Explosive Characteristics and Performance

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Improving Processes. Instilling Expertise.

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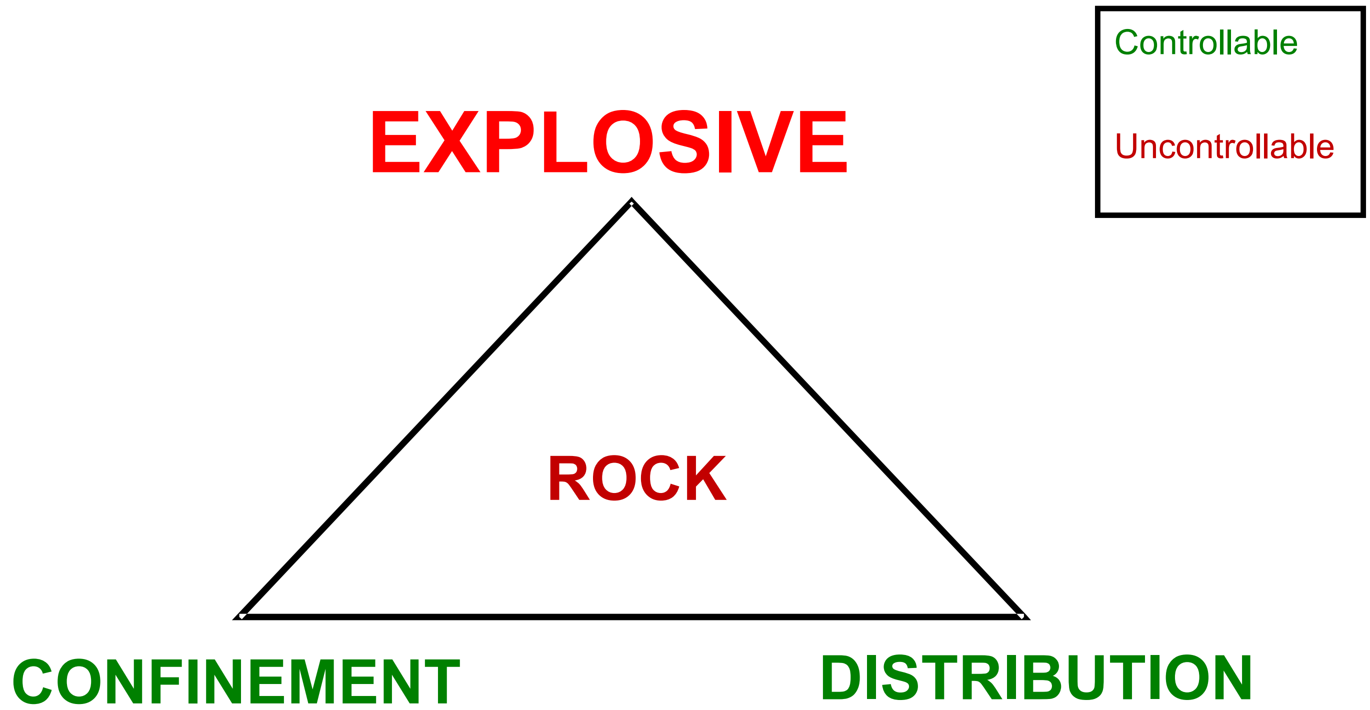
Design Factors for Chemical Crushing



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Course Agenda

- ***What is an Explosive***
- ***Explosive Types***
  - ✓ ***What are best to fuel "chemical crusher"***
- ***Explosive Properties***
- ***Explosive types***
  - ✓ ***Characteristics***
  - ✓ ***General Application***
- ***Explosive selection to meet blasting objectives***

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What is an Explosive

- Intimate mixture of fuel and oxidizer. Can be a molecular solid, liquid or gas and/or mixtures of them.
- When initiated reacts very quickly to form heat, solids and gas. Violent exothermic oxidation-reduction reaction. Detonates instead of burning.
- Rate of reaction is its detonation velocity.

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Explosive Types

- Main Explosive Charge
- Explosive for use in primer make up.
- Initiation System

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Explosive Types – Main Explosive Charge

- **Bulk Explosive**
  - ✓ **Blasting Agent, 1.5 D (not detonator sensitive)**
    - Repumpable
      - Emulsion (available with field density adjustment and/or homogenization)
    - Repumpable ANFO Blend
      - Emulsion (available with field density adjustment)
    - Heavy ANFO Blend
      - Emulsion
    - ANFO

For fueling chemical crusher, application flexibility for changing design is best decision.

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Explosive Types – Main Explosive Charge

- **Packaged Explosive**
  - ✓ **Explosive, 1.1D (detonator sensitive)**
    - Emulsion
    - Dynamite
  - ✓ **Blasting Agent, 1.5 D (not detonator sensitive)**
    - Emulsion
    - Water Gel
    - WR ANFO
    - ANFO

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For fueling chemical crusher, it is best to optimize explosive distribution.

Explosive Types

- **Explosive for use in primer make up.**
  - ✓ **Explosive, 1.1D (detonator sensitive)**
    - Cast Booster
    - Dynamite
    - Emulsion

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For fueling chemical crusher, cast booster is recommended explosive for primer make up.

Explosive Types

- **Initiation System**
  - ✓ **Electronic**
  - ✓ **Non Electric**
  - ✓ **Electric**

For fueling chemical crusher, Electronic Detonator is recommended.

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Explosive Properties

- **Safety properties**
  - ✓ Characterize transportation, storage, handling and use
- **Physical properties**
  - ✓ Characterize useable applications and loading equipment requirements.
- **Detonation properties**
  - ✓ Characterize performance

All properties are important when selecting explosives.

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Safety Properties

- Chemical stability
- Sensitivity
- Products of combustion (After - blast fumes)

Chemical Stability

Defined as the ability to remain chemically unchanged when stored correctly. It is a key parameter in shelf life of many products as it relates to their field performance.

- **Factors affecting shelf life include:**
  - ✓ Formulation / Raw material quality
  - ✓ Storage Container / Packaging
  - ✓ Temperature and humidity of storage environment
  - ✓ Contamination
- **Characteristic signs of bulk explosive deterioration include**:
  - ✓ Crystallization
  - ✓ Increased viscosity and/or change in density
  - ✓ Color change (e.g. bulk emulsions go cloudy as crystallization increases)

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Sensitivity

Defined as ease of initiation of explosive (i.e. minimum energy required to initiate detonation)

- ✓ Varies with composition, diameter, temperature and pressure
- ✓ Friction and impact
- ✓ High Explosive (1.1D) sensitive to No 8 strength detonator or 25 gr/ft cord,
- ✓ Blasting Agent 1.5D insensitive to No 8 strength detonator (requires a high explosive booster for initiation)
- ✓ Can be altered by incorrect use
  - Some blasting agents can become detonating cord sensitive – lateral prime
  - Some blasting agents can be desensitized by detonating cord – lateral dead-press

Testing includes:

- ✓ Minimum detonator / primer, critical diameter, critical density, impact, friction, gap test.

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Detonation Products
After Blast Fume Characteristics

- **Oxygen balanced explosives yield non toxic gases**
  - ✓ CO_2, N_2 and H_2O

- **Quantities of toxic gases can also produced**
  - ✓ Oxides of nitrogen (NOx) result from an excess of oxygen in the formulation (oxygen positive)
  - ✓ Carbon monoxide (CO) results from a deficiency of oxygen in the explosive (oxygen negative)

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Visible orange-brown post blast fumes are oxides of nitrogen (NOx) and are not desirable.

Physical Properties

- **Form**
  - ✓ **Bulk**
    - Free flowing solid mixture
    - Augured solid and or solid/liquid mixture
    - Pumped Liquid/solid mixture
    - Pumped liquid mixture.
  - ✓ **Packaged**
- **Density**
- **Water resistance**
  - ✓ **Sleep time**

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Density (as loaded)

- **Weight per volume (g/cm^3, lb/ft or kg/m)**
  - ✓ Density below 1.0 g/cm^3 means explosive will float in water
  - ✓ High viscosity products such a homogenized emulsion
  - ✓ Loading process such as repump emulsion

Increasing density leads to increasing Velocity of Detonation (VoD) up towards critical density

Increasing density leads to increasing detonation pressure

Higher density for non-ideal explosives risks dead pressing

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Water Resistance

Ability of explosive to withstand exposure to water without losing sensitivity or detonation efficiency.

- ✓ Wide variation depending on product used:
  - ✓ ANFO has none
  - ✓ Emulsion is excellent
- ✓ Dependent on water conditions
  - ✓ Static or dynamic water
  - ✓ Pressure

Water resistance of explosives can be improved by use of hole liners, but usually at the risk of reduced charge per foot or meter of blast hole

Orange-Brown Nitrous Oxide post blast fumes is indication of water degradation of explosive performance.

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Sleep Time

Amount of time an explosive is exposed to the conditions present in the drill hole without losing sensitivity or detonation efficiency.

- **Rock / Ground type**
  - ✓ Wet or dry
  - ✓ pH of water or moisture
  - ✓ Pressure
  - ✓ Reactive to explosive material
  - ✓ Temperature
    - Hot (150º F)
    - Cold

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Detonation Properties

- Critical diameter
- Velocity of detonation (VoD)
- Detonation pressure
- Energy / Strength

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Critical Diameter = D_{crit}

Defined as the minimum diameter at which a explosive can achieve a stable detonation velocity.

- ✓ **Ideal explosives, can be as small as 0.04 inch (1 mm)**
- ✓ **Non-ideal explosives, can be large as 8 inch (200 mm)**
- ✓ **For Non-ideal explosives, D_{crit} can depend on the level of confinement**

D_{crit} is important for determining hole size/explosive type compatibility

- ✓ **D_{crit} is determined predominantly by the size of the reaction zone**
- ✓ **Density also has an effect on D_{crit}**

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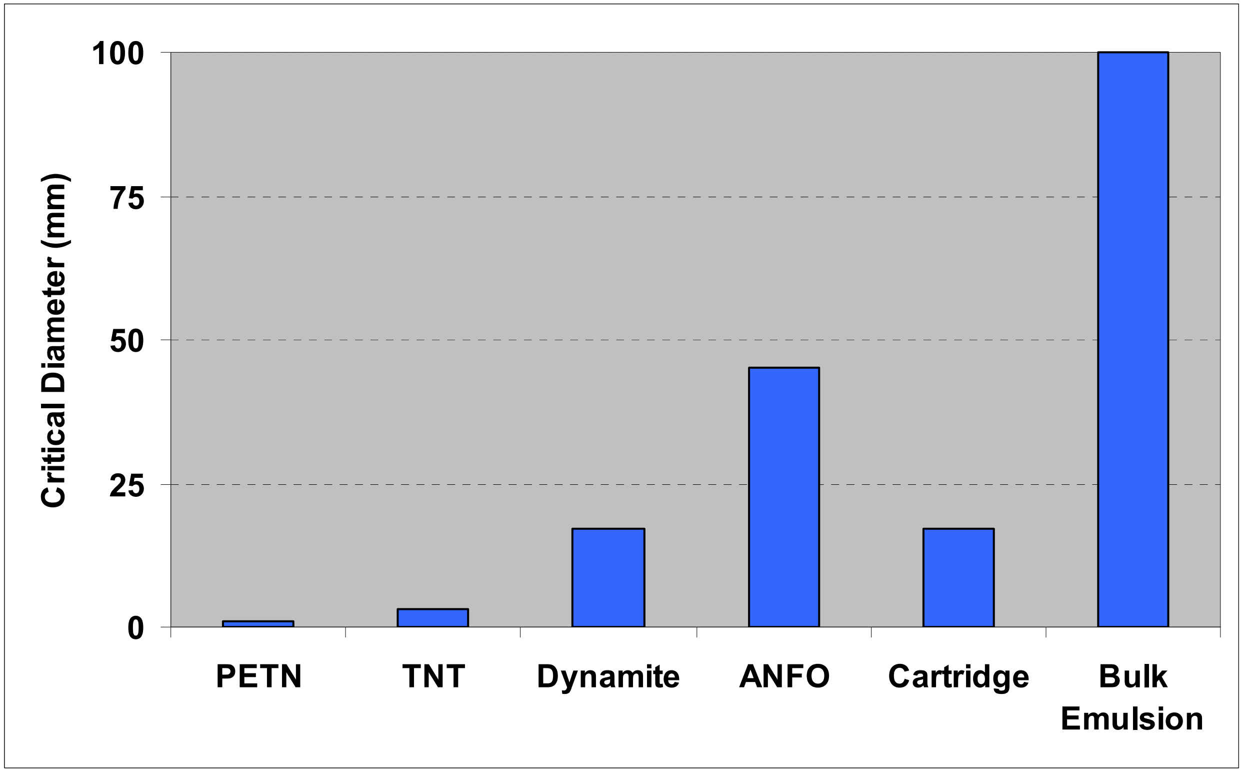
Critical Diameter



Molecular explosives Non-ideal explosives

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Velocity of Detonation (VoD)

Speed that the detonation reaction travels through the explosive, usually expressed in feet per second (ft/s) or meters per second (m/s)

- **Influenced by:**
  - ✓ Explosive formulation
  - ✓ Oxidizer / Fuel Particle size
  - ✓ Charge diameter
  - ✓ Explosive density
  - ✓ Degree of confinement / Rock Type
  - ✓ Primer (size and type)

VoD is a determining factor for how quickly the energy is released from the explosive.

Velocity of Detonation (VoD)

VoD can be a measure of how efficiently the explosive is performing.

- ✓ Comparison of VoD results to technical specifications should be done within the context of the particular blasting situation (i.e. same mine, same rock type). For Example, ANFO VoDs vary from 8,200 to 14,700 ft/s (2,500 to 4,500 m/s) depending on hole diameter in the same rock
- ✓ VoD data should be seen as a statistical variable (i.e. always use multiple data wherever possible) to allow for:
  - Rock type variation
  - Charging variation
  - Reliability of data capture system itself

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Detonation Pressure P_d

Pressure in the detonation reaction zone as it progresses along the explosive charge, expressed in Mpa, Kbars or psi. This is what generates the shock pulse in the rock and pressurizes the borehole.

P_d for commercial explosives:

$$P_d = 0.25 \times VoD^2 \times \rho$$

Example: ANFO at ρ = 0.85 g/cc and VOD = 4,000 m/s (13,123 ft/s)

$$P_d = 0.25 \times 4000^2 \times 0.85$$

= 3400 Mpa

= 34 Kbars

= 499,800 psi

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Detonation Pressure is not same as blast hole pressure.

Available Explosives Energy

The energy that an explosive is able to deliver when detonated:

- ✓ Theoretical energy produced by the oxidation / reduction reaction of the explosive's ingredients before the gasses vent to the atmosphere (Calculated using thermodynamic codes)
  - One critical factor that effects the value determined by this calculation is the reactions cut off pressure. Changing the cut off pressure changes the energy attributed to an explosive. (higher cut off pressure = higher energy value)
- ✓ Effective energy is the total energy transformed into useful rock fragmentation, rock displacement, ground vibration and air overpressure.
- ✓ Ex … ergy (th … of the …)

The actual amount of energy delivered from any blast hole is unknown.

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Absolute Weight Strength (AWS)

Same as Available Explosive Energy.

- ✓ **Presented as cal/g, kcal/kg, or MJ/kg of explosive.**
- ✓ **AWS of ANFO is 880 cal/g for 94% AN and 6% Fuel Oil**

AWS for explosive formulations are not equivalent between explosive manufactures.

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Relative Weight Strength (RWS)

This is the ratio of available explosive energy between a unit weight of explosive and an equal weight of ANFO

- ✓ **RWS for an explosive is the AWS of the explosive divided by the AWS of ANFO, expressed as a percentage:**

$$RWS_{explosive} = \frac{AWS_{explosive} \text{ X } 100}{AWS_{ANFO}}$$

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Absolute Bulk Strength (ABS)

The available explosive energy per unit volume of explosive

- ✓ **ABS for an explosive is its AWS multiplied by its density**

$$ABS_{explosive} = AWS_{explosive} \times \rho_{explosive}$$

Where $\rho_{explosive}$ is the density of the explosive and ABS units are in cal/cc

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Relative Bulk Strength (RBS)

The ratio of the available explosive energy between a given volume of explosive and an equal volume of ANFO

- ✓ **RBS for an explosive is the ABS of the explosive divided by the ABS of ANFO, expressed as a percentage:**

$$RBS_{explosive} = \frac{ABS_{explosive} \times 100}{ABS_{ANFO}}$$

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ANFO

Advantages

- ✓ Easy to manufacture
- ✓ Cost effective
- ✓ High energy

Disadvantages

- ✓ Low density
- ✓ No water resistance
- ✓ Variable after-blast fume generation

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ANFO

Physical properties

- ✓ Bulk poured density: 0.82 - 0.85 g/cm^3 (dependent on AN source)
- ✓ Blow loaded density: 0.85 to +1.05 g/cm^3
- ✓ Water resistance: none. (Actually hydroscopic)

Detonation properties

- ✓ AWS = 880 cal/g (401 Kcal/lb)
- ✓ RWS = 100
- ✓ RBS = 100 to 115
- ✓ VOD = 2,500 to 4,500 m/s (8,200 to 14,700 ft/s)
- ✓ High gas (heave) energy potential

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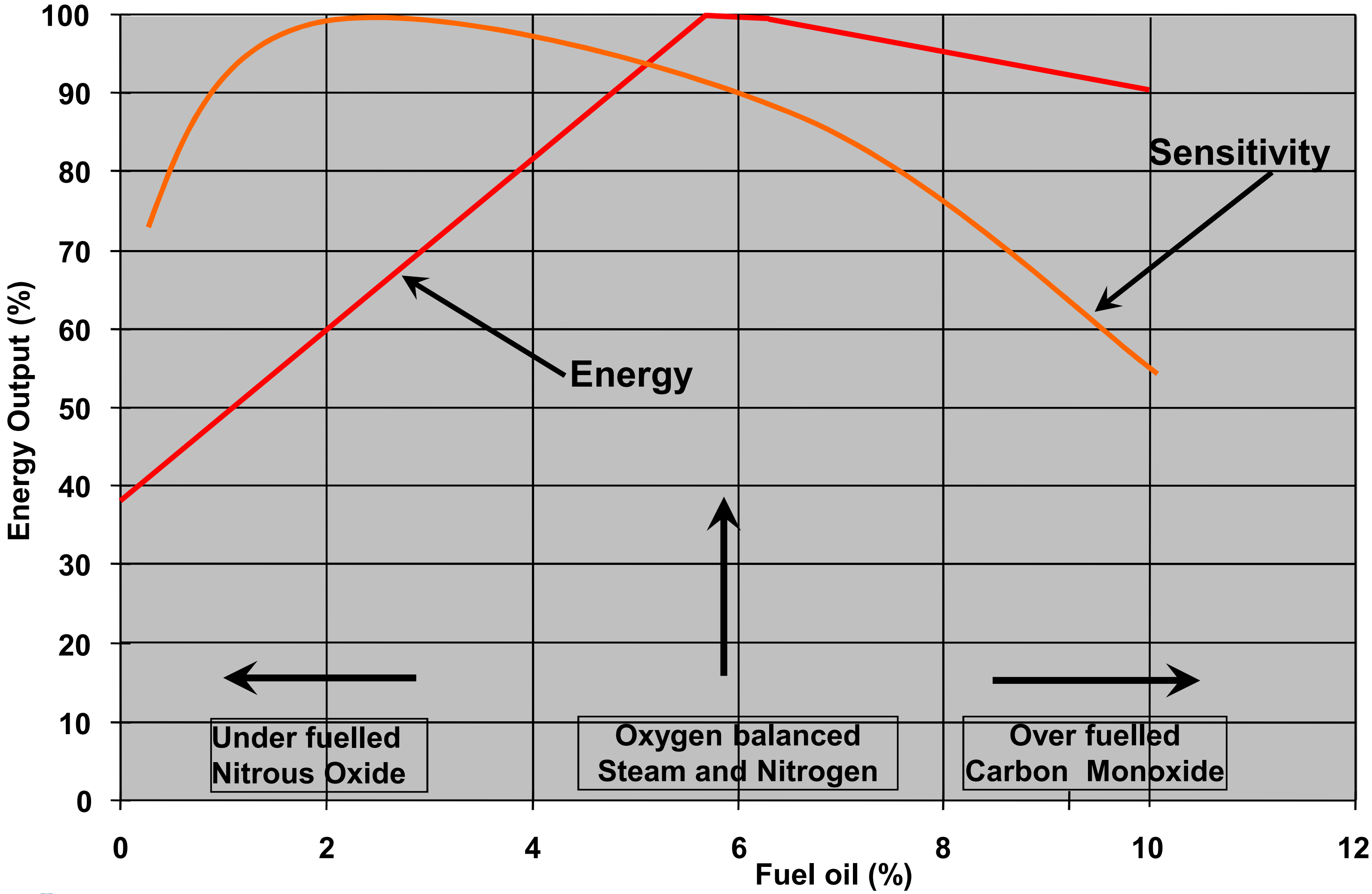
Energy Variation of ANFO



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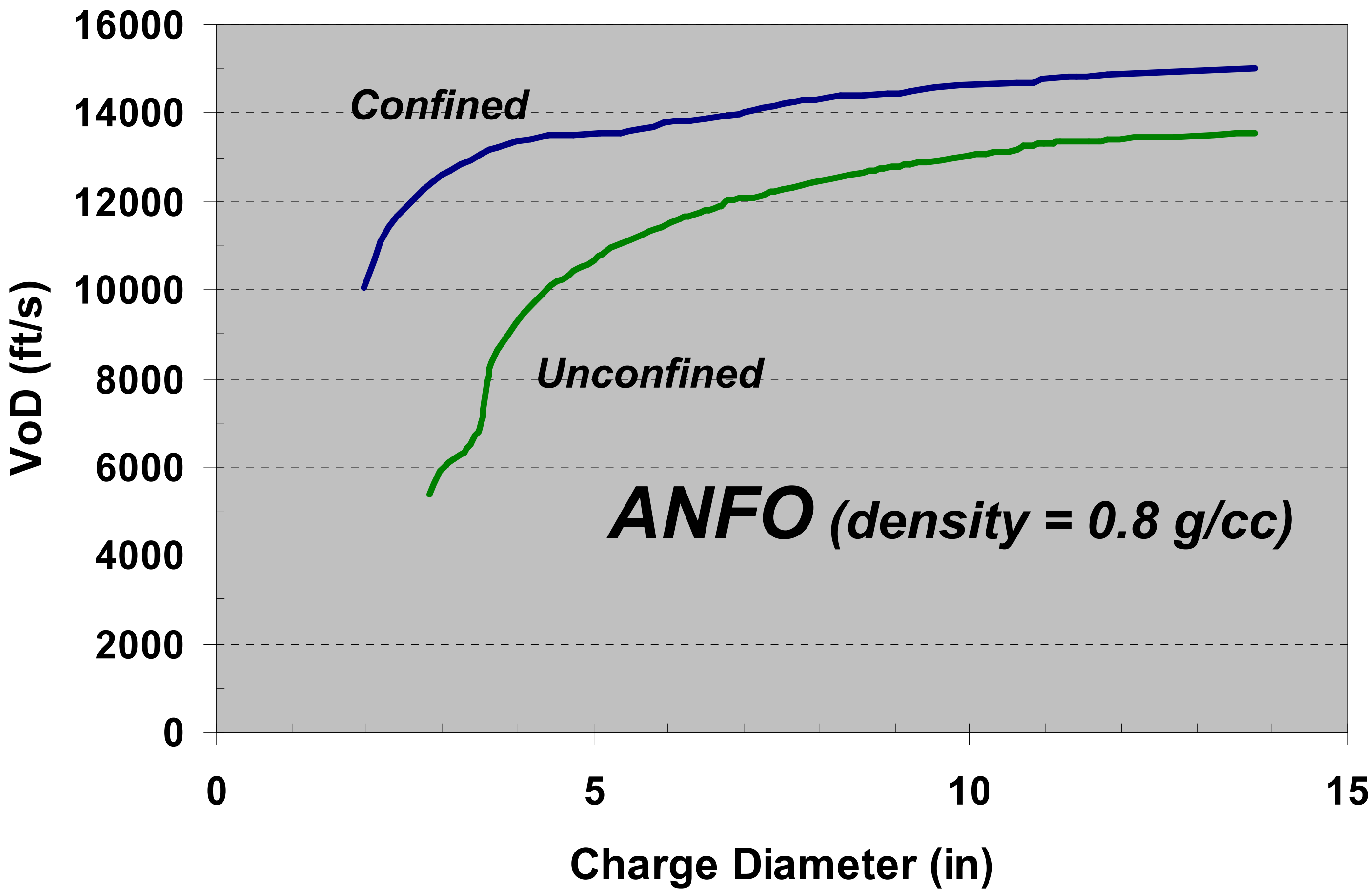
Effect of Confinement on ANFO



Emulsion Explosive

Physical Properties

- ✓ **Types**
  - Pumped Blend (0% ANFO to 45% ANFO)
  - Augured Blend (50% ANFO to 90% ANFO)
- ✓ **Straight Emulsion density range:**
  - Plant sensitized 1.10 - 1.35 g/cm^3
  - Field Sensitized 0.90 - 1.35 g/cm^3
- ✓ **Colour is from additives (e.g. dyes, Aluminium)**
- ✓ **Viscosity can vary from very fluid to thick.**
  - Field adjustable.
- ✓ **Shelf life / sleep time:**
  - **storage** - up to 6 months
  - **blastholes** - 2 weeks max

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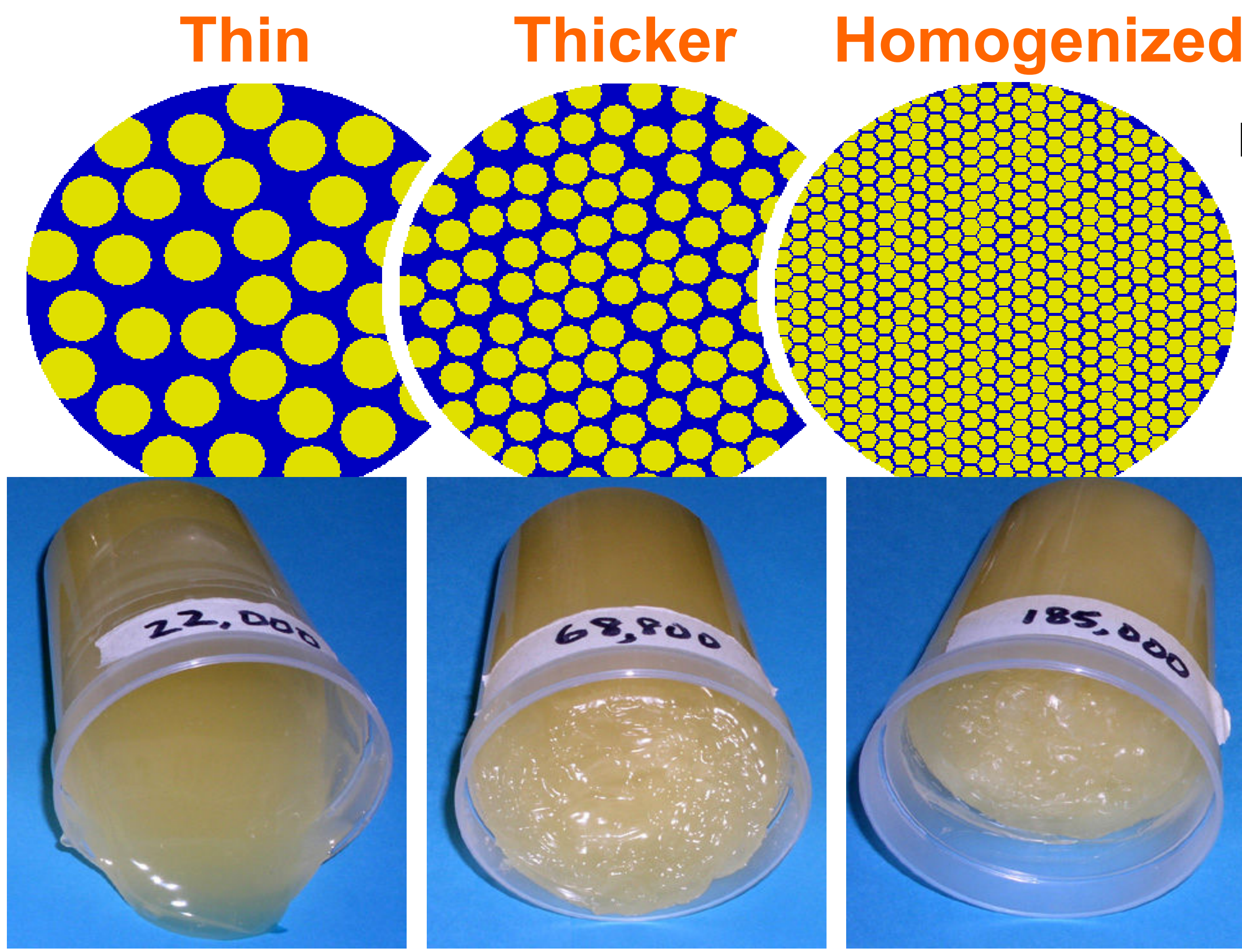
The Structure of Homogenized Emulsion



Magnified Emulsion Cross-Sections

Blue = Fuel
Yellow = Oxidizer Droplets

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Emulsion Explosive

Detonation Properties

- ✓ **Properties vary with composition - can be adjusted to application**
- ✓ **VOD 14,700 – 19,700 ft/s (4,500 – 6,000 m/s)**
  - ✓ depending on hole diameter, density and sensitizer
- ✓ **Weight Strength: generally lower than ANFO**
- ✓ **Bulk Strength: higher than ANFO**
- ✓ **Higher shock energy than ANFO**

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Heavy ANFO Properties

Physical Properties

- 5 to 50% emulsion explosive (augured)
- Bulk density range is 0.95 - 1.35 g/cm^3
- Sensitivity to initiation is low
- Water resistance increases with emulsion content
- Higher water resistance than ANFO

Detonation Properties

- RWS < ANFO*
- RBS > ANFO*
- VoD > ANFO

*Depends on assumptions in energy derivation

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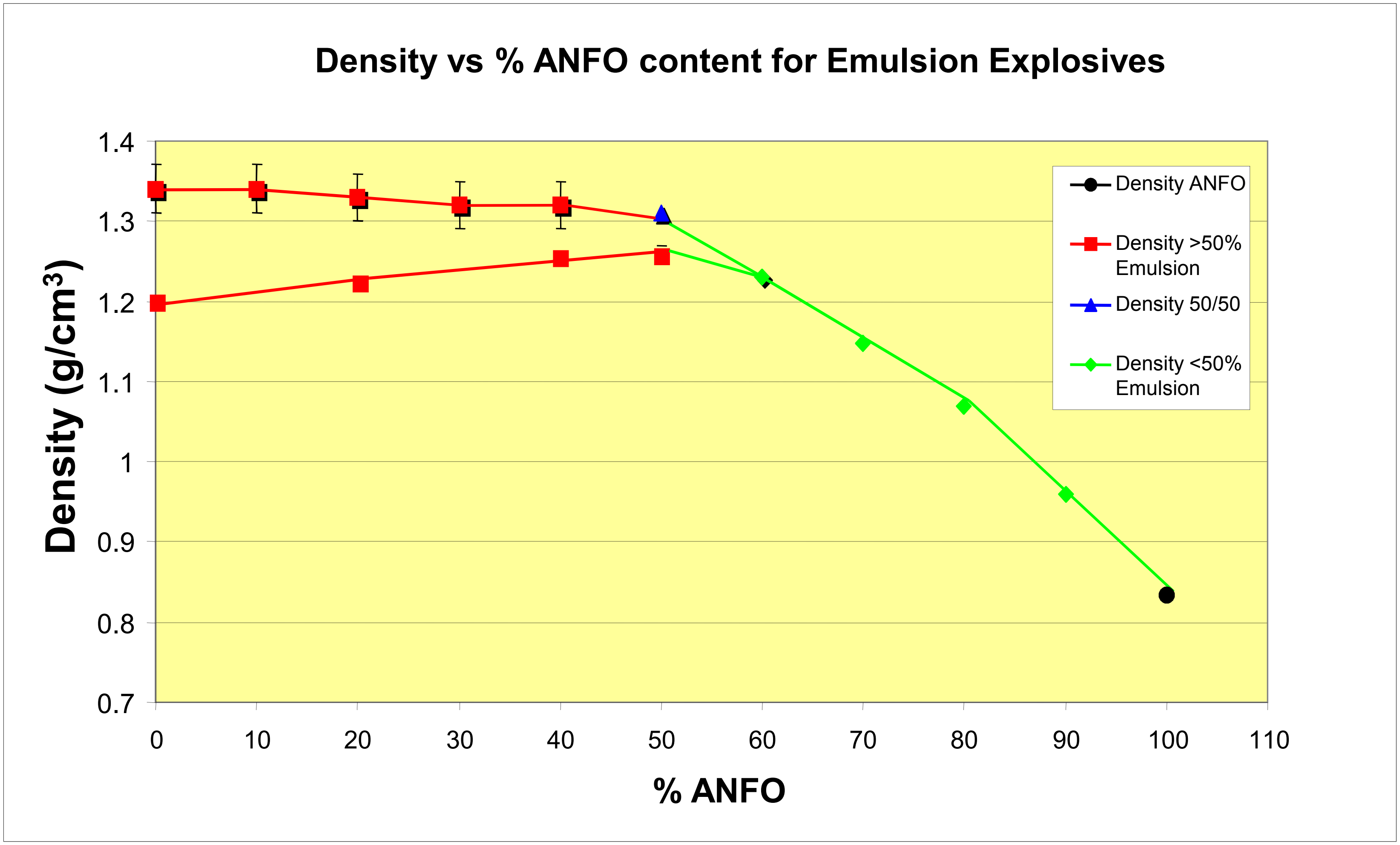
Density Vs % ANFO in Heavy ANFO



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Why use emulsion explosives?

1. **Water resistance**
   - ANFO has no water resistance
   - Emulsion blends can be slept for 2 weeks in wet conditions
2. **Adjustable density**
   - Different Heavy ANFO blends
   - Field sensitization
3. **Adjustable energy**
   - Differing percentages of ANFO and Emulsion
   - Density gradation with field sensitization
4. **Adjustable Detonation characteristics**
   - VOD / Detonation Pressure
   - Heave to shock ratio can be manipulated as needed
5. **Customized formulation**
   - Inhibited formulation for reactive ground

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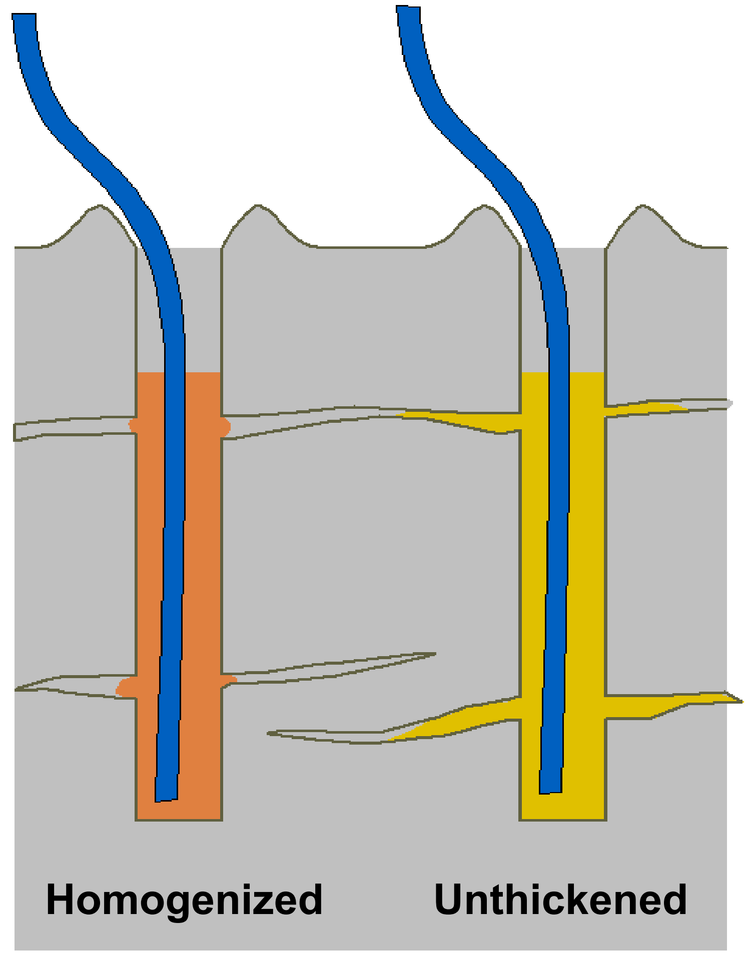
The Benefits of Homogenized Emulsions

Titan Emulsion is *very* thick and resists flowing into cracks or laminations

- Predictable loading density
- More predictable blast results
- More complete detonation
- Generates less fumes
- Reduces possibility of flyrock and blowout



Titan Thickened Emulsion

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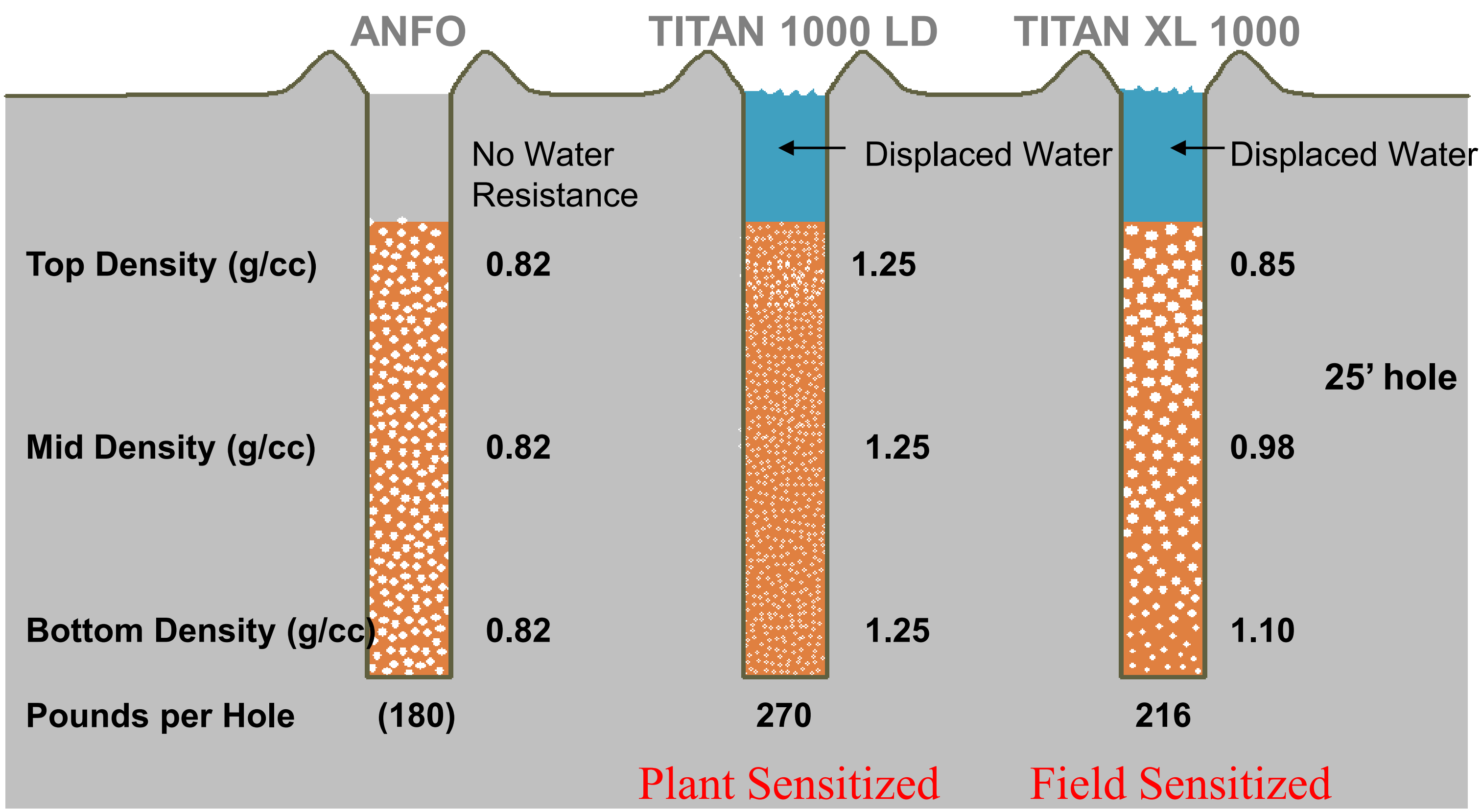
Bulk Explosives Comparison: Energy / Density Profiles

Density gradient produces higher bulk strength and detonation pressure at the bottom of the hole.



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Packaged Products

- ✓ Packaged explosives do not completely fill the drill hole, reduce load factor (lbs/ft) and reduce powder factor (lbs/cu yd rock).
- ✓ Bulk explosives can be placed in shot bags on bench. (must consider critical diameter)
- ✓ Packaged explosives can be used effectively in adjusting blast hole pressure (pre-splitting)
- ✓ Diameter and density can be used to adjust the available energy in specific areas of blast hole.
  - Used effectively to adjust distribution of explosive energy in blast hole.
  - Used effectively for custom loading the front row or critical holes

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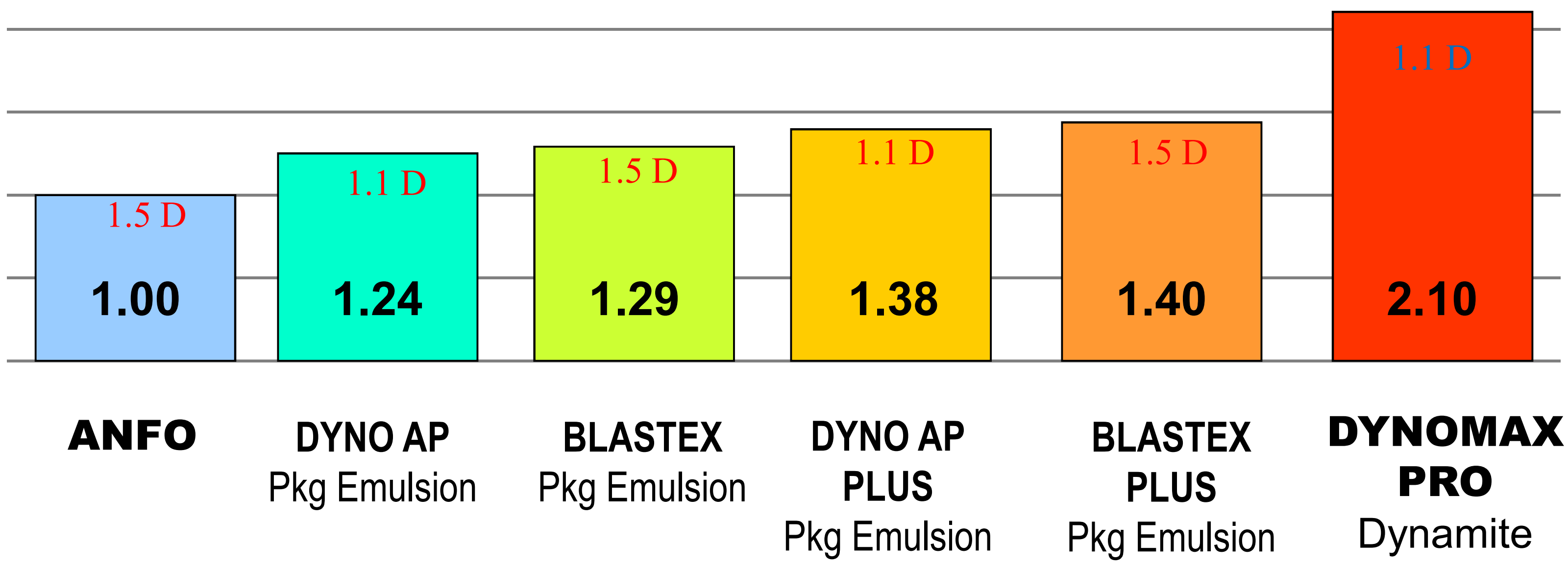
Packaged Explosive

Relative Bulk Strength Comparison



- **When as much rock-breaking energy as possible must be concentrated in the borehole, dynamite is the answer.**
- **Use dynamite to toe load the column to shear the floor.**
- **Load dynamite and drill smaller holes.**

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Primers

The primer initiates the main explosive column. Performance of main explosive column is strongly influenced by choice of primer.

- Primer selection should be based on:
  - Density and detonation velocity
  - Shape (diameter that best matches hole diameter)
  - Sensitivity of main explosive
- Run-up zone extends 1 - 3 hole diameters if primer is inefficient or undersized
  - Ensure molecular explosive primer
- Overdrive zone extends 1 - 3 hole diameters if over primed.
- Additional primers should be used for each 6 m (20 ft) of charge columns
- Recommended minimum detonation pressure for ANFO is 10,000MPa (1,450,000 psi)

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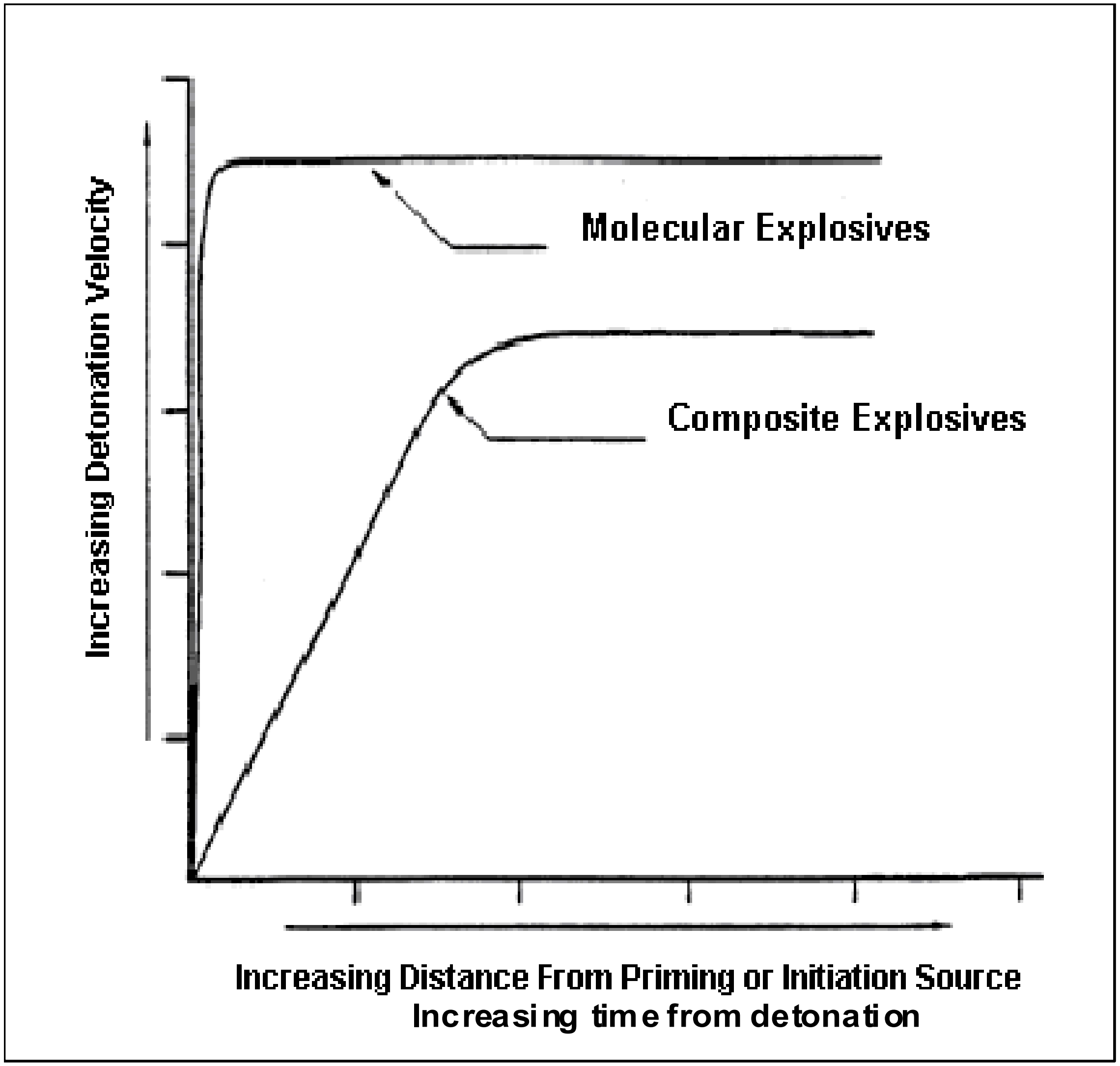
Run-up time


Increasing Detonation Velocity
Molecular Explosives
Composite Explosives
Increasing Distance From Priming or Initiation Source
Increasing time from detonation

Initiation Systems

- **Electric**
  - ✓ **Insulated solid copper leg wires**
  - ✓ **Millisecond delay period detonators (pyrotechnic delays)**
  - ✓ **Blasting Equipment**
    - Standard Capacitor Discharge Blasting Machine
    - Sequential Capacitor Discharge Blasting Machine

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Initiation Systems

- **Nonelectric**
  - ✓ **NONEL**
    - Shock tube lead
    - Millisecond delay period detonators – surface and in-hole (pyrotechnic delays)
  - ✓ **Miniaturized Detonating Cord / NONEL**
    - Low core load detonating cord
    - Millisecond delay period detonators – surface and in-hole (pyrotechnic delays)

Initiation Systems

- Electronic
  - ✓ insulated iron leg wires
  - ✓ Factory assembled buswire connectors
  - ✓ Field programmable precise digital delay detonators
  - ✓ Insulated copper bus wire
  - ✓ Computer testing, programming and blasting equipment.

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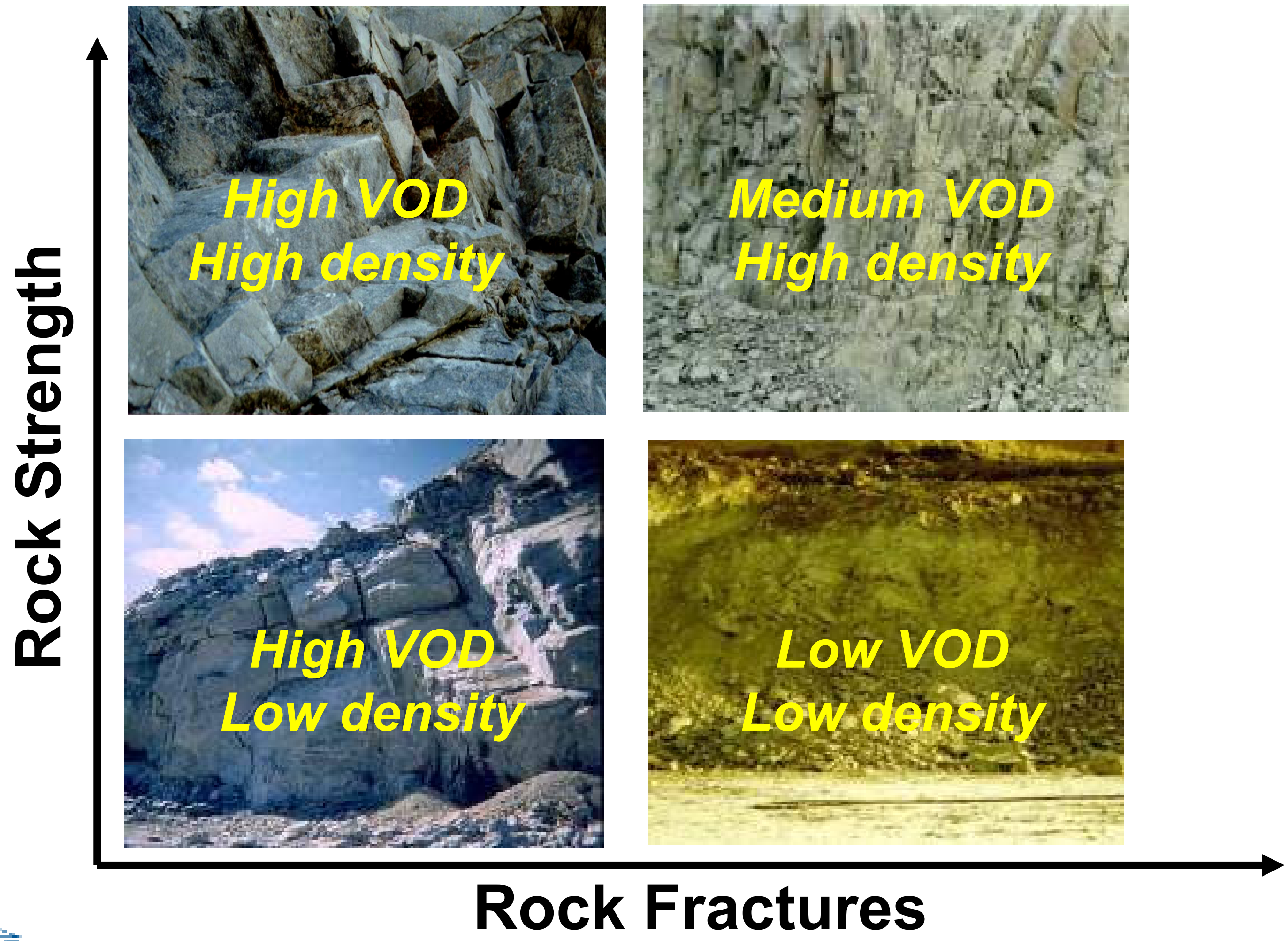
Explosive Selection to Meet Rock Structure and Strength Properties



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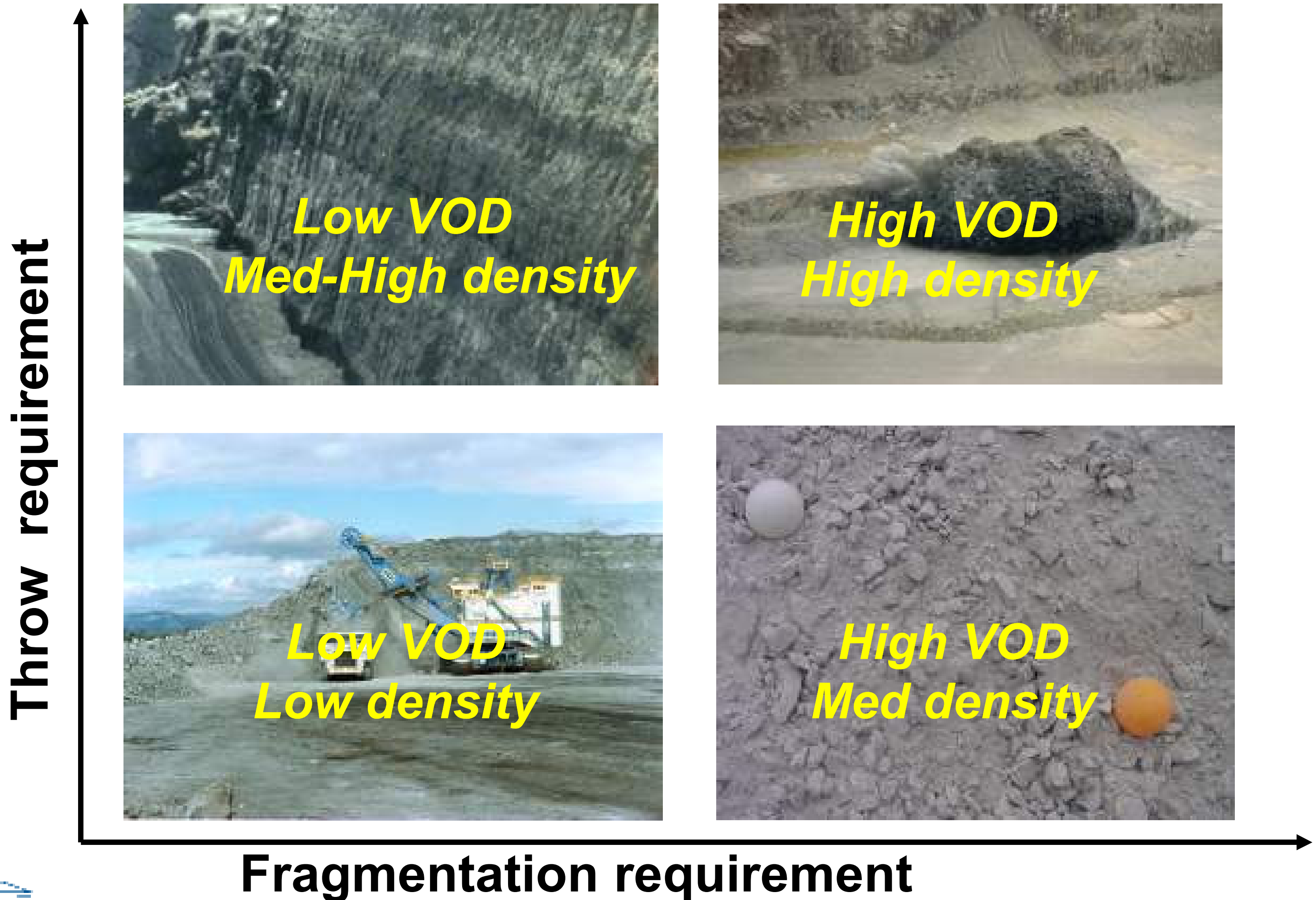
Explosive Selection to Meet Blast Objectives



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