Rapid Advance Using Underground Bulk Emulsion

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***Abstract* — This paper highlights the role Rapid Development as strategic drivers within the mining industry such as operational shift from open pit to underground mining and a greater interest in mass mining technique as well as enhanced focus on safety. Rapid development is key to any mine's performance. Optimizing drill and blast parameters is important to accelerate the development rate of a mine. The parameter that is central to drill and blast practices is explosives. Selecting the correct explosive gives the mine leverage in achieving desired outcomes. Underground Bulk emulsion is one such advancement in the explosives technology**

Keywords—Underground Bulk emulsion; Rapid Development;

I. Introduction

Over the past decade, Underground bulk emulsion has established itself as a highly preferred alternative to packaged emulsion/ANFO in the global hard rock mining fraternity in terms of safety, rapid advance benefit, inventory control and mechanization of blasting process. 100 % coupling and excellent water resistance differentiates this product from the rest of the explosives range used in development blasting. *Powerbulk*™, the trade name of Orica's underground emulsion product, is an water in oil non explosive emulsion matrix developed for development and down hole applications in hard rock underground mining. It is opaque grease like substance loaded into blast holes using specialized delivery system named the *Maxiloaders*™. *Maxiloader*™ is an intrinsically safe delivery system developed by Orica. The pump is designed to externally sensitize the non-explosive emulsion matrix using appropriate gasser solutions. The ability to add gasser solution externally allows for use of different product densities for different blasting application. This provides certain flexibility in blast designs

II. Rock Breakage Mechanism

During the detonation of an explosive charge inside rock, the conditions presented are characterized by two phases of action:

1st Phase: A strong impact is produced by the shock wave linked to the strain energy, during a short period of time..

2nd Phase: The gas produced behind the detonation front come into action at high temperature and pressure, carrying the Thermodynamic or Bubble energy.

(A). Crushing of Rock: In the first instance of detonation the pressure infront of the strain wave, which expands in cylindrical form, reaches values that well exceeds the dynamic compressive strength of the rock, provoking the destruction of its intercrystalline and intergranular structure. The thickness of the crushed zone increases with detonation pressure of the explosive and with the coupling between the charge and the blasthole.

(B). Radial Fracturing: During propagation of strain wave, the rock surrounding the blasthole is subjected to intense radial compression which induces tensile components in the tangential planes of the wave front. When the tangential strains exceed the dynamic tensile strength of the rock, the formation of a dense area of radial cracks around the crushed zone that surrounds the blasthole is initiated. The number and length of these radial cracks increase with:

1. The intensity of the strain wave on the blasthole wall or on the exterior limit of the crushed zone and,

2. The decrease in dynamic tensile strength of the rock and the attenuation of strain energy.

(C). Reflection Breakage and spalling: When the strain wave reaches a free surface two waves are generated, a tensile wave and a shear wave. This occurs when the radial cracks have not propagated farther than one third the distance between the charge and the free face

(D). Fracturing by Release-of-Load: Before the strain wave reaches the free face, the total energy transferred to the rock by initial compression varies between 60 -70% of blast energy (Cook et tal . 1966). After the compressive wave has passed, a state of quasi-equilibrium is produced, followed by a subsequent fall of pressure in the blasthole as the gases escape through the stemming, through the radial cracks and with rock displacement. The stored stress energy is rapidly released, generating an initiation of tensile and shear fracture in rock mass.

(E). Fracturing along boundaries of modulus contrast of shear fracturing: In sedimentary rock formation when the bedding planes, joints etc, have different elasticity modulus or geo mechanic parameters, breakage is produced in the separation planes when the strain wave passes through because of strain differential in these points.

(F). Breakage by Flexion: During and after the mechanism of radial fracturing and spalling, the pressure applied by the explosion gases upon the material in front of the explosive column makes the rock act like a beam embedded in the bottom of the blasthole and in the stemming area, producing the deformation and fracturing of the same by the phenomena of flexion.

(G). Fracture by in-flight collisions: The rock fragments created by previous mechanisms and accelerated by the gases are projected towards the free face, colliding with each other and thereby producing additional fragmentation which has been demonstrated by ultra-speed photographs(Hino, 1959).

III. EXPLOSIVE CRITERIA SELECTION FOR UNDERGROUND OPERATION

(A). Explosive Costing: The cost of explosive is obviously a very important selection criterium. To start with, one must choose the lowest cost explosive with which the work at hand can be carried out.

(B). Critical Diameter: The minimum diameter in which the explosive will detonate/explode consistently and reliably. The critical diameter depends upon the properties of explosive to reliably detonate in the blasthole.

(C). Rock Characteristics: The geomechanic properties of the rock mass to be blasted make up the most important group of parameters, not only for their direct influence upon the results of the blast but for their interrelation with other design variable as well.

(D). Volume of Rock to be Blasted: The volume of the excavation and the work schedule give the amount of explosive necessary for the breakage operation. In large operations the quantity of explosive may be such as to consider its use in bulk form, as it makes mechanized charging possible from the transport units themselves, reducing labor cost and making better use of the volume of rock drilled.

(E). Atmospheric Condition: Low atmospheric temperature have strong influence on the explosive which contain NG as they tend to freeze at temperature below 8^0C. Sub-freezing temperature also creates problem in bulk explosives which depends upon their specification.

(F). Presence of Water: Still or dynamic water has a great influence upon the performance of explosive. When ANFO is in an atmosphere with more than 10% humidity, an alteration is produced which stops detonation. Emulsion explosive have a shear effect which can break the emulsion matrix or render water pocket which can make the explosive ineffective.

(G). Environmental Problem: The main problems that effect areas near the bastings are vibration and air blast. From the explosive point of view, those with high strain energy give higher vibration levels. Thus, when feasible, it is better to use low energy explosives. As to air blast, it is recommended that the explosive have a balanced strain energy/bubble energy relationship and, above all, that the geometric design of the blasting be controlled.

(H). Fumes: Although many explosives are prepared so that their oxygen balance gives maximum energy minimum toxic detonation gases, the formation of harmful fumes with a certain nitrous gas and CO content is inevitable. The fumes enter as a selection criterium in underground only and it must be pointed out that it is more a problem of poor ventilation rather than of the explosive itself. Cap sensitive explosives generally gives gases with good properties, whereas with ANFO certain precaution must be taken as it produces a high concentration of nitrous gases.

(I). Safety Condition: A balance between sensitivity and safety is not always easy to achieve. Gelatin explosives have high sensitivity but if explosives left-overs are found in muck pile and heavy machinery is used, detonation can occur with the consent danger for operator. This problem has been solved with the use of emulsion explosive that are insensitive to being struck, friction or subsonic stimulation, but have an adequate degree of sensitivity for initiation.

(J). Explosive atmosphere: Excavation carried out in gassy atmosphere/hot holes, such as in coal mines as well as in any other metal mines, could cause great catastrophe if secondary blasting occurs. For this reason, in such projects, it is most necessary to undertake the task of studying the atmosphere and environment near the blasting so as to decide whether to use permissible explosive or inhibitor.

(K). Supply problem/Self life: Another final factor to take into account is the available supply in function with the location of the work and the proximity of the explosive and their accessories. If the powder magazines belong to the organization, length of storage must be taken into consideration along with possible variation in the explosive characteristic of some of the products.

IV. RAPID DEVELOPMENT

An underground mining cycle usually consists of drilling, blasting, mucking and scaling/supporting. The cycle time of these activities varies with ground condition, skill, planning and production rate; a faster cycle time would reduce the per meter development fixed cost of a mine which is a huge saving. This is usually termed as rapid development, where we try to reduce the overall cycle time of a mine to reduce the fixed cost associated with per meter of advance rate.

Rapid development is key to any mine's performance. Optimizing drill and blast parameters is important to accelerate the development rate of a mine. Rapid development techniques maximize activity at the tunnel face and advance completion rates without compromising safety. Good project planning should prepare for both expected ground conditions and unexpected variations in the rock mass to be excavated. This will reduce delays and mitigate the effect of poor ground conditions, which can slow advance rates by 50%. Investment in a "rapid development" program is usually justified to realize higher Net Present Value for a project. The risk of not being able to excavate the rock mass as planned can result in inadequate prediction and preparation to deal with the actual ground types encountered.

Strategic drivers within the mining industry, such as an operational shift from open-pit to underground mining had a greater interest in mass-mining techniques as well as an enhanced focus on safety, mean that miners are now seriously interested in drill-and-blast alternatives for rapid mine development. Mechanical rock excavation has had limited success so far in the hard-rock mining industry, mainly due to difficulty with cutting tools in highly competent and abrasive rock formations, but also because standard equipment does not possess the flexibility to cope with the variable nature of the rock, the geometry of mineralisation and the layout of an underground metal mine.

The parameter that is central to drill and blast practices is explosives. Selecting the correct explosive gives the mine leverage in achieving desired outcomes. Underground Bulk emulsion is one such advancement in the explosives technology. Over the past decade, Underground bulk emulsion has established itself as a highly preferred alternative to packaged emulsion/ANFO in the global hard rock mining fraternity in terms of safety, rapid advance benefit, inventory control and mechanization of blasting process. 100 % coupling and excellent water resistance differentiates this product from the rest of the explosives range used in development blasting

Powerbulk™, the trade name of Orica's underground emulsion product, is an water in oil non explosive emulsion matrix developed for development and down hole applications in hard rock underground mining. It is opaque grease like substance loaded into blast holes using specialized delivery system named the *Maxiloaders™*. *Maxiloader™* is an intrinsically safe delivery system developed by Orica. The pump is designed to externally sensitize the non-explosive emulsion matrix using appropriate gasser solutions. The ability to add gasser solution externally allows for use of different product densities for different blasting application. This provides certain flexibility in blast designs.

V. *POWERBULK*™ PROPERTIES AND ADVANTAGES

Powerbulk™ Drive is a primer sensitive bulk emulsion explosive which has the appearance of an opaque fluid, similar in viscosity light grease or heavy oil. It has excellent water resistance as an inherent character due to the emulsion structure. It is manufactured at the blast site from an Orica designed underground pumping unit, which combines the non-explosive emulsion with the sensitizer to deliver the explosive product into the blasthole. The density of the final product can be varied to suite ground conditions or blast design.

Powerbulk™ Drive has been designed specifically to provide explosive performance characteristic best suited to the requirements of typical underground development and tunneling operation. Specific densities can be selected to match desired blast performance criteria. The minimum recommended hole diameter depends on the density selected. The presence of reactive ground can be very catastrophic as it reacts spontaneously with nitrates. Reactive grounds are sulphide bearing rock that reacts spontaneously with nitrates and lead to generation of potentially large amount of heat , it is a self-catalyzing exothermic reaction which does not require heat and the onset can be very sudden. It is a unpredictable rate of reaction and if reaction proceeds to completion, it can result in the explosive decomposition of the nitrate. The risk associated with non-inhibited explosive used in reactive ground sudden or violent decomposition of ammonium nitrate, evolution of toxic NOx and SO_2 fumes, premature initiation of detonators and mass detonation. The indicator of reactive ground is presence of sulphide minerals (pyrrhotite, marcasite, pyrite, and chalcopyrite) exposed fragmented or weathered, hot ground and acidic ground water.

Before starting the charging and loading process with *Powerbulk*™Drive, Orica has certain minimum precaution measure:

- HRG Rock Sample Testing – Lab Analysis at Kuri Kuri
- Orica site specific loading procedure.
- Orica PPS Hot and Reactive ground regular audit.
- Orica special product for HRG application.

The sleeping time must be determined based on reactivity testing. The maximum sleep time in unreactive ground is limited to 7 days, however, sleep time is dependent on factors such as hole diameter, density ground water conditions, initiation system and mining method. The gassing rate is temperature dependent.

Advantages of *Powerbulk*™ Drive includes:

(A) Ease in transportation, handling and storage.

(B) Safety and security: No accumulation of static charge and mixes with gasser solution at the end of nozzle.

(C) Variable density.

(D) Universal explosive.

(E) Low fumes emission.

(F) Excellent resistance to water.

(G) 100% coupling for better energy distribution.

(H) Increased VOD.

(I) Improved work environment.

(J) Shorter Charging Times.

(K) Accurate explosive consumption count.

Safety and Security:

(A). Handling (Transportation and Storage): ANE (Bulk Premix) Matrix is transported from manufacturing unit to the project site stored in BTU (Bulk Transfer Unit) at mine site.

(B). Machinery Safety: The Emulsion Premix is pumped through specially designed piston pump unit called Maxipump™ unit which is very simple, accurate and has no electronic complicated securities.

(C). Operational Safety: In case of any dead head pumping, the pump stalls with no further input of energy due to any of these failure feature; Inlet valve failure, Outlet valve failure and Blocked outlet. In case of dry running, low friction at seals and high rate of conduction of heat by stainless steel ensures no significant temperature rise.

(D). Application and Uses: Unlike opencast system, premix is not mixed with sensitizer while pumping, actual mixing at the takes place at the end of nozzle; thus the mixture turns into explosive after pumped in the hole. The loading hose inner diameter is less than critical diameter of the sensitized explosive. Usage of low energy product helps in design conformance and less damage to the roof.

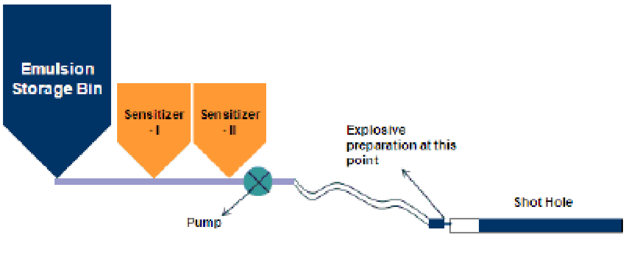

Fig 1: Safety Feature

Water Resistance Property: Unlike ANFO, Emulsion Bulk have excellent water resistance property. A deliberate look up angle and dewatering of blast hole is not needed in bulk emulsion. Water condition increases the probability of ANFO column misfire.

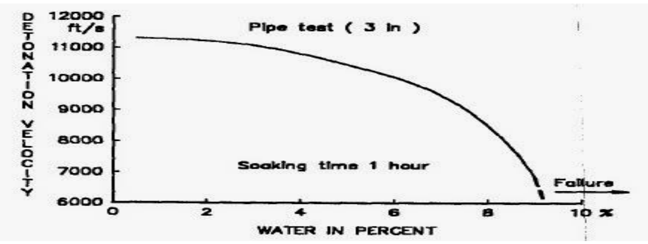

Fig 2: ANFO in water

Fume property of Bulk Emulsion: Oxygen imbalance in ANFO matrix has serious impact on post blast fumes, an oxygen negative matrix leads to high proportion in CO in post blast Fumes.

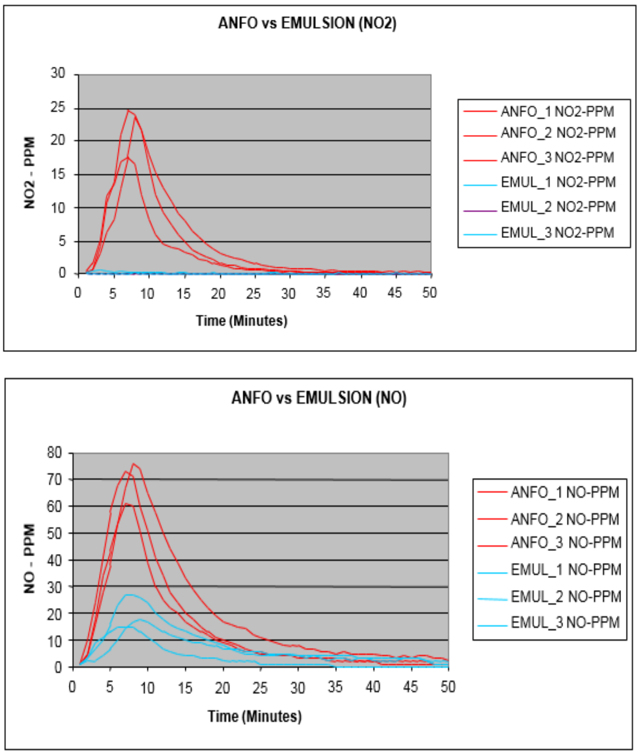

Fig 3: NO2 levels from 6.0m rounds

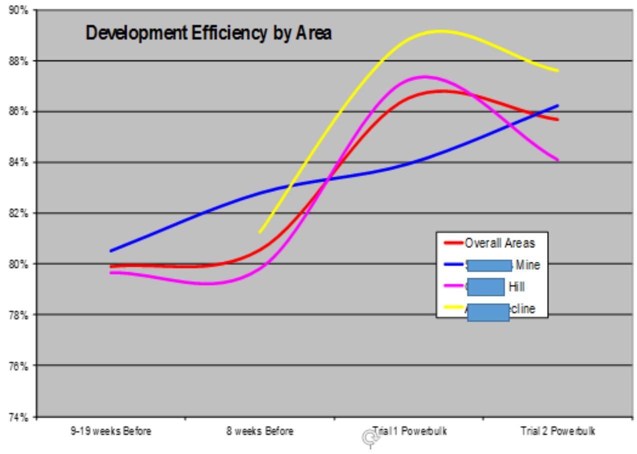

Fig 4: Rapid Advance Benefit using Bulk Emulsion

VI. RAPID DEVELOPMENT IN HINDUSTAN ZINC LIMITED USING POWERBULK™ DRIVE

Hindustan Zinc Limited (HZL) is an integrated mining and resources producer of zinc, lead and silver. It is a subsidiary of Vedanta Resources PLC. HZL is the world's second largest zinc producer. Its FY15 revenues were INR 147.9 billion. Located 200 km apart, Sindesar Khurd and Rampura Agucha are the flagship mines of Hindustan Zinc Limited.

Rampura Agucha operations include both open pit and underground mining. The deposit has a very high zinc content (Feed Grade of 12 % for FY 15).The underground mine produced 1.43 million MT of ROM with 28,000 MT of mined metal (Pb & Zn) in FY15. As part of the on-going expansion programme, ore production capacity at Rampura Agucha is to be increased to 3.75 million MT per annum by FY 20. Sindesar Khurd is the largest underground mine in India and it achieved a production of 3 million MT (ROM in FY 15. It is a silver/lead rich deposit. The mine has multiple standalone deposits or auxiliary lenses. It mines ore from two deposits i.e. main lode and an auxiliary lenses. The ore production capacity of the mine would be enhanced to 3.75 million MT in 2016 by mining multiple auxiliary lenses simultaneously. Both the units are highly mechanized world-class underground mines with state-of-the-art infrastructure facilities.

The Situation: The mines worked with conventional packaged blasting systems with manual loading. The average advance rate per blast was limited to 3.30 m for a hole depth of 3.8 Meters. i.e., an advance rate of approx. 85% and the average charging time ranged between 105-120 mins. For faster development to meet the steep production targets, SK mines and RA mines required to increase the advance per blast round & reduce the cycle time.

Fig 5 : Drilling Operation

Over the past decade, Underground Bulk emulsion has established itself as a highly preferred alternative to packaged emulsion/ANFO in the global hard rock mining fraternity in terms of

- Safety
- Rapid advance benefits
- Inventory Control
- Mechanization of blasting process

HZL after evaluating the potential benefits associated with the system, entered into a contract with Orica to work with Powerbulk™ Drive (UG Bulk emulsion explosive) in its underground mines. HZL and Orica framed a project charter with two Key Performance Indicators (KPIs).

(A). Advance per blast round

(B). Reduction in charging time

Technical Solution: Orica proposed Hypercharge™ Total service for faster development and improved advance rates in the development blasting cycles.

HZL in collaboration with Orica fabricated specialized pumps (MaxiLoader™) on Charmec carriers at both its mine sites. Maxiloader™ is an intrinsically safe underground emulsion delivery system developed by Orica. It delivers the emulsion based explosive into the blast holes.

Fig 6: Maxipump™ in Operation

Powerbulk™ Drive with Exel™ (non-electric detonators) was used to blast the development rounds. Both the mines are geologically very different. While Sindesar Khurd has good ground conditions, Rampura Agucha, with the presence of ore body shears and poor ground, does not present very blast friendly conditions. They required customized blast designs to deliver optimal advance rates. The products were calibrated for different densities. A joint team of HZL and Orica conducted the trials to establish suitable charge plans and initiation sequence for each site. Blast designing was done using Orica's advanced blast design software "ShotPlus™-T".

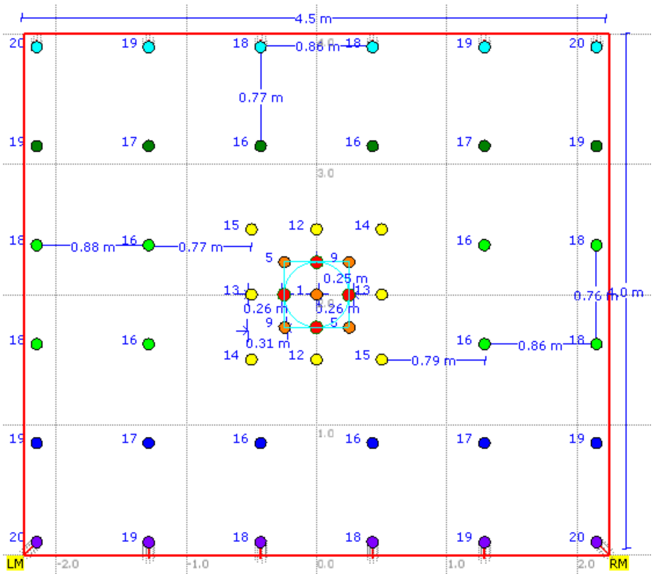

Fig 5: Design using Shotplus™T.

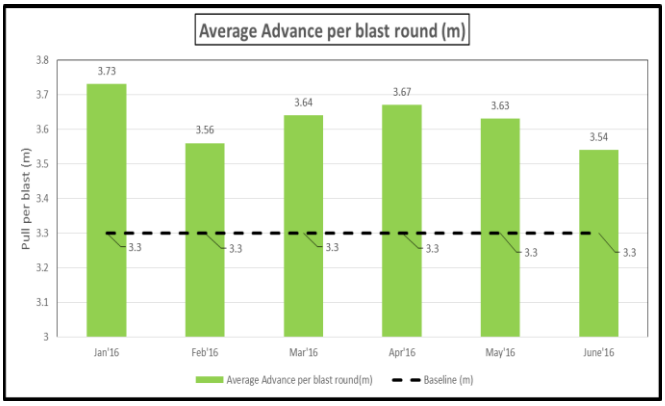

Fig 6: Average Pull

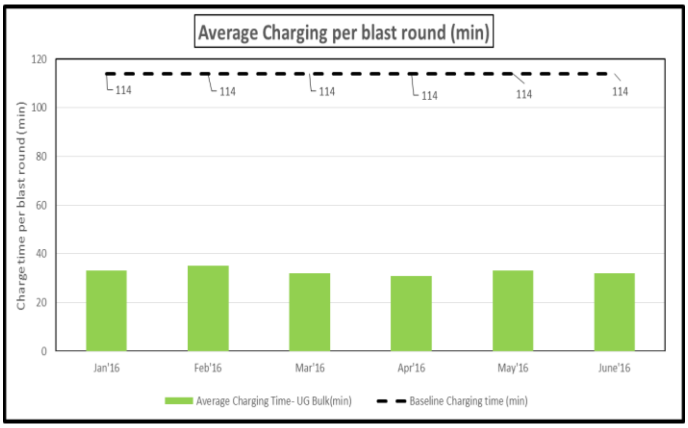

Fig 7: Average Charging Time

The Result: Combination of customised Drill & Blast Patterns, designed using ShotPlus^{TM}-T, along with Powerbulk^{TM} Drive & Exel^{TM} delivered faster advance rate.

Rapid development was achieved by:

(A). Increasing the pull per blast round to 95% from the average of 85% and

(B). Reducing the charging time by 67%.

The consolidated potential annual savings for HZL out of the UG Bulk systems is estimated around INR 130 Mn (A$ 2.5 Mn). The key components for saving in Rapid Development using Powerbulk^{TM} Drive includes:

(A). Blasting cost per cycle Savings.

(B). Inventory Benefit.

(B). Fixed cost per meter saving due to increase in advance.

(C). Cost implication of Over break.