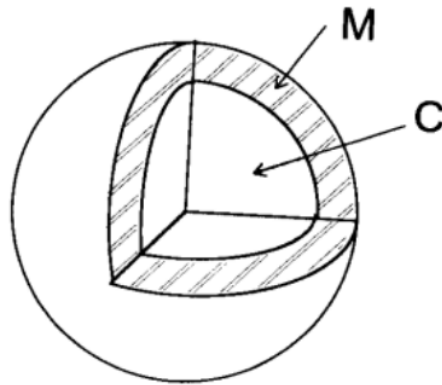


Figure 1 - Spherical configuration Gurney [8].

From the exclusive munitions list in Appendix A, three types of explosives are used across the range of munitions. Each explosive produces a unique fingerprint region when analysed by Fourier Transform Infrared (FTIR) spectroscopy. The explosives considered within this report are Trinitrotoluene (TNT), Research Department Explosive (RDX), and High Melting Explosive (HMX), which differ in their molecular structures. TNT will show strong aromatic and methyl features, whereas HMX and RDX will show nitramine-related vibrations and lack aromatic features. Previous research in Figures 2, 3 and 4 displays the expected FTIR output of each explosive.

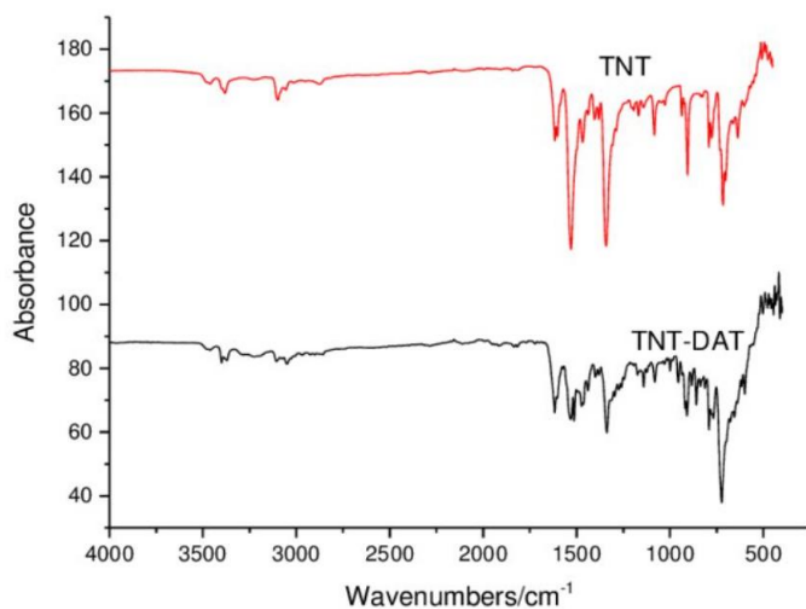


Figure 2 - FTIR for an TNT sample [10].

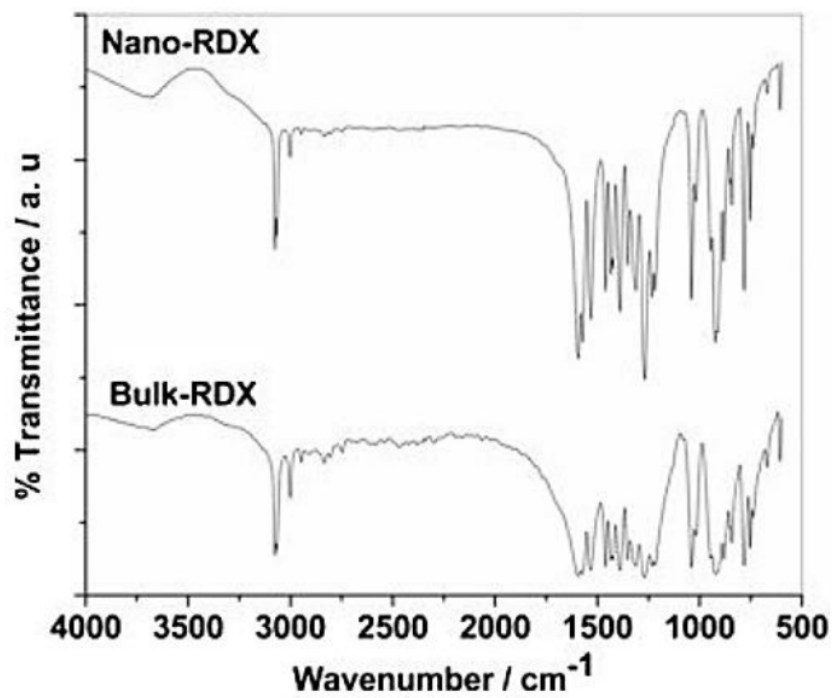


Figure 3 – FTIR for an RDX sample [11].

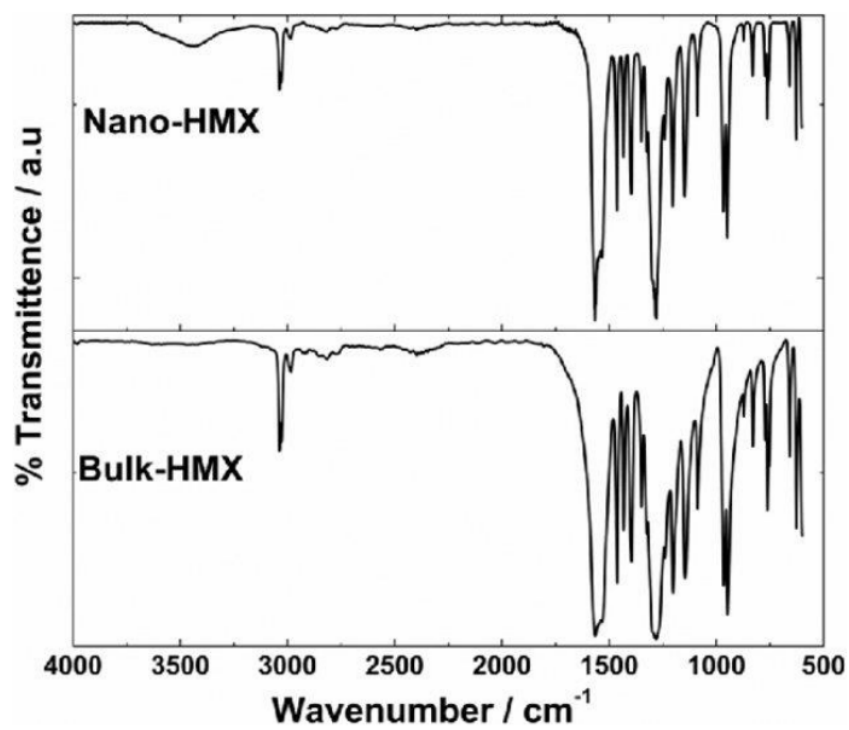


Figure 4 - FTIR of an HMX sample [12].

2.0 Method & Materials

2.1 Trial Equipment

The trial setup follows guidance from ARSP-2 Vol II [1], which provides industry-standard guidance for fragmentation arenas. However, due to limiting factors like cost and time, an abbreviated methodology is implemented. The improvised method will use an arena with a 113° arc of fragmentation capture, using four strawboard packs that stood vertically off the ground.

The following equipment will be used in the trial at COTEC and has been calibrated to meet industry standards:

- 3x Kistler 211B5 IEPE blast over-pressure gauges
- 4x Stands of strawboard (80 sheets)
- Forensic swabs (Post firing data collection)
- 12x Velocity make foils (200mmx200mm)
- Agilent 16804A Logic Analyzer
- Leica Disto Lite Laser Distance
- Vernier calipers
- Weighing scales
- FTIR

2.2 Trial Setup

Figure 5 illustrates the trial site set-up, with the pressure gauges mounted in an incident configuration. The configuration of the gauges are in line with the explosive rather than being front facing (reflected pressure), allowing the overpressure to 'wash over' the gauge without disrupting it. This allows further measurements to be taken behind each gauge. The gauges are positioned at the same height as the munition and self-triggered when a threshold voltage is met on gauge one.

The make-foil configuration, shown in Figure 6, was triggered using a break wire giving a 'time zero' of the munition break up. Post-processing with the logic analyzer uses this data to determine the time taken for fragments to travel a known distance. The distances to each strawboard pack, foils and pressure gauges will be measured using the laser measure described above. As the foils are 200mmx200mm there is a high likelihood that they will be struck whilst still providing acceptable spatial resolution.

The front surface of the strawboard was 1.5m away from the centre of the munition. The munition was raised off the ground on an organic-based table to prevent contamination of fragment data by metallic debris. Post-firing residue samples were collected using swabs for further analysis by FTIR. The fragments were weighed and sized using the weighing scales and callipers outlined earlier.

There are several limitations to a trial setup such as this. Key considerations include the absence of a ricochet stop to arrest any deflected fragments, large foils giving poor spatial resolution and the munition being close to the ground.

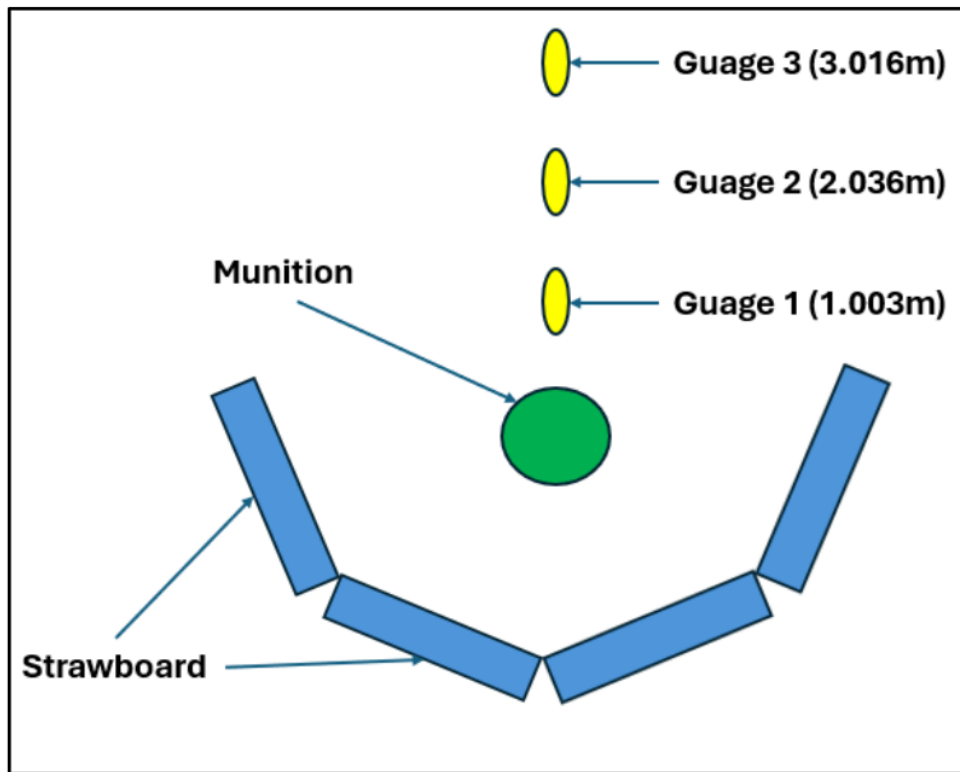


Figure 5 - Trial Setup.

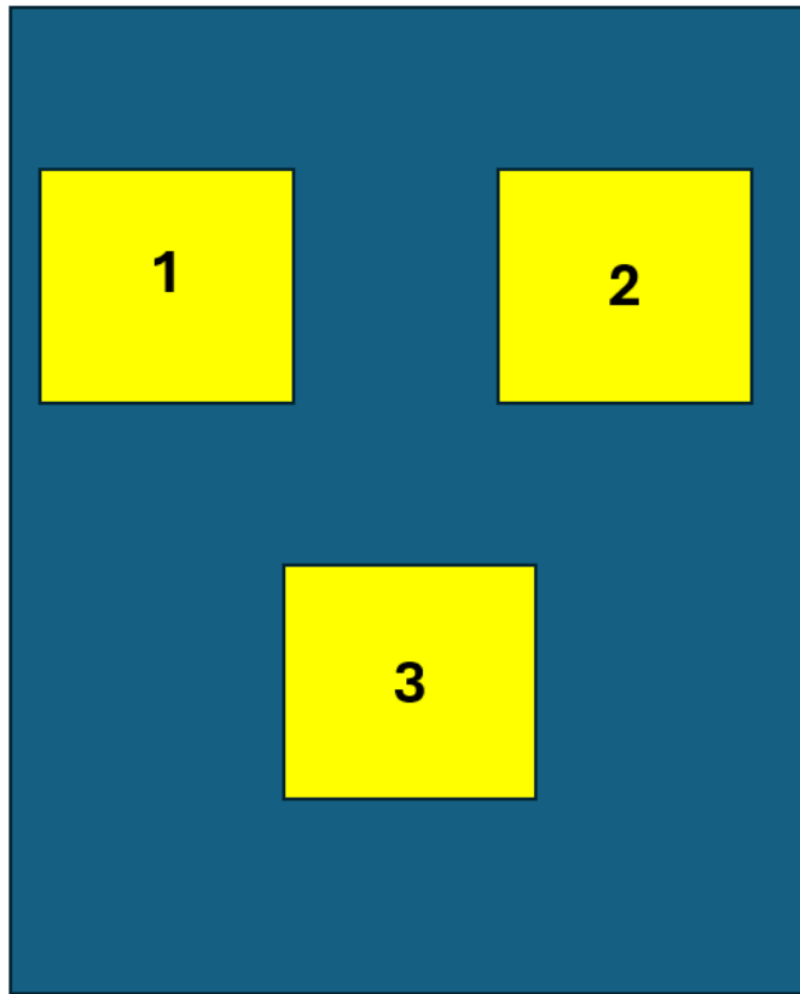


Figure 6 - Foil placement on the strawboard.

3.0 Results

3.1 Pressure Data

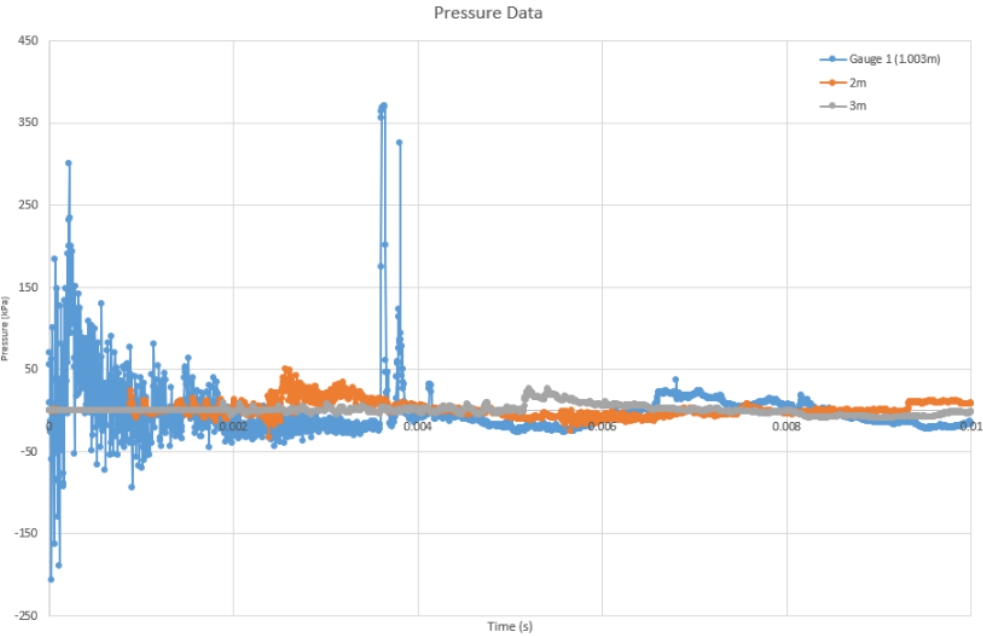


Figure 7 - Blast overpressure data from COTEC.

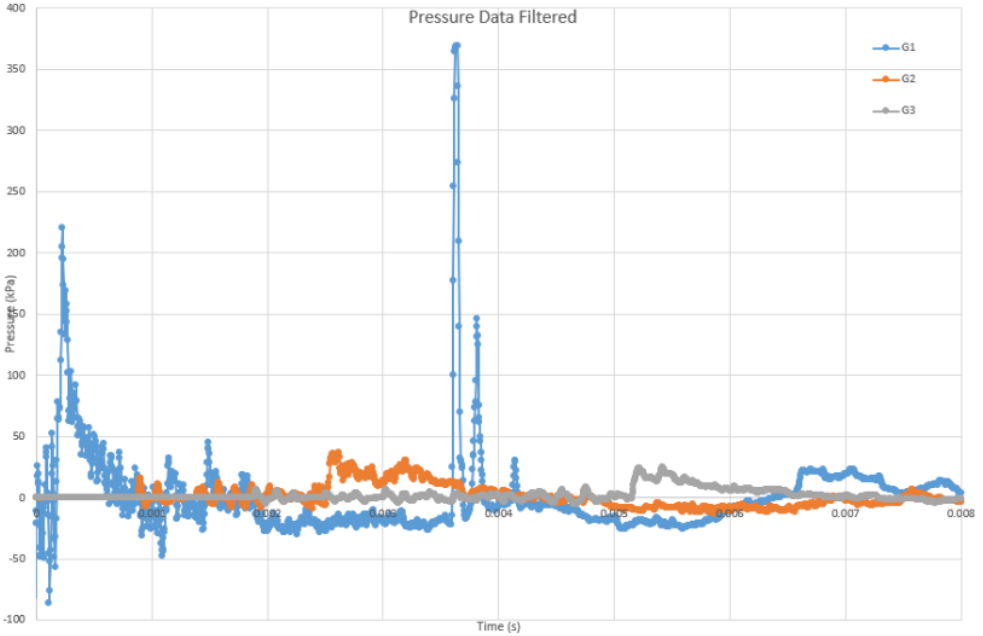


Figure 8 – Filtered blast overpressure data from COTEC.

Table 3 - Summary of peak data.

Distance	Peak 1 (kPa)	Peak 2 (kPa)
1.003m	220.588	366.882
2.036m	35.9006	
3.018m	24.2784	

3.2 Fragmentation Data

Table 4 - Fragmentation information.

Number of Fragments	138
Mass of all Fragments	154g
Average mass of Fragments	1.116g
Average Fragment Area	28.05mm ²
Average Fragment Thickness	1.24mm
Fragment Material	Steel (7860kgm ⁻³)

Table 5 - Fragment velocity results.

Stand Number	Foil ID	Velocity 1 (ms ⁻¹)	Velocity 2 (ms ⁻¹)	Velocity 3 (ms ⁻¹)	Velocity 4 (ms ⁻¹)	Velocity 5 (ms ⁻¹)
1	1	1423.9928	1405.3394	1351.3660	1329.5277	1312.5783
	2	1394.7884	1380.9025	1133.8332	787.1050	
	3	1395.8533	1368.1440	1230.5232	1185.9618	
2	4	1342.5585	1242.0294			
	5	No Strike				
	6	730.1593	705.3698			
3	7	1432.5749	1008.3576			
	8	1339.8531	1280.7749	1279.4147		
	9	1305.4425	1237.2313	1109.4013	1068.7260	
4	10	1360.5140	1208.8294	1128.3300		
	11	465.8556				
	12	341.3035				



Figure 9 - Fragments collect from COTEC.

3.3 Explosive Residue

Spectrum

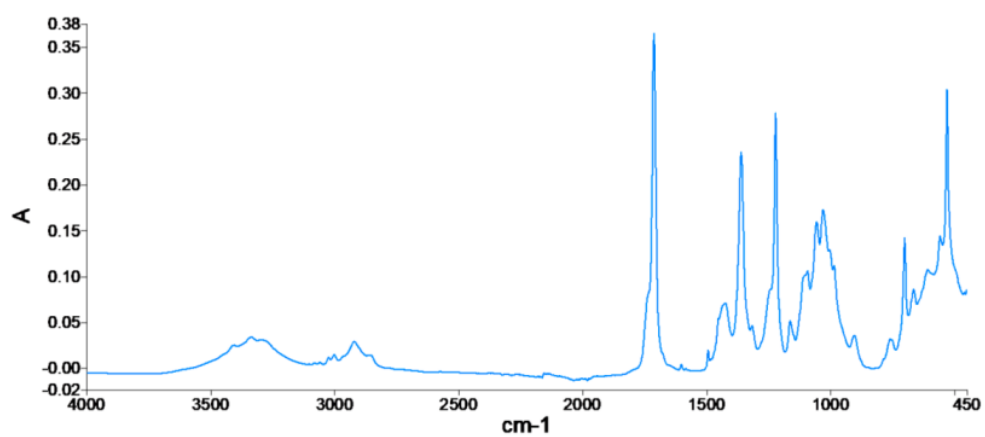


Figure 10 - FTIR Results from explosive residue at COTEC.



Figure 11 – post-firing arena overview.



Figure 12 - post-firing pressure gauge stand (1m) carbon deposit.

4.0 Discussion

4.1 Pressure Data

Upon analysis of the pressure data, it can be seen that the signal is heavily influenced by noise, shown in Figure 7. The noise needs to be filtered out smoothing out the high-frequency oscillations that may obscure peak pressures or impulse data. This improves the clarity and quality of the data. Noise can be induced by numerous factors such as environmental factors, sensor artefacts or electrical interference.

However, by filtering the data there is a potential for information loss, particularly near the peak pressure of an explosive, which could lead to incorrect conclusions being drawn. Furthermore, data filtering may introduce additional bias depending on the choice of filter type and cut-off frequencies. Despite the drawbacks, a 'moving average' filter used in this report has 'cleaned' the signal well and is confirmed by closely matching theoretical/expected values.

The pressure data collected shows notable peaks for gauge one at 220.588kPa and a secondary peak at 367.798kPa. The pressure peaks have corresponding average velocities of 4399.122ms^{-1} and 1099.725ms^{-1} with calculations provided in Appendix B.

The secondary peak is mostly likely attributed to the pressure being reflected off the four strawboard packs within the arena, which focuses the reflected pressure wave at gauge one. The timing information suggests that the speed will reduce as the energy dissipates. Additionally, the proximity of the munition and the gauges to the ground likely induced reflections to the measured pressures.

The most notable finding to emerge from comparing the experimental data presented in section 3.1 with the predictions outlined in Table 2 is that only the M67 and RGD5 grenades reasonably align with the experimental results.

4.2 Fragmentation Data

The results in Table 5 show velocities ranging from 1423ms^{-1} - 1068ms^{-1} for direct fragments, which suggests a low quantity of explosives was used. These velocities correspond well to the RGD5 grenade's theoretical value of 1568ms^{-1} . Given that the fragments travelled 1.5m from the munition, it is reasonable to expect some deceleration to the measured values.

Spurious results of 341ms^{-1} - 787ms^{-1} could be attributed to fragments that have ricocheted off the ground or other structures within the test arena.

Interestingly, the presence of copper was found on some fragments, as shown in Figure 9. This is likely attributed to the copper from the velocity foils and can be ruled out as a material originating from the munition. This conclusion is supported by the low quantity of copper and strikes being in a regular pattern that closely matches the foils.

It was also observed that the fragments recovered were all naturally formed, which, in combination with the data in Table 4, strongly suggests that this was an RGD5 grenade. However, the total mass is unexpected and is likely to be attributed to using pre-used strawboard with several strikes noted before firing.

4.3 Explosive Residue Data

The explosive residue samples collected at COTEC were analysed after being diluted in 99% acetone. It is acknowledged, that the acetone could contribute to background noise that would complicate the identification of the results. However, Figure 10 indicates that the explosive residue has a strong resemblance to TNT, as supported by previous research outlined in Section 1.2. This finding is further supported by significant carbon deposits observed at the trial site as shown in Figures 11 and 12. The presence of carbon deposits is characteristic of oxygen-deficient explosives, such as TNT.

5.0 Conclusion

The report set out to determine the OME item that had detonated at COTEC by applying various data analysis techniques. Results of the investigation show that it was a low quantity of TNT used with a naturally fragmenting case. From the data, it was concluded that an RGD5 grenade detonated at COTEC. However, the mass of recovered fragments deviated from the author's expectations, suggesting potential inaccuracies in the fragmentation data.

A key limitation of this study was the lack of repeated trials, which would have bolstered the reliability and confidence of the data collected. Future research could enhance the quality and accuracy of the data by conducting the trial in a fully free field environment, by raising the height of the munition and the data capture equipment. Expanding the coverage area of the data capture medium, such as strawboard, would provide a more comprehensive dataset, facilitating more reliable and conclusive findings.

6.0 References

- [1] North Atlantic Treaty Organization (NATO), *ARSP-2 Volume II - Guidance on the Development of Weapon Danger Areas/Zones*, A ed., vol. 1, NATO Standardization Office, 2017.
- [2] W. T. Solowki, "Chapter Two - Material point method: Overview and challenges ahead," *Advances in Applied Mechanics*, vol. 54, pp. 113-204, 2021.
- [3] U.S. Army Test and Evaluation Command, "International Test Operations Procedure (ITOP) 4-2-813," Aberdeen Proving Ground, 1990.
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- [5] United Nations, "Kingery-Bulmash Blast Parameter Calculator," [Online]. Available: <https://unsafeguard.org/un-safeguard/kingery-bulmash>. [Accessed 18 12 2024].
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- [8] P. W. Cooper, *Explosives Engineering*, Wiley-VCH, 1996, pp. 385-390.
- [9] International Ammunition Technical Guidelines - Formulae for ammunition management, vol. 3, UNODA, 2021, p. 19.
- [10] N. Sen, "A 1:1 energetic co-crystal formed between trinitrotoluene and 2,3-diaminotoluene," *Macedonian Journal of Chemistry and Chemical Engineering*, vol. 37, no. 1, pp. 61-69, 2018.
- [11] R. Kumar, P. F. Siril and P. Soni, "Preparation of Nano-RDX by Evaporation Assisted SolventAntisolvent Interaction," *Propellants, Explosives, Pyrotechnics*, vol. 39, no. 3, 2014.
- [12] R. Kumar, P. F. Siril and P. Soni, "Optimized Synthesis of HMX Nanoparticles Using Antisolvent Precipitation Method," *Post Communist Economies*, vol. 33, no. 4, 2015.

7.0 Appendix

Appendix A

Types of Munition of Potential Interest

Mk 83 air dropped munition

- Charge Mass – 225 kg
- Mass of case – 229 kg
- AUW – 454 kg
- Explosive – Comp B
- Average fragment area - 0.48 cm²
- Average fragment mass – 0.115 kg
- Frag drag coefficient – 0.82
- Density of air 1.23 kg m⁻³
- Frag V_i = 1950 ms⁻¹
- Frag V_f = 1911 ms⁻¹ at 92 m

M-67 grenade

- Charge mass – 185 g
- Mass of case – 213 g
- AUW – 398 g
- Explosive – Comp B
- Average frag area – 1.0 cm²
- Average frag mass – 2g
- Frag drag coefficient – 0.5
- Density of air – 1.29 kg m⁻³
- Frag V @ 5m -1674 ms⁻¹
- Frag V @ 15m – 1424 ms⁻¹
- Frag V @ 230 m – 44 ms⁻¹

RGD-5 grenade

- Charge mass – 110 g
- Mass of case – 200 g
- AUW – 310 g
- Explosive – TNT
- Average frag area – 1.0 cm²
- Average frag mass – 0.12 - 0.46g

- Frag drag coefficient – 0.5
- Density of air – 1.29 kg m⁻³
- Frag V_i = 1567 ms⁻¹
- Number of fragments 350

81 mm Mortar AR-M81

- Charge Mass – 0.76 kg
- Mass of case – 1.334 kg
- AUW – 4.15 kg
- Explosive – TNT
- Frag drag coefficient – 1.6
- Density of air 1.23 kg m⁻³
- Frag V_i = 1734 ms⁻¹
- Frag V @ 1m – 1700 ms⁻¹
- Frag V @ 4m – 1600 ms⁻¹
- Frag V @ 20m – 1150 ms⁻¹
- Frag V @ 32m – 900 ms⁻¹
- Frag V @ 77m – 357 ms⁻¹

RPG PG-7VL

- Charge mass – 730 g
- Mass of case – 1600 g (including rocket motor)
- AUW – 1975 g
- Explosive – RDX/TNT - 95% HMX 5% wax
- Average frag mass – 0.1 g
- Density of air – 1.29 kg m⁻³
- Frag V_i -1831.5 ms⁻¹

155 mm

- Charge mass – 1150 g
- Mass of case – 3105 g
- AUW – 4255 g
- Explosive – Comp B
- Average frag mass – 2.1g
- Density of air – 1.29 kg m⁻³
- Frag V_i -1551 ms⁻¹

Appendix B

Peak 1

$$S = \frac{D}{T} = \frac{1.003 \text{ m}}{0.000228 \text{ s}} = 4399.122807017544 \text{ ms}^{-1}$$

$$= 4399.122 \text{ ms}^{-1}$$

Peak 2

$$S = \frac{D}{T} = \frac{4.003 \text{ m}}{0.00364} = 1099.725274725275 \text{ ms}^{-1}$$

$$= 1099.725 \text{ ms}^{-1}$$

Distance:

Arena radius = 1.5

reflected pressure ~~2~~

$$= (1.5 \times 2) + 1.003$$

$$= 4.003 \text{ m}$$

Appendix C

Center initiated Spherical charge

$$\frac{V}{\sqrt{2E}} = \left(\frac{m_c + \frac{3}{5}}{C_c} \right)^{-\frac{1}{2}}$$

$$V = \left(\frac{0.2}{0.11} + \frac{3}{5} \right)^{-\frac{1}{2}} \times 2438$$

$$V = 1567.794821$$

$$V = 1568 \text{ ms}^{-1}$$

$\sqrt{2E_{\text{imp}}} = 2438$
 $m_c = 0.2 \text{ kg}$
 $C_c = 0.11 \text{ kg}$

$$V = \left(\frac{0.213}{0.185} + \frac{3}{5} \right)^{-\frac{1}{2}} \times 2774$$

$$V = 2096.137733$$

$$V = 2096 \text{ ms}^{-1}$$

$\sqrt{2E_{\text{comp}}} = 2774 \text{ ms}^{-1}$
 $m_c = 0.213 \text{ kg}$
 $C_c = 0.185 \text{ kg}$

Data Capture and Analysis of An OME Item

GRADEMARK REPORT

FINAL GRADE

72/100

GENERAL COMMENTS

Hi Adam,

This was a well researched and articulated submission, indicating that you have grasped this subject matter. Well done. My only comment to major concern was the lack of attention paid to the FTIR trace. You could have entered data onto that trace to highlight why the explosive was TNT. Some minor observations below.

In detail:

1. A very well laid out and structured report, which was easy to follow from the outset. Most specifically, you separated out all the fragmentation, blast and FTIR data, allowing the reader time to consider the reasons for discounting certain munitions.

2. Abstract is good but two minor comments a) given the limited trials data could you have used 'strongly suggests' as opposed to 'was identified'? b) would every reader understand the term 'make foils'? How could you have described that better?

3. Excellent referencing throughout. Demonstrates your understanding of blast, fragmentation, kinetic energy and directed energy.

4. Did you copy the NEQ of the 155 arty shell correctly? 1.15 kg is very low. I think the range trace would have discounted both the Mk 83 and the 155 mm.

5. Very good use of table 2. What should be expected? Very good to compare your results to for incident blast overpressure.

6. Again, I was very pleased to see your explanation of Gurney for spherical charges. More akin to the grenades than the simple cylinders.

7. You could have placed parts of comments 5 and 6 into your discussion. Would have strengthened your argument.

8. Best explanation of method that I read across all students. Well done. May be your subject area but you wrote it well.

9. You explained the importance of a ricochet stop and how the absence of this impacted upon the validity of some velocity data.

10. Excellent point on the risks of filtering data and the impact on peak pressure readings.

11. Well observed for reflected overpressure. The peak of interest is at 220 kPa. Both the RGD-5 and M67 align reasonably with this given all the caveats considered.

12. Again, your fragmentation average velocity data does correspond well with the RGD-5.

13. Similar to everyone, I found the amount of fragmentation collected quite startling. You could have thought about this a bit more by reviewing the arena arc of 113 degrees and determining how much could reasonably have been expected to be captured from an RGD-5 etc. My sense is about 1/2

to 2/3 what we gathered. Biggest problem was collecting fragmentation from the strawboard below the munition. Nobody actually checked that bundle for previous fragmentation.

14. Why does Figure 10 have a strong correlation to TNT? You should have explained the absorption peaks, particularly those which indicated an aromatic ring. Allows you to discount all other explosives.

15. Good conclusion drawing out a number of shortfalls. For that reason 'possibly' RGD-5 based on data given.

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