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Principles of OME Report

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BEng
Academic Year: 2024 - 2029

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April 2025

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List of Abbreviations

ESD	– Electrostatic Discharge
Fol	– Figure of Insensitivity
IM	– Insensitive Munitions
OME	– Ordnance, Munitions & Explosives
TMD	– Theoretical Maximum Density
VoD	– Velocity of Detonation

1. Introduction

When determining the contents of an explosive train it is important to understand the concepts of critical diameter and critical density as they are fundamental to achieving a stable detonation wave. The progression from a more sensitive primary explosive to a comparably insensitive secondary explosive.

This assignment report will analyse a primary and a secondary explosive via literature review, determining their properties to ensure that a functional explosive train can be determined as well as detailing their energetic properties. Consideration to the role of confinement and how it affects the critical diameter of the explosive and how that benefits design within OME.

At the end of the report, the explosive train will be summarised in a visual representation clarifying the determined explosive train with key information.

When looking to produce a successful detonation of an explosive substance, there are multiple variables which must be considered. The critical diameter or failure diameter is the minimum diameter of a cylindrical charge of high explosive which sustains a high order steady-state detonation [1]. The critical density is the minimum diameter which will sustain a stable detonation [2].

2. Types of explosives and their typical properties

2.1.1. Low and High Explosives

Low Explosives are explosive compositions that deflagrate with the reaction progressing slower than the speed of sound within the material whereas High Explosives detonate, assuming the correct conditions are met, with the reaction front moving faster than the speed of sound within the explosive material.

Typically Figure of Insensitivity (Fol) is used to determine the classification of a High Explosive, this is a scale using RDX as a base holding an Fol of 80.

Low Explosives Categories

- Pyrotechnics
- Propellants

High Explosive Categories

- Primary Explosives, Fol < 50.
- Secondary/Booster Explosives, Fol ≥ 50.

Explosive reaction typical effects

- Gas/Smoke
- Heat
- Light
- Sound
- Pressure

2.1.2. Primary Explosives

Primary explosives typically have the following relative properties:

- Low critical energy – Lower quantity of energy required to start the reaction, high sensitivity.
- Low/Moderate gas output – Smaller quantity of gas and therefore not appropriate for main fills of munitions since breaking of casing requires the production of a large volume of gas.
- Small or needle-like crystal structure – Crystals within their structure increase the sensitivity of the composition due to surface area (increased rate of reaction and localised reaction frequency throughout composition) and inter-crystalline friction. These crystals typically have a layered or weak crystal packing which allows for easier shear of crystals and the structure itself further increasing surface area and friction, therefore reactivity.
- Heavy Metal-Azide or Metal-Nitro composition – Crystal structure contains strong internal stresses increasing the likelihood of breakdown,

and sensitivity, due to crystal fracture. These are ionically bonded compounds with Azide or Nitro based anions.

- Strong reaction to the following stimulus:
 - Impact
 - Friction
 - Heat/Flame
 - Electrostatic Discharge (ESD)

2.1.3. Secondary Explosives

Secondary explosives typically have the following relative properties:

- Covalent structure – Highly organised crystalline arrangement often consisting of benzene ring structures. These crystals are larger and more orderly packed which increases the predictability of the composition and lowers its reactivity due to reduced chance for crystal fracture and a reduction in surface area.
- Nitro-Based composition – Nitro groups (-NO₂), nitrate esters and nitramine structures. These provide larger stored chemical energy and the required weakness between molecules to support chemical reactions. The oxygen within the groups further improves the heat of explosion by tending the oxygen balance within the material further towards 0%. Some secondary explosives contain an excess of oxygen which produces no additional energy unless an additive like aluminium is added.
- Dense crystal arrangement – Secondary explosives have a denser packing of crystals which reduces the likelihood of crystal fracture.

2.1.4. Detonation, Deflagration and Burning

An explosion is defined as the rapid decomposition of a chemical system with the production of heat and gas. Typically an explosion, deflagration or detonation, will take the form of combustion of the material.

Burning is where a surface combustion of the material takes place. This is typically used with low-explosives for propelling and pyrotechnic effects. The changing of the grains surface area will affect this rate of burn. In a burning reaction, the gas produced will propagate in the opposite direction to the reaction front.

Deflagration is a rapid combustion within the material where the reaction front progresses throughout the material below the speed of sound within that material. Within a deflagration reaction, the gas produced will travel in the direction of the reaction front. This is typically used with low-explosives for propelling and pyrotechnic effects. This type of reaction is typically exploited in

the Explosive Ordnance Disposal of munitions as it is generally safer, in comparison to detonation, for the ammunition technicians which carry out this process.

Detonation is a very fast burn whereby the reaction front progresses to a speed beyond the speed of sound within the material resulting in a rapid decomposition of the material, producing gas and waste products almost instantaneously. Detonation is typically the mechanism exploited in the use of OME as it is useful in the production of strong motive force.

2.1.5. Oxygen Balance in Explosive Materials

The Oxygen Balance of an explosive is a measure of the completeness of the explosive materials combustion. Explosive compositions are typically consist of CHNO atoms within its structure. A perfect explosive, with an oxygen balance of 0% will produce H_2O , CO_2 and N_2 (complete combustion). Knowing the oxygen balance and chemical makeup of an explosive is important as it can be used to calculate the heat of the explosive reaction with relative accuracy.

Where explosives have a negative oxygen balance, like TNT at -76%, they will carry out a less complete combustion producing C and CO instead of CO_2 . This affects the smoke plume of the explosion through a change in colour as well as reducing the energy released by the reaction.

Where explosives have a positive oxygen balance, like Ammonium Nitrate at -76%, they will carry out a less complete combustion producing C and CO instead of CO_2 . This affects the smoke plume of the explosion through a change in colour as well as reducing the energy released by the reaction.

3. Literature review of selected explosives

3.1.1. Lead Styphnate

Critical Density:	2.8 g/cm ³	[3]
T. Max Density:	3.02-3.1 g/cm ³	[7]
Critical Diameter:	0.5 mm	[3]
Figure of Insensitiveness:	12	[5]
Ignition Temperature:	275-280°C	[5]
Velocity of Detonation:	approx 4800-5200 m/s	[3]

Table 1 – Lead Styphnate explosive properties

Lead Styphnate is a legacy primary explosive, typically used within primers blasting caps and electric detonators. It's main benefits in use for OME is its high heat sensitivity which allows for reliable initiation through systems like a heated bridge wire as seen sometimes in an electric match. It's legacy purpose

was to be used as a replacement for Mercury Fulminate during the world wars due to its increase in stability.

Whilst the TMD is listed as 3.02 – 3.10 g/cm³, the compound will experience dead pressing at densities of 2.8 – 2.0 g/cm³. This is why the typical pressing of the compound is to around 85-90% of its TMD in order to maintain its sensitivity. The variation in theoretical maximum density is due to the polymorphic nature of Lead Styphnate where multiple forms (Type I and Type II crystals) of the explosive will likely exist post-synthesis within the compound. Another issue experienced with Lead Styphnate is the hydration state of the crystal lattice. Monohydrates are the more stable form of the compound whereas a dehydrated form is possible, which would have an increased TMD but due to the compound being hygroscopic it is impractical and unstable.

One of the major concerns surrounding Lead Styphnate is the toxicity of its production due to the use of the heavy metal Lead which causes harm to people if ingested or if it's dust is inhaled. This has led to the development of alternatives like DBX-1, however this has limited public information due to its classification with military use.

3.1.2. PETN

Critical Density:	0.4 – 0.7 mm	[3]
T. Max Density:	1.78 g/cm ³	[3]
Critical Diameter:	0.3 mm	[3]
Figure of Insensitiveness:	51	[5]
Ignition Temperature	215°C	[5]
Energy Output	5800 kJ/kg	[3]
Velocity of Detonation:	approx 8300 m/s	[3]

Table 2 – PETN explosive properties

PETN is a legacy sensitive secondary explosive which is typically used within detonating cords and booster charges within initiation systems. PETN is useful to the OME professional due to its high detonation velocity, which is what makes it a good booster charge, and it's shock sensitivity. This high shock sensitivity is what allows a smooth progression of the explosive train from the primary compounds used alongside it. PETN has a TMD of 1.78 g/cm³ but in order to increase it's reliability in booster applications, it is pressed to around 1-1.6 g/cm³ as PETN has a lower threshold for detonation at these densities. It has a high velocity of detonation, typically around 8300 m/s at use, and has a high detonation pressure (33GPa at Theoretical Maximum Density (TMD)).

PETN is a nitrate ester which makes it vulnerable to thermal decomposition and the ingress of water due to hydrolysis. Typically, PETN is used alongside stabilisers like diphenylamine for long-term use due to PETN's susceptibility to a

reduction in its thermal decomposition temperature threshold if acidic impurities are within the explosive [8].

3.1.3. Relationship between density and VoD

Density (g/cm ³)	VoD (m/s)	Condition / Note
0.85	~6,800	Coarse powder, unconfined
1.0	~7,200	Pressed powder
1.5	~7,900	Moderately pressed
1.65	~8,200	Pressed charge (92-93% TMD)
1.70	~8,300	Highly pressed
1.78	~8,400 - 8,500	Theoretical Maximum Density
Single Crystal	~8,300	Along different crystal axes

Table 3 – PETN Velocity of Detonation against different densities [3]

By increasing the density of an explosive you are increasing the detonation velocity (see table 3 above). This is caused by the reduction of voids and gaps between the crystals of the explosive improving the progression of the detonation wave through better alignment of the crystals. More explosive mass is also available for the volume it takes up which increases the energy produced by that detonation.

Whilst increasing the density of an explosive is usually beneficial it is possible to encounter the phenomenon of 'dead-pressing'. Dead pressing is point of compression where the structure has become too dense that some of the required voids and therefore hotspot locations have been removed. This makes the explosive more difficult to carry out detonation as well as reducing the velocity of detonation.

3.1.4. Determination of explosive train

The initiation of this explosive train will be conducted through an electric match attached to the Lead Styphnate. This is due to the high heat sensitivity of the composition and will reliably initiate this primary explosive.

The PETN will be another pellet, directly connected to the Styphnate pellet, and will have a minimum diameter of 0.3mm and a minimum density of 0.7 mm. In practice, a larger pellet of PETN will be used than its primary igniting composition as it is typically a booster for initiating other secondary explosives with a higher Fol more reliably. The Lead Styphnate would initiate the PETN through shock as it's shock initiation range is 3-5 GPa whereas Lead Styphnate has a Chapman-Jouguet pressure of 4-8 GPa. Lead Styphnate also produces a very high flame front and creates hot particles which would be 'spat' towards the PETN throughout the Styphnates detonation, causing rapid local heating of hotspots within the PETN leading to it's own detonation.

4. Role of confinement in OME

In the design of OME, the role of confinement plays a big role in successful utilisation of the explosive compositions. An explosion progresses through a detonation wave at the reaction front. In an unconfined detonation, energy losses can be seen at the extremes of the detonation wave (unless self-confining). Confinement reduces the energy losses by containing some of the heat energy as well as reflecting some of the shock back into the explosive. This allows for a faster progression of the detonation as well as reducing the critical diameter of the explosive required for a stable detonation.

Confinement is also exploited in the production of OME due to its role in pressure build-up allowing for the explosive to produce work, like breaking a case for fragmentation/blast effects.

5. Conclusion

Explosives compositions are polymorphic – they have multiple forms/phases which when manufactured have different crystalline structures and arrangement affecting the predictability and sensitivity of the compositions. It is important that when manufacturing these explosives, measures are put in place to ensure that the correct form of compound is being produced.

The diagram below details the explosive train and some of the necessary information.

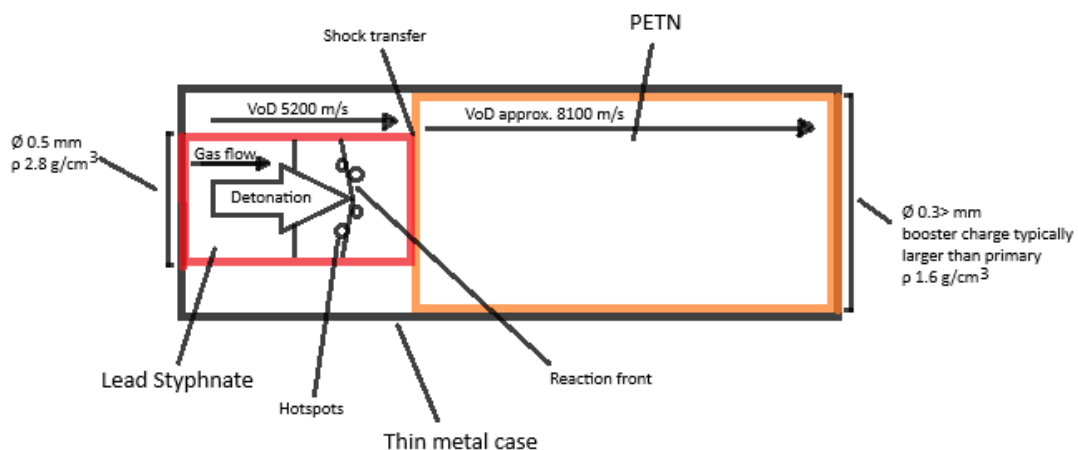


Figure 1 – Labelled explosive train of initiation system with booster

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