Chapter 20

Explosives – their history and composition

20.1 INTRODUCTION

After having dealt with the properties of explosives, desirable and undesirable from the viewpoint of their safe and effective use in mines, it is a place to take detailed account of the actual explosives, their ingredients etc.

Even before taking such account, it is very important to look into the historical developments in the realm of explosives from the viewpoint of their use in the mining and civil engineering domains.

This chapter deals with both the above topics.

20.2 BRIEF HISTORY OF EXPLOSIVES

The following paragraphs give a glimpse of the history of explosives.

Some chemicals, or mixtures of them, that can be considered as explosives by current definitions of the word, may have been known to mankind long before the Christian era, but there are no specific written references to them. Armaments with explosive-type devastating power are said to have been used in the Mahabharata War supposed to have been fought as early as 5000 BC.

Black powder was known to the Chinese from the eighth century but was used only for entertaining the public.

The first written reference to an explosive substance is by Arabian writer named Abd Allah. In the year 1200, he mentioned that saltpeter is the main ingredient of black powder.

In the year 1242, English friar Roger Bacon published the formula for making gunpowder through his book 'De Mirabili Potestate Artis et Nature'. It was in coded language. He also gave details of the destructive power of the powder.

In the year 1380, a German Franciscan monk, by the name of Berthold Schwarts, developed gun powder i.e. black powder. He also used it in guns.

In the year 1617, the use of black powder for the purpose of rock blasting was first proposed by Martin Weigel, a mining superintendent at Frieberg, Germany.

Casper Windt is said to have actually used black powder for rock blasting at a German town Schemitz in the year 1623.

In the year 1670, German miners revealed the secret of using gun powder for the purpose of rock blasting in Cornwall England.

In the year 1675, a factory for making black powder was established in what is now Milton, Massachusetts, USA.

The first instance of the use of black powder for blasting rock in a road-widening project occurred in Switzerland in the year 1696.

In the year 1745, Doctor Watson invented the technique of exploding black powder by electric spark.

In the year 1750, Benjamin Franklin invented a cartridge by compressing black powder in a cylindrical shell with a electric spark generating device in it to cause detonation.

In the year 1773, black powder was used for mine blasting for the first time in a copper mine in Connecticut in what is now the USA.

In 1822 the first hot wire detonator was produced by Dr. Robert Hare. Using one strand separated out of a multi strand wire as the hot bridge wire, this blasting cap ignited a pyrotechnic mixture (likely to be potassium chlorate/arsenic/sulfur) and then a charge of tamped black powder.

Moses Shaw of New York patented a device for electric firing of black powder in the year 1830.

William Bickford of Cornwall, England invented a safety fuse in the year 1831.

In the year 1832, Dr. Robert Hare developed the electric blasting cap.

In the year 1846, an Italian chemist, Ascanio Sobrero, discovered nitroglycerin. While doing so he was nearly killed by the explosion. He therefore never revealed the formulation.

Wilbrand invented TNT i.e. Trinitrotoluene in the year 1863. In the same year Alfred Noble developed a safer variety of nitroglycerin for use in rock blasting. It could not be exploded by a normal fuse.

In the year 1864, Alfred Noble developed the first detonating cap. This became essential for detonating the safer variety of nitroglycerin.

Alfred Noble invented dynamite by mixing kieselguhr with nitroglycerin in the year 1866.

In the year 1870, a plant was set up by the Giant Powder Company for making dynamite at San Francisco, California, USA.

In the year 1875, Alfred Noble patented blasting gelatine. In the same year Perry, Gardiner and Smith independently developed and marketed caps which combined the hot wire detonator with mercury fulminate explosive. These were the first generally modern type blasting caps.

An electric blasting machine containing a rack bar was developed by H. Julius Smith in the year 1878.

In the year 1884, a large scale use of ammonium nitrate, commonly abbreviated as AN, as an additive to dynamite began.

In the year 1895, two-component explosives were used for the first time in New York Harbor.

In the year 1902, detonating cord was introduced in Europe.

In the year 1913, explosive was used by M. Kinley for extinguishing a wildly burning oilwell in California.

In the year 1914, construction of the Panama Canal began. Even today, i.e. after a century, it is considered to be the largest ever engineering project.

In the year 1917 L. Mintrop, a German scientist, invented the seismograph.

A devastating explosion of ammonium nitrate took place in Oppau, Germany in the year 1921. This explosion brought the explosive nature of ammonium nitrate to the notice of scientists.

In the mid 1920s liquid oxygen-based explosives made their appearance in the USA.

In the year 1935 a machine for measuring blast vibrations was developed by the US Geological Survey.

In the mid 1950s high speed photography was introduced in mining for analyzing a blast.

In the year 1955 Bob Akre developed "Akremite".

In the year 1956 a mixture of ammonium nitrate and fuel oil was used for the first time in US Steel Corp.'s Oliver Mining Division for rock blasting. This two-component explosive later got the acronym ANFO. In the same year Mel Cook introduced slurry explosives in mining practice.

A specialized vehicle which could mix the two components of ANFO in precise proportions inside the blasthole was developed in Canada in the year 1957.

By the end of the 1950s prilled AN and fuel mixture became so popular that it shunted out dynamite.

In the year 1967 shock tube type non-electric detonators were introduced in Sweden.

Emulsion explosives first appeared in the year 1969.

Computer modeling of blast design was developed by Land & Favreau in the year 1972.

In the early 1970s electronic recording seismographs were introduced by Dallas Instruments.

In the year 1973, electronic sequential blasting was introduced at the first Kentucky Blaster's Conference.

Shock tube type non-electronic delay detonators were introduced in the year 1974.

The International Society of Explosives Engineers was formed in 1974 in Pittsburgh, Pennsylvania, USA.

In the year 1977 glass "bubbles" were introduced in mining blast practice.

Digital sampling seismographs were developed in the 1980s. In this decade the earliest computer programs for improving blast timing patterns and blast plans were introduced in mining practice.

The technique of laser profiling for blast design and analysis, that was developed in Britain, was introduced in USA in the year 1988.

In the late 1980s electronic delay detonators were introduced.

Nearly 700 oil well fires in Kuwait after the Gulf War 1n 1992, were put out by means of explosives.

20.3 TYPES OF EXPLOSIVES IN A BLASTHOLE

A blasthole may contain two to four of the following entities of explosives.

1 Detonator i.e. Blasting Cap
2 Primary Explosive

3 Booster Explosive
4 Main Explosive

A blasthole charged with them is shown in Figure 20.1. Their primary functions are as under.

20.3.1 Detonator (Blasting cap)

A detonator is the device that starts the process of detonation in a blasthole. It is made from a very sensitive explosive such as lead azide or mercury fulminate. Initial energy delivery to the detonator is by means of a spark/heat generated through two electric wires or fire propagated up to it through a safety fuse.

When a detonator is detonated by means of a safety fuse it is called a blasting cap.

Modern explosives used in mines are very safe. In other words they do not detonate unless a very high quantum of energy is imparted to them. This is the reason for the need of a detonator.

Detonation in a blasthole is always started from the bottom of the blasthole. Hence, the detonator is always placed in the bottom of the blasthole after connecting it to a safety fuse or electric wires.

A detonator always consists of explosives that are sensitive to heat.

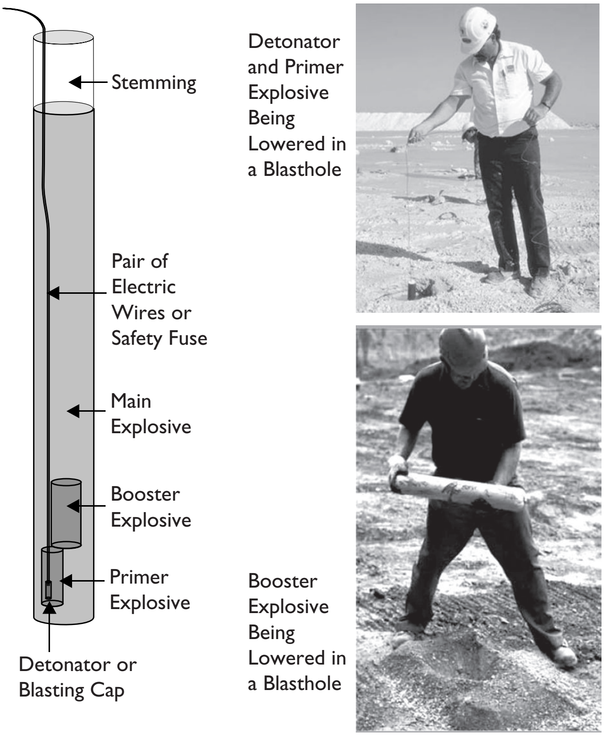

Figure 20.1 A charged blasthole.

20.3.2 Primary explosive

Many explosives used in large surface mines are very insensitive. As they do not get effectively detonated even by using blasting cap no. 8, they are called cap insensitive. They need more powerful explosive to start the detonation of the main explosive in the blasthole. Primary explosives are made for this purpose.

Primary explosives come in the form of a cylindrical-shaped cartridge and contain a detonator embedded within them. The explosives used for making primer are PETN, TNT, RDX, Tetryl, etc. The properties of these are presented in Table 20.1.

20.3.3 Booster

A booster is also made by using PETN, TNT, RDX, Tetryl, Picrite etc. It is used anywhere in the blasthole where there is a need for generating higher energy. Since both these are cap sensitive, they easily detonate by the detonation wave traveling in the main explosive. Therefore, they do not need any embedded detonator.

The most common place for a booster is at the bottom of the blasthole where the burden is usually more than in the rest of the blasthole. At this place much higher energy is required to be generated so as to ensure that no stumps are formed and the rock mass in the wider burden gets well fragmented.

20.3.4 Main explosive

The main explosives used in mining blasts are usually multi-component type. They contain fuel, oxidizer and in many cases a sensitizer as well.

Fuel is meant to burn and generate heat.

The oxidizer ensures proper burning of the fuel without formation of poisonous gases. It also accelerates the process of burning.

Where high energy output is needed a sensitizer is added to the explosive mixture.

The fuel, oxidizer and sensitizer combination of Dynamite, ANFO, Slurry and Emulsions is given in Table 20.2.

The main explosives used for mine blasts are made from many components. Some of these are

1 Nitroglycerin
2 Nitrocellulose
3 Ammonium Nitrate
4 Sodium Nitrate
5 Fuel Oil
6 Wood Pulp
7 Sulfur
8 Antacid

Of these nitroglycerin and nitrocellulose are explosives, ammonium nitrate, fuel oil, wood pulp and sulfur are combustible, sodium nitrate is an oxygen carrier and antacid as the name indicates is an anti-acidity compound. The properties of these components are as follows.

Table 20.1 Properties of some primary explosives.

Explosive	*Chemical formula*	*Full or other name*	*Appearance*	*Molar Weight in g/mol*	*Density in g/cc*	*Melting Point °C*	*Sensitivity (shock, heat)*	*Pure water resistance*	*Velocity of detonation in m/s*	*Detonation pressure in GPA*
PETN	$C_5H_8N_4O_{12}$	Pentaerythritol tetranitrate	White Crystalline Solid	316.1342	1.77	141.3	Medium, Medium	Excellent	8400	33.5
TNT	$C_7H_5N_3O_6$	Trinitrotoluene	Pale Yellow Solid Block After Casting	227.1315	1.654	80.35	Insensitive, Insensitive	Excellent	6900	22.7
RDX	$C_3H_6N_6O_6$	Research Development Explosive	White Crystalline Solid	222.1164	1.82	205.5	Low, Low		8750	33.9
Tetryl	$C_7H_5N_5O_8$	Nitramine or Tetralite	Yellow Crystalline Solid	287.1435	1.73	129.5	Sensitive, Sensitive	Very Good	7570	Unknown
Picric Acid	$C_6H_3N_3O_7$	Phenol trinitrate	Colorless to Yellow Solid	229.1037	1.763	122.5	Sensitive, Sensitive	Very Good	7350	25.1
Lead Azide	$Pb(N_3)_2$		White Powder	290.24	4.71	Explodes 350	Very Sensitive	Low	5180	
Mercury Fulminate	$Hg(CNO)_2$		Grey Crystalline Solid	284.624	4.43	Explodes 180	Very Sensitive		4250	

Table 20.2 Composition of main explosives used in mine blasts.

Explosive type	*Oxidizer*	*Fuel*	*Sensitizer*
Dynamite	Solid Nitrate Salts	Solid Carbonaceous Oil	Liquid Nitroglycerin, Voids, Bubbles
ANFO	Solid Ammonium Nitrate	Liquid Diesel Oil	Voids, Friction
Slurry	Solid or Liquid Salt Solutions of Nitrates	Solid or Liquid Carbonaceous Fuel, Aluminum	Solid or Liquid TNT, Fine Aluminum, Bubbles
Emulsion	Liquid Nitrate Salt	Liquid Carbonaceous Oils	Bubbles

20.3.4.1 Nitroglycerin

Nitroglycerin is a clear yellowish/colorless liquid. It has chemical formula $C_3H_5(NO_3)_3$, molar mass of 227.0845 g/mol, density 1.6 g/cc at 15°C and melting point of 13.2°C.

Maximum detonation pressure generated by nitroglycerin is about 26.9 GPa.

Nitroglycerin is highly sensitive to shocks and heat. It detonates with even the slightest shock. It decomposes through detonation at low temperatures of 50 to 60°C, which means it is also highly sensitive to heat.

Due to extreme sensitivity nitroglycerin is never used in pure form for mining applications. By mixing it with other components its sensitivity reduces considerably and then it can be used with care. Such products are called dynamite and many other trade names.

20.3.4.2 Nitrocellulose

Nitrocellulose is a yellowish white cotton-like filament. It has chemical formula $(C_6H_7(NO_3)_3O_2)_n$, molar mass of $(297.1313)_n$, density of about 0.69 g/cc at 15°C and melting point between 160 to 170°C.

Nitrocellulose is an explosive. It is rarely used without addition of other components to the explosive mixture. In its non-compressed form, called smokeless powder, at a density of 0.69 g/cc, it has a velocity of detonation of 4492 m/s. If it is compressed to attain a density of 1.2 g/cc it attains a velocity of detonation of 7300 m/s. In this form it is called guncotton.

Maximum detonation pressure generated by nitrocellulose is guessed to be between 16 to 27 GPa.

Nitrocellulose is a dangerous material to store. It is hygroscopic and has a very high detonation temperature.

20.3.4.3 Ammonium nitrate

Ammonium nitrate is a white solid. It has a chemical formula $(NH_4)(NO_3)$ with molar mass of 80.043 g/mol, density 1.725 g/cc at 20°C, and melting point of 169.6°C.

By itself ammonium nitrate is not considered as an explosive because it does not detonate even with blasting cap no. 8. It has very low shock sensitivity as well as very low heat sensitivity. When engineered to detonate with a combustible, it attains detonation velocities up to 5250 m/s.

Ammonium nitrate is a most widely used component because it is an excellent oxidizer. It generates 60% oxygen by weight. Due to this property and its low price it is most commonly used in making explosives with a suitable fuel. Ammonium nitrate is also used in many non-ANFO explosives.

Ammonium nitrate is highly soluble in water. In 100 ml water its solubility at 0, 20, 40, 60, 80 and 100°C is 118, 150, 297, 410, 576 and 1024 g respectively.

Apart from being an abundantly used component in mining explosives, ammonium nitrate is also used as a fertilizer.

Both fertilizer and explosive grade ammonium nitrate is in prill form as shown in Figure 20.2. However, there is a big difference in the porosity of these two types. The fertilizer grade ammonium nitrate is meant to slowly dissolve in ground water and moisture. Therefore, it has low porosity on the microscopic scale and a density of about 1.40 to 1.45 g/cc. Prills meant for explosive use have much higher porosity and lower density of about 0.7 to 0.85 g/cc. Such high porosity of explosive grade AN prills is needed because they can absorb the fuel oil when mixed and form uniform ANFO.

20.3.4.4 Sodium Nitrate

Sodium nitrate is a white powder or colorless crystals. It has chemical formula $NaNO_3$ with molar mass of 84.994 g/mol, density 2.257 g/cc at 20°C, and melting point of 308°C.

Sodium nitrate does not detonate. It is also highly soluble in water. As the price of sodium nitrate is low it is used as an oxidizer in many mining explosives. It generates nearly 56% oxygen by weight.

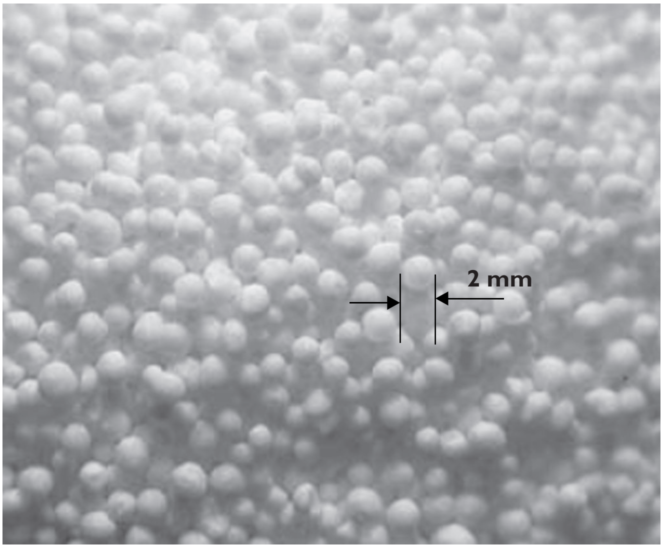

Figure 20.2 Explosive grade prills of ammonium nitrate.

20.3.4.5 Fuel oil

During the distillation of crude mineral oils, apart from petroleum many other products are formed. Most of them are in the form of hydrocarbon carbon chains and have a chemical formula $(CH_3)_2(CH_2)_n$, where n indicates the number of links in the chain.

There are six classes of fuel oil, numbered 1 to 6 according to their boiling points. The boiling points of the fuels in these six classes range between 175 to 600°C and the length of a chain ranges between 9 to 70.

The most common fuel oil used in explosive ANFO is diesel oil because it has a relatively high flash point.

20.3.4.6 Wood pulp

Wood pulp is made by chemically or mechanically separating fibers from wood. Usually softwood trees like spruce, pine, fir, larch or some hardwoods such as lime, birch or eucalyptus are chosen for the purpose.

Wood pulp has a chain structure with a common chemical formula $(C_6H_{10}O_5)_n$, where n is the number of links in the chain.

Because of the need of forest conservation the use of wood pulp has decreased drastically over the years.

20.3.4.7 Sulfur

Sulfur is a lemon yellow crystalline solid. It is one amongst 92 naturally occurring elements. It burns with a blue flame that emits sulfur dioxide, carbon disulfide, and hydrogen sulfide.

It has a molar weight of 32.066 g/mol, density between 1.92 to 2.07 g/cc depending upon its form and melting point of 115.21°C.

For more than a thousand years it has been used as an active combustible component of gunpowder. Sulfur is insoluble in water.

20.3.4.8 Antacid

Acidity of an explosive mixture is an undesirable property because it considerably reduces the shelf life of the product by corroding the container.

Zinc oxide is the most commonly used antacid component in an explosive mixture.

20.4 EXPLOSIVE MIXES USED IN MINE BLASTS

As stated in chapter 19, dry blasting agents, slurry, emulsion and dynamite are the main classes of explosives used in mine blasts.

20.4.1 Dry blasting agents

Dry blasting agent is a term given to components of an explosive which themselves are not classified as explosives but when mixed together they form a mixture that can explode.

In large surface mines the most commonly used explosive mixture is called ANFO because it is formed by mixing ammonium nitrate with fuel oil. Even after mixing these two components the final product remains fairly dry because the percentage of fuel oil in the mix is very small and moreover the fuel oil is absorbed in the pores of the prills of ammonium nitrate.

Use of standard diesel oil no. 2 as a fuel in ANFO has become almost universal. Other used oils, such as engine oil or compressor oil etc. should not be used because they are not well absorbed into the prills. Moreover, they also form harmful gases, and particularly metallic free radicals which remain unchanged in the atmosphere over a long period of time.

A lot of research has been carried out about ANFO because of its extensive use in mining practice. The following are some of the outcomes of the research.

In terms of chemical equations, if three molecules of ammonium nitrate react with one link of fuel the end products are harmless, as shown by the following equation.

$$3NH_4NO_3 + CH_2 \Rightarrow 3N_2 + 7H_2O + CO_2 + 940 \text{ kcal/kg}$$

The above means that for a perfect reaction as above the weight of ammonium nitrate should be equivalent to molecular weight of its three molecules and the weight of fuel oil should be equivalent to its one link. From this it can be concluded that with each 94.3 kg of ammonium nitrate about of 5.7 kg of diesel oil should be used.

If the weight proportion of AN and FO is 92 to 8, the equation happens to be

$$2NH_4NO_3 + CH_2 \Rightarrow 2N_2 + 5H_2O + CO + 820 \text{ kcal/kg}$$

Similarly, if the weight proportion of AN and FO is 96.6 and 3.4, the equation happens to be

$$5NH_4NO_3 + CH_2 \Rightarrow 4N_2 + 11H_2O + CO_2 + 2NO + 610 \text{ kcal/kg.}$$

The energy output as well as the velocity of detonation from the explosion is maximum when the weight proportion of the AN and FO is 94.3 to 5.7, as illustrated by Figure 20.3.

The output of poisonous gases is also lowest when the proportion of AM to FO is 94.3 to 5.7 as illustrated by Figure 20.4.

Even the sensitivity of ANFO also changes with the proportion of AN and FO, as can be seen from Figure 20.5.

As has been stated in chapter 18, the velocity of detonation of ANFO increases as the diameter of the blasthole increases. Data presented in Figure 20.3 are sufficient to prove this fact but data in Figure 20.6 do it more convincingly.

There are two disturbing aspects about use of ANFO in large surface mines. The first is the quick evaporation of diesel oil and the second is the high solubility of ammonium nitrate in water.

When the atmospheric temperature and humidity are high it becomes essential to add extra fuel in the ANFO mix to take care of the degree of evaporation likely up to the time of detonation. How much extra can be determined by technical common sense.

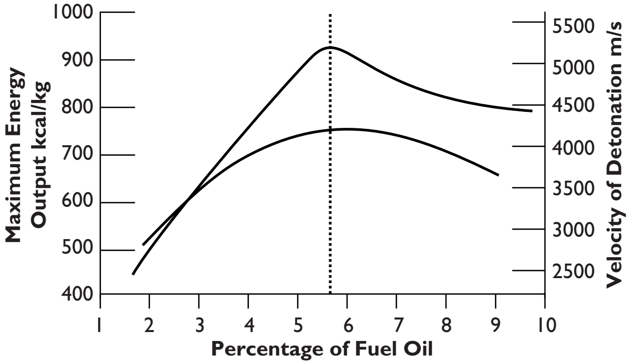

Figure 20.3 Variation of velocity of detonation and energy output with percentage of fuel oil in ANFO mixture.

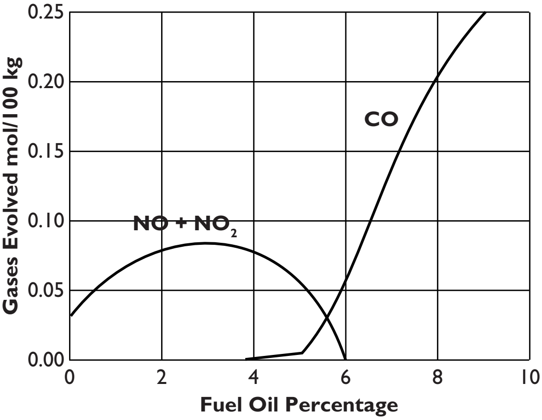

Figure 20.4 Variation of quantity of gases evolved by explosion of ANFO with percentage of fuel oil in ANFO mixture.

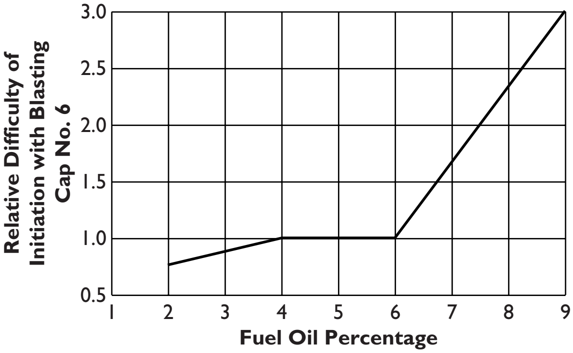

Figure 20.5 Variation of sensitivity of ANFO with percentage of fuel oil in ANFO mixture.

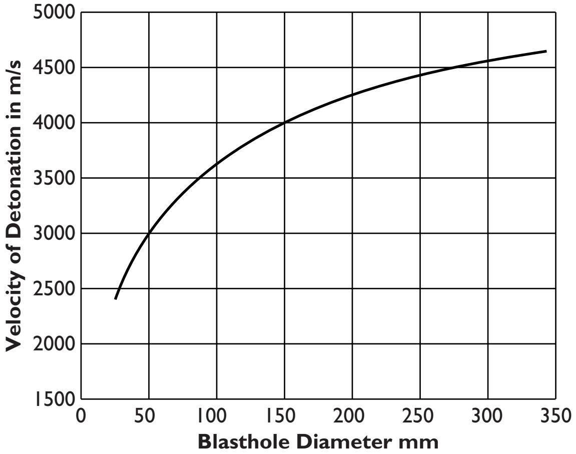

Figure 20.6 Variation of velocity of detonation with diameter of blasthole.

If the humidity of the atmosphere is very high the ammonium nitrate, being highly hygroscopic, absorbs a large quantity of water and in the process becomes less effective. The decrease in velocity of detonation with percentage of water in the ANFO mix is shown in Figure 20.7. In this context it is worth noting that after about 9% water content, the ANFO mix becomes insensitive and fails to detonate.

Heavy ANFO is the name given to an ANFO mix that contains aluminum as a sensitizer. Such mixture is also called ALANFO.

When ALANFO detonates some molecules of AN chemically react with the molecules of FO and evolve energy as per the chemical equation mentioned earlier. Due to sufficient energy generated in such reaction, some molecules of AN also react with aluminum in the mixture and evolve even higher energy as shown by following equations.

$$2\text{Al} + 3\text{NH}_4\text{NO}_3 \Rightarrow 3\text{N}_2 + 6\text{H}_2\text{O} + \text{Al}_2\text{O} + 1650\ \text{kcal/kg}$$

If the proportion of aluminum in the mix is higher then the equation is as under:

$$2\text{Al} + \text{NH}_4\text{NO}_3 \Rightarrow \text{N}_2 + 2\text{H}_2 + \text{Al}_2\text{O}_3 + 2300\ \text{kcal/kg}$$

The above equations clearly indicate that the energy yield of ALANFO is higher than ANFO. The variation of energy yield with percentage of aluminum in ALANFO is presented in Figure 20.8.

ALANFO is particularly useful for blasting hard rock masses. The most commonly used percentage of Al in ALANFO is between 10 to 15%.

The aluminum powder to be mixed with ANFO for making ALANFO must have particle size between 20 to 150 mesh i.e. 0.853 to 0.104 mm. The purity of the aluminum should be more than 94%. As this purity is easily attainable, even the low grade

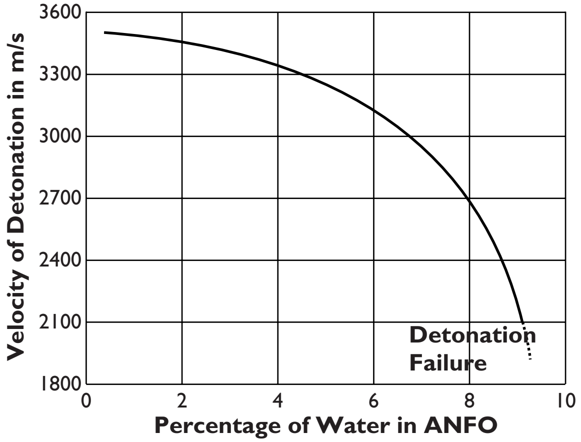

Figure 20.7 Variation of velocity of detonation with percentage of water in ANFO mix.

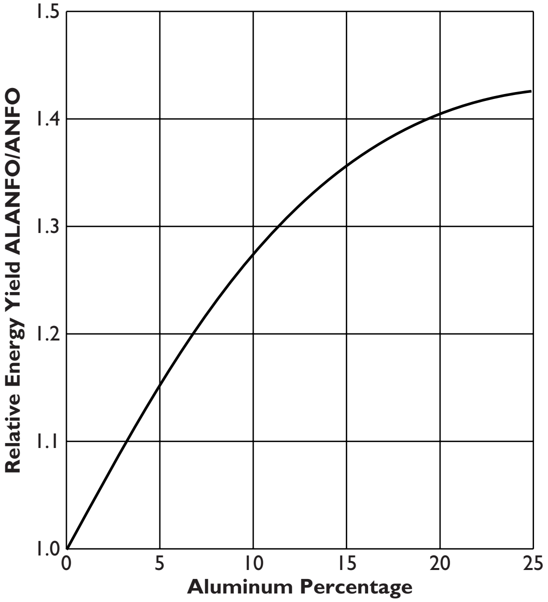

Figure 20.8 Variation of energy yield with aluminum percentage in ALANFO.

aluminum can also be used for mixing in ANFO provided the impurities do not yield harmful products.

Table 20.3 gives a general idea about the properties of ANFO. For any calculations or taking any type of decisions, similar data should be obtained from the manufacturers.

Table 20.3 Properties of ANFO explosives.

Property	*Poured ANFO*	*Package ANFO*
Heat of Explosion in kJ/kg	4079	4079
Gas Volume in L/kg	928	928
Temperature of Explosion in °C	2749	2749
Oxygen Balance in %O_2	0.17%	0.17%
Velocity of Detonation in m/s (65 mm non confined)	4000	4000
Velocity of Detonation in m/s (95 mm Blasthole)	4100	4100
Detonation Pressure in GPa	2–6	2–6
Brisance According Hess in mm	15	15
Strength According Trauzl Test in cm^3	400	400
Relative Working Ability in %	89	89
Gap Sensitivity in mm for 30 mm Cartridge	-	40
Gap Sensitivity in mm for 65 mm Cartridge	-	20
Bulk Density in kg/m^3	>800	
Density in Cartridge in kg/m^3		1050
Detonation by Blasting Cap	No. 8	No. 8
Water Resistance	Poor	Very Good for Intact Package
Fume Quality	Good (Depends on Conditions)	Good to Very Good (When Cartridges are Intact)
Temperature Resistance –18 to –38°C	Poor Above 32°C	Poor Above 32°C
Smallest Diameter of Blasthole in mm	60	30
Shelf Life in Months	-	6
Availability	In Truckloads or 25 kg Bags	Cartridge L × D mm 30 × 135, 65 × 585, 75 × 585, 90 × 585

The forms in which ANFO is supplied are as follows:

1 Poured ANFO
2 Packaged ANFO
3 Heavy ANFO

20.4.1.1 Poured ANFO

Where the quantity of explosives is large – such as in larger surface mines, this form of ANFO is supplied in separate component containers on a truck, mechanically mixed at the worksite and poured into blastholes. Hence, it is also called bulk ANFO. Where the requirement is low it is usually supplied in nylon bags. Poured ANFO proves more effective than the packaged form, as it fills the entire cross section of the blasthole whereas the package leaves a gap between the walls of the blasthole and external diameter of the package.

20.4.1.2 Packaged ANFO

If a blasthole has a significant quantity of ground water seeping into it, it cannot be charged by poured ANFO. In such cases the packaged form offers a good alternative. In this form ANFO is premixed and packed into thick cylindrical plastic bags sealed at both the ends. Packaged ANFO evolves larger quantities of poisonous gases from their blasts due to plastic packing. To reduce this cylindrical textile or cardboard tubes with plastic liners are used.

Charging a blasthole with packaged ANFO is more tedious and time-consuming.

20.4.1.3 Heavy ANFO

Heavy ANFO is so called not only because it has higher density but it is also meant for "heavy duty" blasts in hard rock in large mines. It is a mixture of ANFO and emulsion explosive in which the interstitial space between the ANFO prills is filled by the emulsion.

When the proportion of emulsion in the mix increases, the strength, velocity of detonation, and water resistance increase. With a normal range of compositions, density increases with emulsion contents up to a maximum of 1.3 kg/L. The charge sensitivity varies inversely with density and emulsion contents.

Like bulk ANFO this form is also mixed at the bench and immediately loaded into a blasthole. The proportion of emulsion and ANFO in the mix can be chosen while the products are being mixed so the mix has the desired properties.

The cost of heavy ANFO rises with increasing amount of emulsion.

20.4.2 Slurry

Slurries are also called water gels. They are made from ammonium nitrate partly in an aqueous solution. Their further classification into a blasting agent or an explosive depends upon other ingredients used with them.

As slurry explosive is fluid, it is pumpable and miscible with water. They get good water resistance from the gaur gum mixed with them. "Slurry boosting" is practiced when slurry and a dry blasting agent are used in the same blasthole. Most of the charge will come from the dry blasting agent. Boosters placed at regular intervals may improve fragmentation.

Slurries are available in highly viscous tooth paste-like form as well as in cartridge form. Slurries are also made dimensionally stable and water-resistant by adding cross-linking agents.

Slurries cost more, give somewhat unreliable performance and deteriorate with long storage.

Water gel explosives, a special form of slurry explosive, contain significant amounts of water and separate oxidizer and fuel components, making them less sensitive than water-free nitroglycerin dynamites. Water gels are made up of oxidizing salts and fuels dispersed in a continuous liquid phase. The addition of gelants and cross-linking agents thickens the mixture and makes it water-resistant. Ammonium nitrate, sodium nitrate, and calcium nitrate are the commonly used oxidizing salts, whereas aluminum, coal, sugar, ethylene glycol, and oil are common fuels. The addition of nitrate salts of organic amines, nitrate esters of alcohol, perchlorate salts, fine particle size aluminum, or other explosives may adjust the sensitiveness of the water gels. Also, physical sensitizers such as plastic bubbles or glass ‘micro balloons’, may be blended into the gel either alone, or in combination with other chemical sensitizers.

The density of most water gels ranges from 1.0–1.35 g/cc. Water gels may be formulated to be either cap sensitive, or insensitive. In either case they are less sensitive to abusive impact, shock, or fire than dynamite. They are explosives, however, and should never be abused.

The sensitivity of water gels is affected by temperature, with higher temperatures increasing the sensitivity of the products.

Slurry explosives are supplied in two forms viz. bulk slurry and cartridged slurry.

20.4.2.1 Bulk slurry

Bulk slurry explosives are supplied in component form contained in tanks on an off-highway truck. They are thick and appear as shown in Figure 20.9. They can be pumped into a blasthole through tubes. Their critical diameter is relatively small and can be used for charging blastholes of diameters ranging between 50 to 150 mm. For blastholes of larger diameter it is more economical to use ANFO with addition of slurry in certain portions of the blasthole depending upon the need dictated by the site conditions.

20.4.2.2 Cartridged slurry

When slurry explosives are to be used in blastholes of smaller diameter, pumping it inside the blasthole is not advisable. In such case cartridges filled with slurry are used. Cartridges are made from hard plastics or cardboard and are rigid.

Since they do not deform easily they can be lowered in a blasthole very easily.

Cartridges are available in different diameters and lengths to suit blastholes of different diameter.

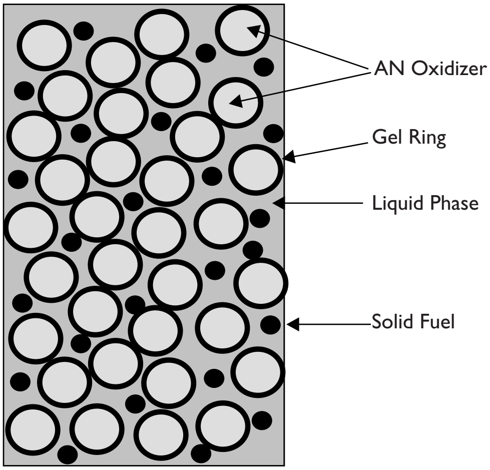

Figure 20.9 Emulsion explosive.

20.4.3 Emulsions

Emulsion explosives are formed by four components viz. an oxidizing agent (usually AN), water, combustible material (mineral oil, paraffin or microcrystalline wax) and gas-filled micro balls of glass or special plastic.

The water droplets, in which ammonium nitrate is dissolved, are covered by a very thin film of fuel oil. An emulsifier is used for stabilization of these oxidizer droplets. These droplets are dispersed in the liquid phase. The ratio of oxidizer to fuel in an emulsion is typically 9:1. The liquid phase also contains solid fuel. Voids in the form of micro-balls make the emulsion more sensitive. The contents of a typical emulsion are shown in Figure 20.9.

Sensitivity of emulsions decreases with increasing density. Dry products like aluminum powder are used to adjust strength. Gasifying products are used for reducing density.

Emulsions have excellent water resistance, are relatively insensitive to temperature changes, have high energy and give dependable performance.

Emulsions provide increased explosive efficiency because both oxidizer and fuel phases are liquid and the dispersed nitrate solution droplets are microscopically small i.e. about 0.001 mm. As they are tightly packed within the fuel phase the contact surface is very large. This ensures very rapid reaction.

Properties of a particular variety of emulsion are presented in Table 20.4.

The direct cost of an emulsion explosive is higher but this is offset by time saved in loading.

Table 20.4 Properties of an emulsion.

Property	*Emulsion*
Heat of Explosion in kJ/kg	2800
Gas Volume in L/kg	800
Temperature of Explosion in °C	1800
Oxygen Balance in $\%O_2$	+ 0.5
Velocity of Detonation in m/s (30 mm non confined)	>4400
Velocity of Detonation in m/s (65 mm non confined)	5100
Detonation Pressure in GPa	4–9
Brisance According Hess in mm	20
Relative Working Ability in %	63
Gap Sensitivity in mm in 50 mm non Confined Cartridge	30
Density in Cartridge in kg/m^3	>1050
Detonation by Blasting Cap	No. 8
Water Resistance in Small Dia. Cartridge	10 hrs/0.35 MPa
Fume Quality	Good to Very Good
Temperature Resistance –18 to –38°C	Good
Smallest Diameter of Blasthole in mm	30
Shelf Life in Months	12
Availability	Cartridge D × L mm 30 × 680, 38 × 393, 50 × 540, 65 × 660, 75 × 520, 90 × 450

20.4.4 Dynamite

The original dynamite made by Alfred Nobel was a mixture of nitroglycerine and kieselguhr i.e. diatomaceous earth. The diatomaceous earth absorbed the oily nitroglycerine and the mixture became quite insensitive to shock. It could be used far more safely than nitroglycerine. Over the years formulations of dynamite have changed but nitroglycerine has still remained the main detonating component. Other components of modern dynamites are nitrocellulose, ammonium nitrate, sodium nitrate, wood pulp, carbonaceous fuel, sulfur, antacid etc.

Three basic types of dynamites are granular, gelatin and semi-gelatin.

20.4.4.1 Granular dynamite

Granular dynamite is in granular form but is still very sensitive and cannot be poured like ANFO. Granular dynamite is available in cartridges of different diameters and lengths.

There are two types of granular dynamite viz. straight dynamite and extra dynamite.

Straight dynamite has all the common components such as nitroglycerin, sodium nitrate, carbonaceous fuel, sulfur, antacid and moisture but is without ammonium nitrate. Extra dynamite additionally contains ammonium nitrate.

Both straight and extra dynamite have a pungent, sweet odor because they contain nitroglycerin. Inhalation of the nitroglycerin fumes will usually cause a severe and persistent headache. Straight dynamite generally has a light tan to reddish-brown color. In extra dynamite the reddish tint is lesser. The texture of straight dynamite can be described as a loose, slightly moist, oily mixture. Extra dynamite, in addition, has a pulpy appearance.

Ammonia dynamite is less sensitive to shock and friction than straight dynamite because a part of the nitroglycerin content has been replaced with ammonium nitrate and nitroglycol.

Compositions of some of the straight and extra dynamites are given in Table 20.5 and Table 20.6.

The properties of straight and extra dynamite presented in Table 20.7 are indicative. In any case when authentically confirmed data on properties is needed, the manufacturer should be contacted.

Table 20.5 Composition of some straight dynamites.

Ingredient proportion by weight					
Nitroglycerin	*Sodium nitrate*	*Carbonaceous fuel*	*Sulfur*	*Antacid*	*Moisture*
56.8	22.6	18.2	-	1.2	1.2
49	34.4	14.6	-	1.1	0.9
39	45.5	13.8	-	0.8	0.9
29	53.3	13.7	2	1	1
20.2	59.3	15.4	2.9	1.3	0.9

Table 20.6 Composition of some extra dynamites.

Ingredient proportion by weight						
Nitroglycerin	*Sodium nitrate*	*A. nitrate*	*Carbonaceous fuel*	*Sulfur*	*Antacid*	*Moisture*
22.5	15.2	50.3	8.6	1.6	1.1	0.7
16.7	25.1	43.1	10	3.4	0.8	0.9
16.5	37.5	31.4	9.2	3.6	1.1	0.7
12.6	46.2	25.1	8.8	5.4	1.1	0.8
12	57.3	11.8	10.2	6.7	2.2	0.8

Table 20.7 Properties of straight and extra dynamite.

Property	*Str. dynamite*	*Extra dynamite*
Heat of Explosion in kJ/kg	4680	>4100
Gas Volume in L/kg	717	858
Temperature of Explosion in °C	3400	>3000
Oxygen Balance in %O_2	+1.5	+2.2
Velocity of Detonation in m/s (65 mm non confined)	6400	>6000
Velocity of Detonation in m/s (28 mm non confined)	>6000	2400
Detonation Pressure in GPa	4–7	3–6
Brisance According Hess in mm	22	>14
Strength According Trauzl Test in cm^3	380	>385
Relative Working Ability in %	70	>78
Gap Sensitivity in mm in 90 mm cartridge	100	>40
Density in Cartridge in kg/m^3	1450	>1300
Detonation by Blasting Cap	No. 8	No. 8
Water Resistance in Large Dia. Cartridge	24 hrs/0.8 MPa	4 hrs/0.3 MPa
Water Resistance in Small Dia. Cartridge	10 hrs/0.3 MPa	2 hrs/0.3 MPa
Fume Quality	Poor to Good (When Cartridges are Intact)	
Temperature Resistance –18 to –38°C	Poor to Good	Poor to Good
Smallest Diameter of Blasthole in mm	22	28
Shelf Life in Months	12	9
Availability	Cartridge D × L mm 22 × 220, 25 × 220, 28 × 220, 38 × 320, 50 × 440	Cartridge D × L mm 28 × 220, 38 × 320, 50 × 440, 65 × 550, 70 × 450, 80 × 450, 90 × 480

20.4.4.2 Gelatin dynamite

Gelatine is a name added to dynamite when the composition of dynamite includes nitrocellulose. Nitrocellulose is of cotton-like form with significant volume of voids. It can absorb the nitroglycerine mixed with it to attain a very viscous gel form.

Gelatin dynamite is also made in three forms viz. straight gelatin, extra gelatin and semi gelatin.

Straight dynamite contains nitrocellulose in higher proportion but lacks ANFO or other oxidizers. Here the principal source of energy is nitroglycerin.

In ‘ammonia’ or so-called ‘extra’ dynamites, ammonium and sodium nitrates along with carbonaceous fuel replace a large portion of the nitroglycerin to create a less expensive and more impact-resistant dynamite. In these dynamites the ammonium and sodium nitrate along with carbonaceous fuel act as the principal source of energy, while nitroglycerin acts as a sensitizer.

Compositions of some varieties of straight and extra gelatin dynamite are given in Tables 20.8 and 20.9 respectively.

Semi-gelatin dynamites do not contain any ammonium nitrate prills. Therefore, they are in semi-gel form rather than granular. Compositions of some varieties of semi-gelatins are given in Table 20.10.

Properties of straight, extra and semi-gelatins are presented in Table 20.11. The data presented in the table are from different manufacturers. Hence, the values may not be very compatible.

Table 20.8 Composition of straight gelatins.

Ingredient proportion by weight				
Nitroglycerin	*Nitro cellulose*	*Wood pulp*	*Antacid*	*Moisture*
91	7.7	0.3	0.8	0.2

Table 20.9 Composition of some extra gelatins.

Ingredient proportion by weight							
Nitroglycerin	*Sodium nitrate*	*Nitro cellulose*	*A. Nitrate*	*Carbonaceous fuel*	*Sulfur*	*Antacid*	*Moisture*
35.3	33.5	0.7	20.1	7.9	-	0.8	1.7
29.9	43	0.4	13	8	3.4	0.7	1.6
26.2	49.6	0.4	8	8	5.6	0.8	1.4
22.9	54.9	0.3	4.2	8.3	7.2	0.7	1.5

Table 20.10 Compositions of some semi gelatins.

Ingredient proportion by weight						
Nitroglycerin	*Sodium nitrate*	*Nitro cellulose*	*Carbonaceous fuel*	*Sulfur*	*Antacid*	*Moisture*
49.6	38.9	1.2	8.3	-	1.1	0.9
40.1	45.6	0.8	10	1.3	1.2	1
32	51.8	0.7	11.2	2.2	1.2	0.9
25.4	56.4	0.5	9.4	6.1	1.2	1
20.2	60.3	0.4	8.5	8.2	1.5	0.9

Table 20.11 Properties of gelatin explosives.

	Straight gelatin	*Extra gelatin*	*Semi gelatin*
Energy kcal/kg	1055	1055	955
Energy kcal/L	1510	1510	1240
Gas Volume in mol/kg	32	32	37
Detonation Pressure in kbar	130	106	60
Velocity of Detonation in m/s	6000	5300	4300
Relative Bulk Strength wrt ANFO in %	210	210	172
Relative Weight Strength wrt ANFO in %	120	120	109
Fume Class	IME1	IME1	IME1
Density in Cartridge in kg/m^3	1.5	1.51	1.3
Detonation by Blasting Cap	No. 8	No. 8	No. 8
Water Resistance	Excellent	Excellent	Good
Smallest Diameter of Blasthole in mm	32	25	29
Availability	Cartridge D × L mm – (25, 29, 32, 40, 45, 50, 75) × 200, (32, 50, 60, 65, 70, 75) × 400	Cartridge D × L mm – (25, 29, 32, 40, 45, 50, 75) × 200, (50, 60, 65, 70, 75) × 400	Cartridge D × L mm – (25, 29, 32, 40, 50) × 200, (50, 60, 65, 70, 75) × 400

The use of dynamite as a main explosive has declined considerably ever since ANFO entered mining as an explosive. With rare exceptions it is hardly ever used in large surface mines.