Chapter 2
EXPLOSIVES

This chapter classifies commercial blasting compounds according to their explosive class and type. Initiating devices are listed and described as well. Military explosives are treated separately. The ingredients and more significant properties of each explosive are tabulated and briefly discussed. Data are summarized from various handbooks, textbooks, and manufacturers' technical data sheets.

THEORY OF EXPLOSIVES

In general, an explosive has four basic characteristics: (1) It is a chemical compound or mixture ignited by heat, shock, impact, friction, or a combination of these conditions; (2) Upon ignition, it decomposes rapidly in a detonation; (3) There is a rapid release of heat and large quantities of high-pressure gases that expand rapidly with sufficient force to overcome confining forces; and (4) The energy released by the detonation of explosives produces four basic effects; (a) rock fragmentation; (b) rock displacement; (c) ground vibration; and (d) air blast.

A general theory of explosives is that the detonation of the explosives charge causes a high-velocity shock wave and a tremendous release of gas. The shock wave cracks and crushes the rock near the explosives and creates thousands of cracks in the rock. These cracks are then filled with the expanding gases. The gases continue to fill and expand the cracks until the gas pressure is too weak to expand the cracks any further, or are vented from the rock.

The ingredients in explosives manufactured are classified as:

Explosive bases. An explosive base is a solid or a liquid which, upon application or heat or shock, breaks down very rapidly into gaseous products, with an accompanying release of heat energy. Nitroglycerine is an example.

Combustibles. A combustible combines with excess oxygen in an explosive to achieve oxygen balance, to prevent the formation of nitrous oxides (toxic fumes), and to lower the heat of the explosion.

Oxygen carriers. Oxygen carriers assure complete oxidation of the carbon in the explosive mixture, which inhibits the formation of carbon monoxide. The oxygen carriers assist in preventing a lowering of the exploding temperature. A lower heat of explosion means a lower energy output and thereby less efficient blasting.

Antacids. Antacids are added to an explosive compound to increase its long term storage life, and to reduce the acidic value of the explosive base, particularly nitroglycerin (NG).

Absorbents. Absorbents are used in dynamite to hold the explosive base from exudation, seepage, and settlement to the bottom of the cartridge or container. Sawdust, rice hulls, nut shells, and wood meal are often used as absorbents.

Antifreeze. Antifreeze is used to lower the freezing point of the explosive.

Air gap sensitivity. Air gap sensitivity is a measure of an explosive's cartridge-to-cartridge sensitivity to detonation, under test conditions, expressed as the distance through air at which a primed half-cartridge (donor) will reliably detonate an unprimed half-cartridge (receptor).

Cap Sensitivity. Cap sensitivity is a measure of the minimum energy, pressure, or power required for initiation of a detonation; i.e., "cannot be detonated by means of a No. 8 test blasting cap when unconfined."

Strength Two strength ratings are used for commercial dynamites. Weight strength compares products on an equal-weight basis, and cartridge strength or bulk strength compares products on an equal-volume basis. Both are expressed in percent, using straight nitroglycerin dynamite as a standard. Complicating this picture is the variety of ingredient mixes among manufacturers, so that 40 percent gelatin dynamite and a 40 percent ammonia dynamite do their work differently; similarly, a 40 percent ammonia dynamite from two different manufacturers will give somewhat different results. Thus, a blaster who had always used one manufacturer's product could change suppliers and suddenly start complaining about "bad powder." To further confuse the issue, some manufacturers continue to use the terms "weight strength" and "bulk strength" as a comparative numerical rating against ANFO at 100.

With the advent of new explosives, particularly the ANFOs and the slurries, the dynamite method of judging strength failed to give relevant data. It became necessary to account not only for a product's relative stored energy, but also its rate of energy release, its gas volume potential, and its heat of detonation. A number of factors are currently used to judge an explosive's ability to do the work desired, and today's blaster must consider at least the following:

Detonation Pressure is a measure of the product's shock wave energy, influenced by the product's density (latent energy) and detonation velocity (rate of energy release).

Pressure Magnitude or **Gas Pressure** is a measure of the potential expanding-gas energy, influenced by the product's density (latent gas volume) and the heat and velocity of detonation (rate of gas production and expansion).

Though oversimplified, one way to think of "strength" is to compare an explosive to a mechanical means of breaking and moving rock. We can break rock with a sledgehammer, and a detonation pressure is our explosive hammer. As density increases, the "weight of the hammer" increases; as velocity increases, we "swing the hammer" faster and harder. We can move rock with a bulldozer, and gas pressure is our explosive dozer. As density increases, the dozer gets bigger; as velocity increases, the dozer runs faster—sometimes so fast that it outruns the rock it is trying to move.

BLASTING MECHANICS

Upon detonation, explosives affect rock by various interrelated means. While the following discussion simplifies a complex and (in some aspects) largely theoretical subject, it should provide a basic grasp of blast mechanics. The same mechanisms apply to whatever material is being blasted (wood, concrete, steel, soil, ice, etc.); however, results are highly dependent on material integrity. As a result, this discussion will consider only monolithic bedrock in order to avoid confusion.

1. Detonation Shock Wave

Upon initiation, the detonation (explosive oxidation) zone proceeds down the column of explosive at the product's detonation velocity. At the front of this detonation zone, an energy pulse or "shock wave" is generated and transmitted to the adjacent rock; any air space between the explosive and the rock absorbs wave energy and reduces its effect on the rock.

The shock wave travels outward as a compression wave in all directions from the borehole, moving at or near detonation velocity. The rock immediately surrounding the borehole is crushed to some extent, dependent on how much the force of the wave exceeds the compression strength of the rock. The force of the wave overcomes the elastic limits of the rock, causing it to bend outward and crack. These are radial cracks in that they radiate out from the borehole and they are generated at speeds related to the sonic velocity of the rock itself (+/–8,000 fps in hard rock, +/–1,500 fps in soft rock). If the rock mass is too large to permit bending, such as behind the borehole, no radial fracture occurs; the wave energy is simply absorbed by the rock.

2. Shock Wave Reflection

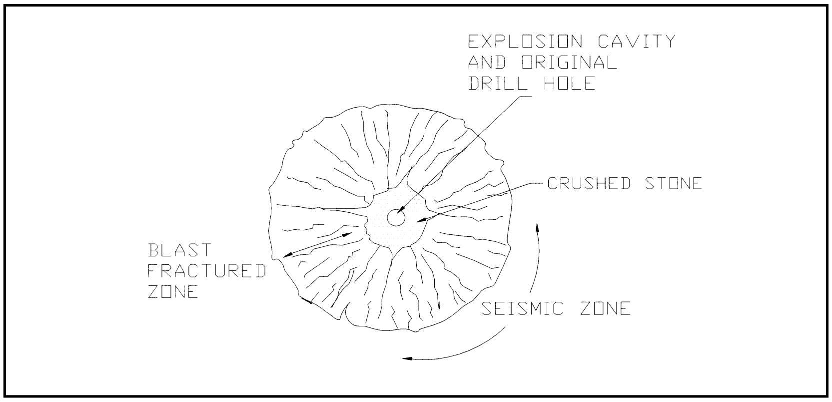
At this point, the result of the blast will only be very large wedge-shaped blocks, still interlocked. However, when the shock wave reaches a free face, the outward-bending compressive force releases, and the wave is reflected back into the rock as a tension wave. The speed of the shock wave has been slowed somewhat, and its energy lowered, but if the distance from the borehole to the free face is not too great, it still carries enough force to overcome the tensile strength of the rock.

Rock, like concrete, has far greater strength in compression than in tension (for instance, granite with a compression strength of 30,000 psi has a tensile strength of only 1200 psi). The reflected tension wave causes lateral cracking in the rock between the radial cracks, creating "fragmentation." Obviously, the greater the distance between the borehole and the free face, the more the wave energy is used along the way, and the larger those "fragments" will be. If there is no free face, such as behind the borehole, there will be no wave reflection and no lateral cracking. A point to remember is that any break in rock continuity will act as a free face; a crack or weather seam is as good as a quarry face in this regard.

3. Gas Pressure and Rock Movement

Upon detonation, along with the shock wave, the solid explosive is instantly converted to superheated gas that is trying to occupy a space 10,000 to 20,000 times its original solid volume, and exerting a pressure that can exceed 1.5 million psi. Without this gas pressure, the fractured rock would not move and would remain interlocked.

The fractured rock mass has a certain inertia (consider this a desire to stay where it is), which the gas pressure must initially overcome to start rock movement. Thus, there is "hesitation" between detonation and the start of rock movement, lasting roughly one millisecond per foot of distance between the borehole and the free face (i.e., if the distance is 10 feet, movement will start roughly 10 milliseconds after detonation). Once inertia is overcome, the rock moves outward away from the borehole at around one foot each 10 milliseconds, or between 40 and 70 mph, although smaller fragments can move faster and be shot out as flyrock. As with the detonation shock wave, nice even results in rock movement require rock continuity; cracks and weather seams will allow gas venting, and result in uneven and sometimes surprising directions and distances of rock throw.



(Figure 2-1) The mechanics of blasting.

DETONATION VELOCITY

Detonation velocity is an important property to consider when rating an explosive. It may be expressed as a confined or unconfined value and is normally given in feet per second (fps). The confined detonation velocity measures the speed at which the detonation wave travels through a column of explosive within a borehole or other confined space. The unconfined velocity indicates this rate when the explosive is detonated in the open. Because explosives generally are used under some degree of confinement, the confined value is more significant. Most manufacturers, however, measure detonation velocity in an unconfined column of explosive 1 1/4 inches in diameter, although some measurements are made within the confinement of an iron pipe or using a different diameter.

The confined detonation velocity of commercial explosives varies from 5000 to 25,000 fps (Tables 2-1 through 2-6). With cartridge explosives, the confined velocity is seldom attained because complete confinement is usually impossible. For blasting in hard rock, a high-velocity explosive is preferable. In a softer or highly jointed rock, a low-velocity explosive , for example,(ANFO) with a heaving action may give satisfactory results at a lower cost. Some explosives, and particularly blasting agents, are more sensitive to diameter changes than others. In charges with larger diameters, say six inches or more, the velocity may be medium to high. But as diameters get smaller, the velocity is reduced until, at the blasting agent's critical diameter,(approximately three inches for ANFO, propagation is no longer assured and misfires are likely).

PROPERTIES OF EXPLOSIVES

By knowing what properties are critical to performance, meaningful predictions can be made in blast design. These properties are: detonation velocity, density, detonation pressure, water resistance, and fume class. For a given explosive, these properties vary with the manufacturer.

DENSITY

The density of an explosive may be expressed in terms of specific gravity. Specific gravity is the ratio of the density of the explosive to the density of water under standard conditions. The specific gravity of commercial explosives ranges from 0.6 to 1.7 g/cc. For free running explosives, the density is often specified as the pounds of explosives per foot of charge length in a given size borehole. With few exceptions, denser explosives give higher detonation velocities and pressures.

Density is an important consideration when choosing an explosive. For difficult blasting conditions or where fine fragmentation is required, a dense explosive is usually necessary. In easily fragmented rock or where fine fragmentation is not needed, a low-density explosive will often suffice. Low-density explosives are particularly useful in the production of riprap or other coarse products. The density of an explosive is also important when working under wet conditions. An explosive with a specific gravity of less than 1.0 will not sink in water.

Weight strength (percent)	Cartridge strength (percent)	Density	Confined velocity (VOD)(fps)	Water resistance	Fume class*	Cartridge count
60	52	1.3	12,500	Fair	Good	110
50	45	1.3	11,500	Fair	Good	110
40	35	1.3	10,500	Fair	Good	110
30	25	1.3	9,000	Fair	Good	110
20	15	1.3	8,000	Fair	Good	110

(Figure 2-2) Properties of a high-density ammonia dynamite.

Weight strength (percent)	Cartridge strength (percent)	Density	Confined velocity (VOD)(fps)	Water resistance	Fume class*	Cartridge count
65	50	1.2	8,100	Fair	Fair	120
65	45	1.1	7,800	Poor	Fair	129
65	40	1.0	7,500	Poor	Fair	135
65	35	1.0	7,200	Poor	Fair	141
65	30	.9	6,900	Poor	Fair	153
65	25	.9	6,500	Poor	Fair	163
65	20	.8	6,300	Poor	Fair	174

(Table 2-3) Properties of a low-density ammonia dynamite, low-velocity series.

Product	Density g/cc	Velocity ft/sec	Water Resistance	Fume Class	Shelf Life
Thermex Y	1.22	20,000	Package only	1	1
Kinestick	1.1	18,000	Package only	1	1

(Figure 2-4) Properties of two-component explosives.

Detonation and Borehole Pressure

Detonation pressure is a function of the detonation velocity and density of an explosive. The nomograph (Figure 2-2) can be used to approximate the detonation pressure of an explosive when the detonation velocity and specific gravity are known. As can be seen, the detonation pressure is more dependent on detonation velocity than specific gravity. A high detonation pressure is necessary when blasting hard, dense rock. In softer rock, a lower pressure is sufficient. Detonation pressures of explosives range from 10 to over 140 Kilobars (l Kilobar = 14,504 psi).

Water Resistance

An explosive's water resistance is a measure of its ability to withstand exposure to water without deteriorating or losing sensitivity. Sensitivity is the ease with which an explosive detonates.

In dry work, water resistance is of no consequence. If water is standing in the borehole, and the time between loading and firing is fairly short, an explosive with a water-resistance rating of "good" is sufficient. If the exposure is prolonged, or if the water is percolating through the borehole, "very good" to excellent" water resistance is required.

In general, gelatins and emulsions offer the best water resistance. Higher-density explosives have fair to excellent water resistance, whereas low-density explosives and blasting agents have little or none. Brown nitrogen oxide fumes from a blast often mean the explosive has deteriorated from exposure to water.

Fume Class

Ideally, detonation of a commercial explosive produces water vapor, carbon dioxide, and nitrogen. In addition, undesirable poisonous gases such as carbon monoxide and nitrogen oxides are usually formed. These gases are known as fumes, and the fume class of an explosive indicates the nature and quantity of the undesirable gases formed during detonation. Better ratings are given to explosives producing smaller amounts of fumes. For open work,
fumes are not usually an important factor, In confined spaces, however, the fume rating of an explosive is important. In any case, the blaster should ensure that everyone stays away from fumes generated in a shot. Carbon monoxide gradually destroys the brain and central nervous system, and nitrogen oxides immediately form nitric acid in the lungs.

Fume classes can be from poor to good and are rated Class A or B by the Bureau of Mines and class 1, 2, 3, by IME. Class A and Class 1 typically emit less noxious fumes per gram of explosive than Class B or Classes 2 or 3.

Shelf Life

Shelf lives of various products described are listed in their respective tables. For most explosives products, a shelf life of one year is recommended, although satisfactory performance can be expected from most products two, three, and even four years later. Consult the appropriate manufacturer to determine shelf life ratings beyond one year. *NPS-65* mandates a maximum shelf-storage of two years.

Permissibles or Permitted Explosives

A permissible explosive is one which has been approved by the U.S. Bureau of Mines or the British Ministry of Fuel and Power for the use in gas or dust-filled mines. When detonated or exploded, all explosives produce a flame that varies in volume, duration, and temperature.

Black powder produces the longest lasting flame, while dynamites typically produce a shorter lasting, but more intense flame. Permissible explosives are especially designed to produce a flame of low volume, short

Borehole diameter (inches)	Confined velocity (fps)	Loading density (lb/ft of borehole)
2	5,000 - 7,500	1.1 - 1.3
3	9,000 - 10,000	2.5 - 3.0
4	10,500 - 11,500	4.4 - 5.2
5	11,500 - 12,500	6.9 - 8.2
6	12,000 - 12,800	9.9 - 11.7
7	12,300 - 13,100	13.3 - 15.8
8	12,500 - 13,300	17.6 - 20.8
9	12,800 - 13,500	22.0 - 26.8
10	13,000 - 13,500	27.2 - 32.6
11	13,200 - 13,500	33.0 - 39.4
12	13,300 - 13,500	39.6 - 46.8

[1]Density: .85-.95 g/cc.
Water resistance: Packaging only; do not use under wet conditions.
Shelf life: 1 year (fuel oil begins to separate after 6 months and will stain bags.)

(Figure 2-5)

Product	Density g/cc	Velocity ft/sec	Water Resistance	Fume Class*	Shelf Life
Emulex 510	1.15	16,300	Excellent	1	No change after 1 year
Emulex 520	1.16	15,200	"	1	"
Emulex 710	1.19	18,000	"	1	"
Emulex 730	1.21	17,000	"	1	"
Emulex 750	1.35	19,000	"	1	"

(Figure 2-6) Properties of emulsion.

Product	Density g/cc	Velocity ft/sec	Water Resistance	Fume Class*	Shelf Life
Tovex 90	0.90	14.100	Good	1	1 year
Tovex 100	1.10	14,860	Excellent	1	"
Tovex 300	1.02	11,500	Good	A	"
Tovex 650	1.35	14,750	Excellent	1	"
Tovex 800	1.20	15,750	Excellent	1	"
Tovex T-1	0.25 lb/ft	22,000	Good	3	"

(Figure 2-7) Properties of water gels.

duration, and low temperature. This is accomplished by adding certain salts to the explosives formula in order to cool or quench the flame to prevent the ignition of gas or dust within the confined space of a mine.

Permissible explosives are generally modified types of emulsions, water-gels, or ammonia dynamites, all in cartridge or chub form.

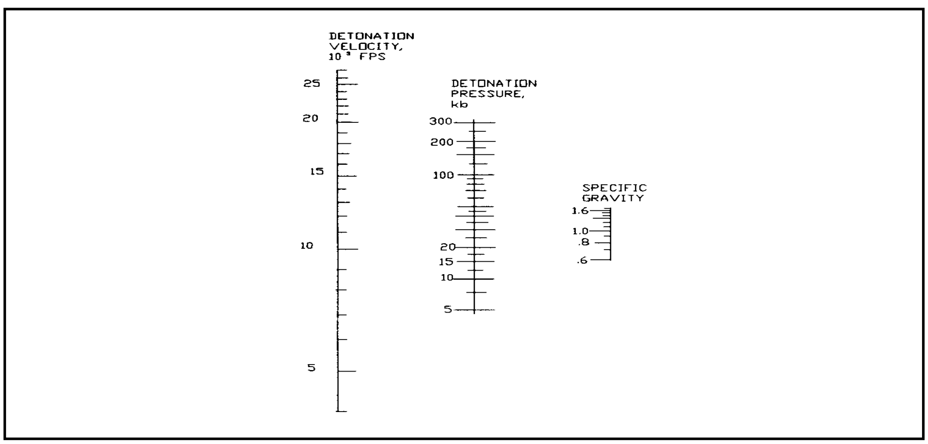
CLASSIFICATION OF EXPLOSIVES

Low Explosives: Low explosives deflagrate rather than detonate. Their reaction velocities are 2000 to less than 3000 feet per second. Black powder is a good example. These materials normally have little water resistance, are highly flammable, sensitive to a No. 6 strength blasting cap, and have a heaving action during blasting. Low explosives generally do not fragment rock as well as high explosives.

Weight strength (percent)	Cartridge strength (percent)	Density	Confined velocity (VOD)(fps)	Water resistance	Fume class*	Cartridge count
60	60	1.3	19,000	Good	Poor	106
50	50	1.4	17,000	Fair	Poor	104
40	40	1.4	14,000	Fair	Poor	100
30	30	1.4	11,500	Poor	Poor	100
20	20	1.4	9,000	Poor	Poor	100

* See Section 2.2.5, pg. 18

(Figure 2-8) Properties of a straight nitroglycerin dynamite.



(Figure 2-9) Nomograph for finding detonation pressure.

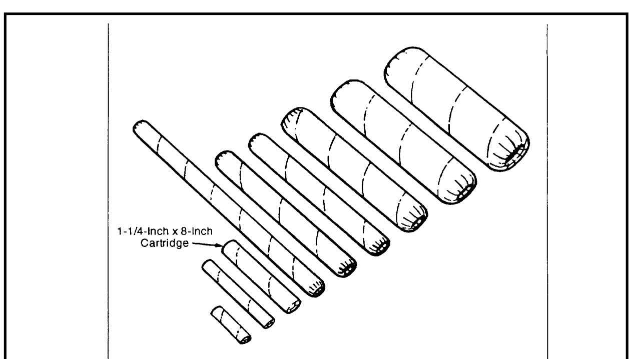
High Explosives: A high explosive is any chemical mixture that detonates with a reaction velocity over 5000 feet per second. The reaction can be initiated by a No. 8 strength blasting cap (i.e., high explosives are 1. Straight Dynamite - Nitroglycerin in an absorbent, with velocities between 10,000 and 20,000 feet per second. This dynamite is the most sensitive of all commercial explosives. The weight strength is the actual percentage of nitroglycerin in the cartridge. This explosive has poor fumes, good water resistance, and poor cohesion.

2. Ammonia Dynamite - This is similar to straight dynamite except that ammonium and/or sodium nitrate and various carbonaceous fuels are substituted for a portion of the nitroglycerin. There are three subclasses of ammonia dynamite:
   High Density: This product has a detonation velocity of 8000 to 13,000 feet per second, good water resistance, and fair to good fumes.
   Low Density: This product has detonation velocities between 7,000 and 11,000 feet per second, fair to good fumes and fair to poor water resistance.
   Permissible Types: These products are similar to the low- density ammonia dynamites except that they contain cooling salts such as sodium chloride. Permissibles must be approved by the U.S. Bureau of Mines under specified conditions of usage. This material usually has good fumes and fair to poor water resistance.

3. Gelatin Dynamite - Contains nitroglycerin gelled with nitrocellulose, and various absorbent filler materials. Forms a soupy to rubber-like mixture which is water-resistant.
   (a) *Straight Gelatin* - Has a detonation velocity of 13,000 to 23,000 feet per second. Varieties with strength rating above 60 percent have poor fume characteristics. Water resistance is excellent and material is very cohesive.
   (b) *Ammonia or Special Gelatins* - Similar in composition to straight gelatin except that some of the nitroglycerin is replaced with ammonium and sodium nitrates and carbonaceous fuels. Has a detonation velocity between 10,000 and 23,000 feet per second. Water resistance is good.

4. Semi-gelatin Dynamite - A combination of ammonia gelatin and ammonia dynamite, with lower strength than gelatin, yet has good water resistance. Velocities between 10,000 and 15,000 feet per second. Fume rating is good.

Two-component Explosives: These, as packaged, can be shipped by any means because each separate component is nonexplosive. Mixing, however, produces a class A explosive that must be handled and stored as such.



(FIGURE 2-10)

BLASTING AGENTS AND AMMONIUM NITRATE

A blasting agent is any material or mixture consisting of a fuel and oxidizer that is intended for blasting and that is not otherwise classified as an explosive.

A blasting agent consists primarily of inorganic nitrates (ammonium and sodium nitrates) and carbonaceous fuels. The addition of an explosive ingredient, such as TNT, in sufficient quantity, changes the classification of the mixture from a blasting agent to an explosive.

When unconfined, blasting agents cannot be detonated by means of a No. 8 test blasting cap unless an explosive ingredient or sensitizer is added. No. 8 test caps contain the equivalent of two grams of a mixture of 80 percent mercury fulminate and 20 percent potassium chlorate. Nitrocarbonitrate is synonymous with a blasting agent, including ANFO, and is an official classification for interstate transportation. Blasting agents may be classified as (1) dry blasting agents, (2) emulsions, (3) water gel or (4) slurry blasting agents.

Bulk Mixed Compounds: This includes the majority of the ammonium nitrate-fuel oil mixtures and bulk slurries which are often mixed on the job by the supplier in the delivery truck. The detonation velocities range between 9000 and 15,000 feet per second. This product has no water resistance and fair to good fumes, if properly mixed and detonated.

Pre-mixed Nitrocarbonitrates (NCN): Another term for ammonium nitrate mixes. These include products prepared by a commercial manufacturer and purchased by the consumer in the ready-to-use package form. The densities of these products are variable. Velocity ranges from 12,000 to 15,000 feet per second.

Cycling of Ammonium Nitrate: Ammonium nitrate, for its weight, supplies more gas upon detonation than any other explosive. In pure form, ammonium nitrate is almost inert (powerless) and is composed of 60 percent oxygen by weight, 33 percent nitrogen, and seven percent hydrogen.

Two characteristics make this compound both unpredictable and dangerous. Ammonium nitrate is water soluble and if uncoated, can attract water from the atmosphere and slowly dissolve itself. For this reason, most prills have a protective coating of wax or clay which acts as a moisture retardant. The second and most important characteristic is a phenomenon called "cycling." This is the ability of a material to change its crystal form with temperature. Ammonium nitrate will have one of five crystal forms depending on the temperature.

The cycling phenomenon can seriously affect both the storage and performance of any explosive which contains ammonium nitrate. Most dynamites, both regular nitroglycerin or permissibles, contain some percentages of ammonium nitrate, while blasting agents are almost totally comprised of this compound. The cycling effect in dynamite is not due to other ingredients mixed with the ammonium nitrate. For this reason, cycling does not greatly affect dynamite the way it does ANFO. The two temperatures at which cycling will occur under normal conditions are 0 and 90°F. This is to say that products which are stored over the winter, or for a period of time during the summer, most likely will undergo some amount of cycling. During the summer, in poorly ventilated powder magazines, the cycling temperature may be reached daily.

The effect of cycling of ammonium nitrate when isolated from the humidity in the air is that the prills break down into finer and finer particles, or enlarge to the point at which they are virtually inert. When the temperature exceeds 90°F, the prills break down into smaller crystals. This causes the density to increase from 0.8 to 1.2 gm/cc. A density increase will also increase the detonation velocity of the compound. The detonation velocity of ammonium nitrate with a density near 0.8 is around 10,000 feet per second. Ammonium nitrate with a density near 1.2 may have a velocity of 15,000 feet per second.

To further complicate the situation, some blasting agents are not sealed well enough to exclude humidity. After the ammonium nitrate has undergone one cycle, the waterproof protective coating is broken and the water vapor in the air condenses on the particles. As cycling continues and more water collects, the mass starts to dissolve and upon dissolving, starts to recrystallize into large crystals.

Therefore, it is evident that a volume of ANFO after cycling may have very dense areas and areas of large crystals which are not as dense. The performance of this product may range from that of a very powerful explosive to one that just burns, or one that will not shoot at all.

BLASTING AGENTS

	ANFO 50 LB. BAG	ANFO CARTRIDGED	BULK ANFO	ENRICHED ANFO CARTRIDGED	BULK ENRICHED ANFO	SLURRY CARTRIDGED	BULK SLURRY	EMULSION SLURRY CARTRIDGED	BULK EMULSION SLURRY	WATER GEL SLURRY CARTRIDGED	BULK WATER GEL SLURRY
ANGUS	ANFO	ANFO HD	BULK ANFO	COMSOL 166 170 266 300							
APACHE	CARBAMITE P			CARBAMAL 5 10 15		CARBAGEL 5 10 15 100					
ATLAS	PELLITE	PELLITE HD	PELLITE BULK	POWER AN 300 500	POWER AN 300 500			AFEX 220 220 240 340 260 360	AFEX 1200 1300		
AUSTIN	AUSTINITE 15	AUSTINITE 30	AUSTINITE 15 BULK	AUSTINITE 30 AL	HEF	SLURMITE 205 405 50					
DUPONT								TOVEX E, EA1 EA2 EA3 EA4 E881	TOVEX E, EA1 EA2 EA3 EA4 E881	TOVEX-EXTRA	TOVEX-EXTRA
GULF	NCN 100		NCN 100 BULK	NCN 750						NCN 600 NCN 705 NCN 805 NCN 806	NCN 600 NCN 591 IR SLURRIES
HERCULES	HERCOMIX		BULK ANFO	VIBRONITE S-1 IMPULSOR		HP-348 HP-373 HP-374 HP-380 HP-381 HP-382 GEL-STRIP FLOGEL GELPOWER-D					GEL-FLO
INDEPENDENT	AMMONITE	HI POTENCY 93 AMMONITE WR	BULK ANFO							SURE-X	SURE-X
IRECO	IREMEX 100 106 108 110		IREMEX		IREMEX E 460 560 660		IREGEL 604 SERIES	IREGEL 1105 SERIES	IREGEL 1106 SERIES	IREGEL 305A SERIES	
NITROCHEM	ANDIL FR	ANDIL HD	BULK ANDIL	DELLECK 10	NOVON AN-1	MS-80 SERIES ML 500 ML 700 W SERIES THERMO-PRIMER	MS-80 SERIES				
TROJAN											
GOEX											

(*Figure 2-11)*

PETN-PETN (pentaerythritoltetranitrate) has a crystal density of 1.76 g/cc and a confined detonation velocity of over 25,000 fps. In various degrees of granulation it is used as a priming composition in detonatators, a base charge in blasting caps, a core load for detonating cord, and in the manufacturer of pentolite. PETN is a secondary explosive and as such is not as sensitive as primary explosives such as lead azide. Cast primers of PETN are also supplied as shaped charges.

RDX - RDX (cyclotrimethylenetrinitramine) is second in strength to nitroglycerin among common explosives substances. When compressed to a density of 1.70, it has a confined detonation velocity of 27,000 fps. RDX is a primary ingredient in composition B. Plasticity and high detonation velocity make it ideal in shaped charges for oil well perforators (jet perforators) and furnace papers jet tappers. RDX is sometimes the base charge for detonators.

Composition B - Composition B is a mixture of RDX and TNT with one to four percent wax added. When cast, it has a density of 1.65 and a detonation velocity of about 25,000 fps. Like pentolite, composition B is used in the cast form as a primer and booster for blasting agents.

Pentolite - Pentolite is a mixture of PETN and TNT. The percentage of PETN can be from 20 percent to 50 percent, with the remainder being TNT. It was originally used for booster charges in military explosives devices and is now used for commercial boosters.

SELECTION OF EXPLOSIVES

There have been many systems developed to rate the strength or power or an explosive. Although these systems work, it is still not clear as to whether or not the information is useful to the field blaster.

There are many reasons for choosing an explosive. These reasons range from the specifications of the product, the price, availability, and reliability. Whatever the reason for selection, the blaster should consider the following properties:

Velocity - If fragmentation is desired, the best results are obtained when the detonation velocity is at or near the sonic velocity of the rock. If mass movement is more important (as in blast casting) or very large fragments are desired (as in riprap production or slabbing), detonation velocity should be notably below the rock's sonic velocity.

Sensitivity - When using charges in small diameter boreholes, the blaster needs sensitive products such as cap sensitive emulsions or water gels. The smaller the hole, the more sensitive the product needs to be. ANFO functions well in large diameter holes (four inches and above), but has trouble sustaining detonation in small holes.

Gas or Pressure Release - This is the amount of gas and pressure released when the explosive or blasting agent detonates. Generally, the more gas release, the more heave or displacement that is possible.

Water Resistance - In conditions where the holes are producing water or ground water is a problem, packaged ANFO, water gels or emulsions function best. There are also plastic borehole liners that can be used for bulk loading operations.

Fume Quality - When working in a poorly ventilated operation such as in a tunnel, mine, or deep trench, select a product with a good (Class I) fume rating. Even when working in the open, allow all evidence of smoke and dust to clear before reentering the blast area, and remember that the toxic gases produced are colorless, odorless, and potentially lethal.

When selecting explosives there are four basic categories:

1. **Dynamites, including Granular Dynamite** (Straight Dynamite, High-Density Extra Dynamite, and Low-Density Extra Dynamite) and **Gelatin Dynamite** (Straight Gelatin Dynamite, Ammonia Gelatin Dynamite, and Semigelatin Dynamite). Use is prohibited by policy unless a case specific waver is obtained from the regional blasting officer.

2. **Water Gels, Emulsions, and Slurries** - Consisting of Cartridges and Bulk products.

3. **Dry Blasting Agents** - Consisting of Poured or Bulk ANFO, Aluminized ANFO, Densified ANFO, and Packaged (waterproof) ANFO.

4. **Binary Explosives** - Consisting of two-component products that are mixed in the field to form an explosive.

GENERAL PROPERTIES
Detonation Velocities (FPS)

Type	**Boreholes or Charge Diameter**		
	1-1/4"	**3"**	**9"+**
Granular Dynamite	7 to 19,000	8 to 19,000	N/A
Gelatin Dynamite	12 to 25,000	13 to 20,000	N/A
Cartridged Water Gel	13 to 22,000	14 to 19,000	N/A
Bulk Water Gel	N/A	14 to 16,000	12 to 19,000
Air-emplaced ANFO	7 to 10,000	12 to 13,000	14 to 15,000
Poured ANFO	6 to 7,000	10 to 11,000	12 to 15,000
Packaged ANFO	N/A	10 to 12,000	14 to 15,000
Cartridged Emulsion	14 to 19,000	14 to 20,000	N/A
Packaged Binary	19 to 20,000	19 to 21,000	N/A

Density (g/cc)

Type	**Density**
Granular Dynamite	0.8 to 1.4
Gelatin Dynamite	1.0 to 1.7
Cartridged Water Gel	1.1 to 1.3
Bulk Water Gel	1.1 to 1.6
Air-emplaced ANFO	0.8 to 1.0
Poured ANFO	0.8 to 0.9
Packaged ANFO	0.8 to 1.2
Cartridged Emulsion	1.1 to 1.

SENSITIVITY

Type	Hazard Sensitivity	Performance Sensitivity
Granular Dynamite	Moderate to High	Excellent
Gelatin Dynamite	Moderate	Excellent
Cartridged Water Gel	Low	Good to Very Good
Bulk Water Gel	Low	Good to Very Good
Air-emplaced ANFO	Low	Poor to Good
Poured ANFO	Low	Poor to Good
Packaged ANFO	Low	Good to Very Good
Cartridge Emulsion	Low	Good to Very Good
Packaged Binary	Low to Moderate	Very Good

WATER RESISTANCE

Type	Resistance
Granular Dynamite	Poor to Good
Gelatin Dynamite	Good to Excellent
Cartridged Water Gel	Very Good
Bulk Water Gel	Very Good
Air-emplaced ANFO	Poor
Poured ANFO	Poor
Packaged ANFO	Very Good (*if package is not broken or torn*)
Cartridge Emulsion	Very Good
Packaged Binary	Poor to Good

GUIDE FOR EXPLOSIVE SELECTION

	Borehole Diameter		
Type	2" or less	2" to 4"	4"+
Granulate Dynamite	USE	N/A	N/A
Gelatin Dynamite	USE	N/A	N/A
Cartridge Water Gel	USE	USE	N/A
Bulk Water Gel	N/A	USE	N/A
Air-emplaced ANFO	NR	USE	USE
Poured ANFO	NR	USE	USE
Packaged ANFO	N/A	USE	USE
Cartridged Emulsion	USE	USE	N/A
Packaged Binary	USE	USE	N/A

INITIATING DEVICES

Electric Blasting Caps (EBC)

The electric blasting caps are commonly used devices for initiating high explosives. The cap may be inserted directly into the explosive cartridge or used in conjunction with detonating cord. An electric blasting cap consists of two insulated leg wires inserted through insulation into a metal capsule and connected by a thin-filament bridgewire. When enough current is applied to the leg wires, the bridgewire gives off heat energy and ignites a flash charge of heat sensitive explosive, usually lead styphnate. The explosion of the flash charge detonates a primer charge, lead azide, which in turn detonates a base charge of powerful explosive such as PETN or RDX. In some cases, the flash and primer charges are combined. The base charge of the cap detonates with sufficient force to initiate a cap sensitive explosion or detonating cord.

The advantages of electric blasting caps over cap-and-fuse include safety in handling, variety of delay periods, and the ability of the blaster to choose the exact time of detonation. When working in populated areas, noise and resulting public relations problems are reduced by initiating the charge in the borehole with delay caps instead of using trunklines and downlines of detonating cord.

When using electric blasting caps, avoid stray electric currents, such as those caused by power cables lying on the ground, particularly when the ground is wet. Lightning is another source of possible premature detonation. Radio frequency energy is a potential hazard, although the possibility of premature detonation due to this source is remote, except for high-energy, long wavelength transmitters (see IME Publication No. 20).

Consult manufacturer's data for electric current requirements. They vary from brand to brand, so mixing brands in a circuit can cause a misfire and is not recommended. In a delay electric blasting cap, a delay element containing specially blended powders is interposed between the bridgewire and the primer charge. The delay element is accurately calibrated to give a specified time lapse between the application of electric current and the detonation of the base charge.

Two basic series of delay are available: (1) Short or millisecond delays and (2) longer delays, often called slow delays. The millisecond delays have delay increments ranging from 25 to 50 milliseconds; the longer delays, from 0.5 to 1 second. In normal blasting, where maximum fragmentation is desired, millisecond delays produce good breakage and reduce air blast and ground vibration. Slow delays are primarily for underground, quarry, or tunnel work, where they provide enough time for rock movement between delay periods. Longer delays may result in coarser fragmentation than millisecond delays.

Blasting caps are a mass-produced item with extremely tight quality control. The chances of "bad caps" reaching the consumer are only one in several million, and a manufacturing defect will occur in an entire batch (1000 or more) rather than in a single cap. A check of each cap with the galvanometer before loading will identify any "bad cap" before it ends up in the explosive product.

Exploding Bridgewire Detonators (EBW)

The compounds of an exploding bridgewire detonator (EBW) are similar to those in a standard electric blasting cap (EBC), but more stable. The major difference is that EBWs contain no primary explosive. A fine gold bridgewire is in contact with PETN, a secondary explosive, which in turn initiates an RDX base charge.

To function properly, a very large electric current must be delivered to the bridgewire in a very short period of time. This heats the wire through the vaporization phase so rapidly that the wire explodes with enough force to detonate the secondary explosive. If either the amount of current or the rate of application is incorrect, the EBW will not function properly. It may deflagrate, but will not detonate. This means that most sources of extraneous electricity that may detonate an EBC are not hazardous when using an EBC. Static electricity, radio transmissions, automotive batteries or systems, chain saw magnetos, or most generator-type blasting machines will not detonate an EBW. However, EBWs provide no protection against lightning. A special field-firing set capable of generating a timed 3000 volts is required. A special model suitable for seismic work is also available.

An EBW can be inserted directly into explosives or can be used to initiate detonating cord, similar to an EBC. A maximum of six detonators can be fired simultaneously in series, but because tolerance can vary among EBWs, consult the manufacture before firing more than two in series.

Because an EBW contains only secondary explosives (PETN and RDX), delay detonators are not available. EBWs are recommended for situations where static or other extraneous is a concern, or where fire or impact are factors to be considered, and where unit cost is not extremely important.

Detonating Cord

Detonating cord consists of a core of high explosives, usually PETN, enclosed in a reinforced covering of various combinations of textile, plastic, and waterproofing materials. The different reinforcing covers have different degrees of tensile strength, abrasion resistance, and flexibility. Detonating cord with core loading ranging from 1.4 gr/ft to 400 grains/ft of PETN is available for various uses. Unconfined cords fire at around 21,000 fps. Pure cast RDX has a hydrodynamic velocity of 26,000 and cast PETN is slightly lower.

A PETN core load of 50 gr/ft is used for most applications, and is specifically recommended for down hole use. However, 25 gr/ft detonating cord is recommended for most trunkline applications. Its marked insensitivity to external shock and friction makes detonating cord ideal for use as both a down line and trunkline for primary blasting. The blasting cap need not be connected into the circuit until just before firing, eliminating most hazards of premature detonation. An option is to tape a cap to a 24-inch length of detonating cord. This is called a “pigtail.” Just before the blast is ready, the blaster ties this length to the main line. This keeps the sensitive cap out of the circuit until it is needed.

A 25 or 50 gr/ft detonating cord detonates almost any cap sensitive explosives in contact with it, but will not reliably detonate a blasting agent. However, some cap-sensitive emulsions and water gels which are reliably detonated by the point impact of a blasting cap are not reliably detonated by the linear impact of detonating cord. Detaprimes must be used with cord. Always check the manufacturer's recommendations.

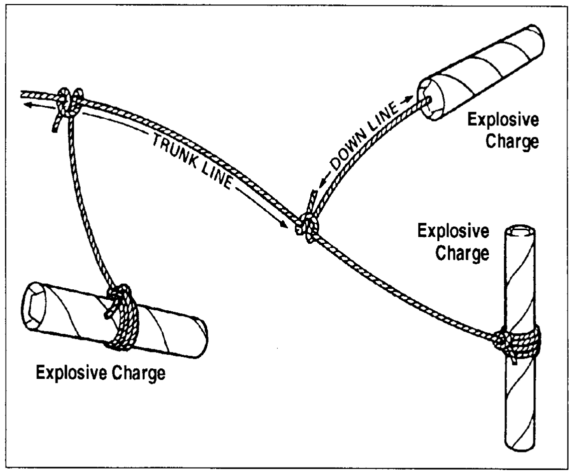
Detonating cord has wide application in underground work. In a wet environment, the ends of the detonating cord should be protected from water. PETN will slowly absorb water and become insensitive to initiation. Even when damp, however, detonating cord detonates if initiated on a dry end.

Millisecond delay connectors are available. The connectors are tied between two ends of detonating cord in the trunkline and permit the use of an unlimited number of delay periods. Delay connectors are commonly available in periods of 5, 9, 17, 25, 35, and 45 milliseconds.

Detonating cord with a core load of 1.4 to 5 gr/ft of PETN, known as low energy detonating cord or LEDC has two principal uses. The first is trunkline, where firing with detonating cord is desired, and air blast presents a concern. LEDC produces virtually no air blast. The second use is a down line where center or bottom initiation is desired. Detonating cord with core loads as high as high as 200 gr/ft are laced together to make fireline explosives with combined loading of up to 1400 gr/ft.

AGAIN, There is less risk in handling and loading when using detonating cord than there is when using caps. However, any blasting system is hazardous. Blasting safety depends on the training and experience of the blaster and the blasting crew. Explosive is required to provide adequate initiation for the charge. Primers come in two basic forms: cast (often called high-density or HDP primers) for holes of two-inch diameter or more, and Elastomeric (PETN and latex mixes, such as detaprimes) for holes under two inches in diameter.

Primers are supplied in a variety of sizes and are generally cast PETN, RDX, Pentolite, or Composition B. Provisions are made for initiating the primer with detonating cord (usually a 25 or 50 gr/ft) or a No. 6 or a No. 8 blasting cap.



(Figure 2-12) Use of detonating cord for simultaneous nonelectric

NONEL CORDS AND PRIMADET

Nonel is a .12-inch diameter plastic tube with a thin reactive coating on the inside surface. When initiated with an EBW, EBC, or detonator cord, the tube transmits a low energy signal from one point to another by means of a shock wave phenomenon similar to a dust explosion. It will propagate around sharp bends and through kinks. Because such a small amount of reactive material is used, the reaction will not initiate the explosives and the tube remains intact during and after functioning. Noise levels are extremely low.

Nonel is not initiated by stray currents, fire, or most light impact, shock and friction hazards encountered in normal blasting work. However shock initiators using 12 gauge shot shell primers are used to initiate Nonel.

Nonel is available in several factory-assembled lengths with nonelectric delay detonators crimped on end, called Primadets, that will detonate cap sensitive cartridge explosives.

PRIMERS

With non-cap-sensitive blasting agents, the initiation sensitivity is so low that a primer (any cap sensitive explosive) is required to provide adequate initiation for the charge. Primers come in two basic form: cast (often called high-density or HDP primers) for holes of two-inch diameter or more, and Elastomeric (PETN and latex mixes, such as detaprimes) for holes under two inches in diameter.

Primers are supplied in a variety of sizes and are generally cast PETN, RDX, Pentolite or Composition B. Provisions are made for initiating the primer with detonation cord (Usually a 25 or 50 gr/ft) or a No 6 or No 8 blasting cap.