Comminution costs represent a large part, 30-50%, of total mining operation costs. Rock fragmentation through blasting influences downstream operations such as crushing and grinding. "Many studies have shown that both mechanical impact and blasting loading produce micro cracks in rocks, and such cracks in fragments have a beneficial effect on grinding. Therefore, an optimum fragmentation from mine to mill is necessary. 1  

"Optimum rock fragmentation from mine to mill may be realised nowadays under certain conditions. First, electronic detonators should be used to assure an effective stress superposition from neighbouring holes. Second, a redistribution of the energy consumption from drilling/blasting to crushing and grinding should be included to reduce total energy consumption. Third, blasting parameters should be chosen theoretically by using detonation, stress wave and other relevant theories." 2  

Cutting explosives consumption has become even more critical recently with soaring prices for natural gas and agricultural-grade ammonium nitrate hitting explosive prices. Newmont Mining, the world’s second-largest gold producer, said it spent approximately $70 million on explosives last year, but this year expects to pay 16% more.

Drilling is perhaps the most important operation in mining. As Sweden’s Rock Tech Centre (RTC) notes, accurate drilling reduces the mining cost:  

- With accurate drilling it is possible to increase the distance between sublevels and reduce development (the most expensive mining operation)
- Accurate drilling reduces dilution, overbreak, damage and ore losses
- Accurate drilling improves fragmentation and reduces disturbances in the whole mining process from loading to mill
- With accurate drilling it is possible to reduce specific drilling and blasting

The RTC notes the interest in other parts of the world. For instance, CANMET 2004 made a study and as a result, the Canadian mining industry made drilling technology the most important area for research and development. In Australia, accurate drilling and minimising rod handling time has high priority in AMIRA’s Drilling Technology Roadmap.

Guided drilling (used, for example, to drill holes at the intended position) will be instrumental in better fragmentation and increased recovery, lower site characterisation costs etc. The prerequisite for any steering system is to first pinpoint the location of the drill bit, and several options exist. A seismic system is being tested to determine the location of the drill bit but also to provide a rock quality designation by interpretation of the seismic velocity field.

One of the lowest cost methods to produce better fragmentation is to use the proper delay times in the blastholes. Are you using cartridged explosives rather than bulk explosives? The additional explosive that you can place into the blasthole because you are filling the annular space that you would not fill with cartridged explosives will allow you to reduce the drilling cost by expanding the drill pattern.

ITH drilling  
Measurements of production drill holes at Kiruna mine have shown that rigs equipped with Wassara water hammer for in-the-hole drilling are able to drill straight holes, i.e., with acceptable hole deviation. 2  "The results from the measurements indicate a borehole deviation of about 1-1.5% of its length for 54 m long holes. Furthermore, hole deviation occurs in a forward pattern minimising thus its negative impact on blasting and fragmentation. These results indicate that any equipment used to measure hole deviation in long production boreholes at Kiruna should have at least an accuracy of 0.5%.”

Messrs Quinteiro and Fjellborg of LKAB note that further reductions in hole deviation from plan can be achieved by improving the drill rigs’
ability to consistently collar long holes accurately. “It is very important that the rigs are able to drill production holes according to the planned starting direction and co-ordinates. The rigs should be able to be fully anchored in the drift with at least four stingers in order to be very stable while drilling.

“Measurement of hole deviation requires accurate measurement of borehole direction.” Measurements of borehole direction (after drilling) carried out at Kiruna indicate the difficulty in achieving good accuracy, since it is dependent on blasthole wall conditions. They believe that “equipment to measure hole deviation requiring an initial value of drilling direction as input data are not suitable to use in sublevel caving production holes, unless one assumes the planned drilling direction or measures this direction while drilling or find a better way of measuring borehole direction.”

Rockmore International’s new thread system, the XR32, for underground drifting and tunnelling applications, is to replace the standard existing R32 bit-rod connection that has been on the market for several decades. With a stronger more robust design aimed at extending thread life and promoting straighter holes, this innovative thread is reverse compatible with male and female R32 threads. Other options do exist in the market today as replacement to the R32 thread, but they are not compatible to R32 and one must insist on both male rod and female bit thread to be from the same captive supplier. But the XR32 provides technical advantages and may be reverse compatible with the market standard R32 thread.

Extensive lab and field testing has demonstrated the effectiveness of the XR32 thread system in providing more efficient energy transfer, higher bit penetration rates, and longer thread life for both bit and rod. The new XR32 thread is employed at the bit connection end for hex drilling and tunneling rods, and is used for both male and female components - both bit and rod. The other end of the rod, connected to the coupling or shank adapter, has a standard thread such as R38 or T38. That means smooth integration into existing drill strings.

In standard R32 connections, the end of the male rod is seated at the bottom of the bit cavity. As a result, percussive energy travels...
through the rod and bit threads, causing excess vibration and thread wear. The new XR32 connection provides stability at the thread end, reducing stress on the thread connection. The innovative ContactZone design provides stronger rod support, increased rigidity and added strength to minimise rod bending due to complex rock formations or uneven surfaces. This means less wear, higher precision collaring and straighter holes.

**Analysing fragmentation**

Wipware reports mining companies turning to photoanalysis systems for blast quality control. Tom Palangio, President of WipWare, a leading producer of these technologies has spent over 20 years providing applications for just about any type of mining process:

Mine engineers are beginning to realise the importance of quantifying materials being processed, "he says. "If a company can monitor the size of materials being processed, it can then determine the effectiveness of blasts, reduce the cost of energy used by crushers, and ultimately provide a better end product at a cheaper cost."

WipWare is in the process of creating the newest version of the first portable photoanalysis system ever, WipFrag Solo. This device, Palangio says, is an image analysis system that can be moved from one conveyor operation to another in as little as 30 minutes.

Other systems that WipWare provides include WipFrag Momentum, a device used for larger mining operations; WipFrag Reflex, which can detect the size distribution of materials while being transferred on LHDs and trucks; and WipFrag software that allows the user to manually take image samples and have them analysed.

Wipware says the technology provides pin-point accuracy. "Just by looking at the results from our technology, mine operators can see what blasting method was most effective."

The authors note that "the state of the art shows that the design of the layout has a relative uncertainty due to an incomplete interpretation of the phenomenon of the gravitational flow. For instance, some designs show important deformations in the areas of influence of extraction points, with overlaps of ellipsoids in some directions and excessive distances in others, where the ore does not move. This is derived from the priority that designers gives to the ore handling system against others factors such as ore recovery and the minor quantity of dilution even though they do impact economical results."

Analysing Chuquicamata, the concept of the

**Mass mining**

There was, naturally, a great deal of discussion about fragmentation at this June’s MassMin conference in Lulea, Sweden, as in the paper noted above. Another explains how underground mine planning for Chuquicamata has taken rather unique directions, with consideration being given to fragmentation needs determining drawpoint spacing. On one hand a regional fault next to the orebody limits the mineralisation and brings its own unique geological and structural characteristics. On the other hand, the large cavity resulting from a century of open pit operations induces a configuration of stresses and unstable balances in final walls. These conditions have forced a rethink of the designs of the extraction layouts that historically have been used in the other Codelco underground mines.

The authors note that “the state of the art shows that the design of the layout has a relative uncertainty due to an incomplete interpretation of the phenomenon of the gravitational flow. For instance, some designs show important deformations in the areas of influence of extraction points, with overlaps of ellipsoids in some directions and excessive distances in others, where the ore does not move. This is derived from the priority that designers gives to the ore handling system against others factors such as ore recovery and the minor quantity of dilution even though they do impact economical results.”
FragmenTation

diameter of the extraction ellipsoid is being introduced for the design of LHD layout. This element shows that the drawpoint spacing, controlled by material fragmentation, is different from that obtained from material handling system criteria. By keeping this distinction in mind, some recommendations for innovative studies and improvements to the design of LHD layouts can be obtained.

Applying this to a "teniente LHD" layout it is possible to increase the spacing between drawpoints as a way to avoid the overlapping of the extraction ellipsoids of two contiguous points. Dilution and stability can be improved and development costs can be reduced.

At Northparkes mine, "the high stresses present in Lift 2, combined with the fracture frequency and joint spacing in the rock led to the fragmentation observed in the drawpoints being significantly finer than expected. This has undoubtedly contributed to the efficiency of the LHD loading cycles as the loading portion of the cycle was more straightforward than that typically experienced in a block cave drawpoint containing coarse material." Over recent years, several block cave operations have adopted an aggressive approach to drawpoint spacing design in efforts to reduce upfront capital costs and maximise production using large LHDs. The design philosophy has been to space drawpoints as wide as the ore fragmentation will allow drawzone interaction. However, the "current limited ability to predict fragmentation size and the overoptimistic presumption of drawzone interaction has often led to situations where late or no drawzone interaction is the norm, particularly during the early stages of production. Ultimately the consequences of poor draw interaction are often dire and the outcomes are realised as unpredicted cave propagation, rapid breakthrough, early dilution entry, point loading on the extraction level and poor reserve reconciliation, to name but a few." van As and Van Hout examine the shortcomings of spacing the drawpoints too widely apart and attempt to highlight the common pitfalls to drawpoint spacing selection. Finally, they put forward an alternate and more rigorous drawpoint spacing methodology for future block caving projects.

"One of the advantages of a panel cave approach over a block cave is that the effect of fragmentation would not affect maximum production in the same way." It is crucial to be able to predict fragmentation reporting to drawpoints because many block cave engineering decisions are based on this key variable. These can include: drawpoint size and spacing, equipment selection, draw control procedures, operational blasting requirements (hang-ups and oversized), in-draw-column comminution processes, and costs. "Achievable production schedules/budgeting is particularly affected by draw point reliability which is arguably largely controlled by fragmentation." The importance of this issue has resulted in many commercial fragmentation prediction packages for mine planning such as: Simblock, MakeBlock, StereoBlock, Block Caving Fragmentation (BCF), Core2Frag, FracMan [Goldsers], JFKrag among others.

At Grasberg, working for Freeport McMoran Copper and Gold on the transition of the Grasberg pit to underground, Call & Nicholas, Inc (CNI) uses the primary and secondary fragmentation estimates from the Core2Frag analysis, and the mining schedule to estimate fragmentation for mining simulation years. "One of the primary goals is to estimate mining equipment requirements for hang-ups and secondary breakage. Mine engineering and mill groups are, in turn, using these results to estimate crushing requirements for the project. CNI transmits the fragmentation estimates as distributions in a database format. The fragmentation is estimated by both primary and secondary as a function of draw height, and by rock type, alteration type, and mill material zone.

"There is still significant work that needs to be done to better understand, measure, and then estimate fragmentation for block caves. Through future work, a goal of improved fragmentation estimation is to develop the model to a resolution for use in estimating input fragmentation at the mill."

Better blasting
An experimental investigation of blastability has been performed at both small- and full-scale levels by continuous critical burden tests. "A single inclined borehole is drilled into the rock face thus eventually exceeding a technically feasible burden. A useful definition of the 'critical' burden Bcrit can be made by the study of the shape of the breakage area and it is defined by the maximum burden with complete breakage from the hole to the surface and by the shape factor (SF) that approaches a minimum at the same time. It has been shown that Bcrit is primarily a function of the specific charge and the prevailing rock conditions."

"Concerning the optimisation of drilling and blasting patterns, an 'optimum' burden Bopt can be found by systematic analysis. At this burden the specific charge shows a minimum and this
has a positive influence on the size distribution of blasted rock, i.e. less fines.

“Full-scale experiments have shown that at smaller burdens the energy is sufficient for considerable breakage sideways whereas with increasing burden the shape of breakage becomes generally narrower, depending on the actual orientation of the strata. Bopt can be found at the section where the maximum area is obtained under the condition that Bcrit is still not exceeded and over-break ≥ 0 as well as 0 ≤ SF ≤ 1 at the same time. The study of experimentally derived breakage areas at Bopt can be useful in quantifying interactions between adjacent holes and thus be used in the design of spacing. Within operational possibilities the influence of the local rock conditions on the shape of the breakage area should additionally be considered in designing a blast.”

In the Instantel Just for the Record newsletter, Bob Turnbull, Product Manager, explains Signature Hole Analysis and why it is so important. The company’s Signature Hole Analysis software tool can be used to help optimise and improve blast performance. It is a modelling technique used to help control blast induced vibrations. The process involves controlling the frequency content by adjusting delay times within a blast containing several explosive charges. The risk to adjacent structures is thereby mitigated.

This method of simulating waveforms has been around for several years. Today, with the growing adoption rate of electronic initiation systems as a tool to control nuisance vibrations, the modelling techniques are becoming more popular.

Instantel has recently developed and launched a Signature Hole Analysis software tool. This tool will be included in the Blastware® Advanced Module software. These tools allow users to simulate a large number of charge delay times very quickly. All of the simulation waveforms and timeline files are conveniently saved in a user specified project directory for convenient reference and future use. To manually search through all of these simulations for the best result would be a very time consuming and tedious task. To simplify this process, Instantel offers a wide variety of sort options to quickly and efficiently reduce the results down to a manageable number.

Once the sort criterion has been applied to the complete list of waveform simulations, the remaining entries will be displayed in a tabular format. Refining the sort criteria and redisplaying the results only takes seconds. These results can be further sorted by simply clicking on any of the column titles to sort the displayed entries in an ascending or descending order.

When the delay times that best suite requirements have been selected, the simulated waveforms can be viewed to make sure the results look like what would be expected from the associated time delays.

Predicting the result of a mine blast is something of a ‘holy grail.’ “Today, the effects of an explosion are no longer shrouded in mystery,” says Dr Thierry Bernard, one of the key people behind the DNA-Blast model, developed after 15 years experience using explosives to blast rocks in mines. “In order to understand the efficiency of this model, it is first
FRAGMENTATION

useful to describe its structure,” he continues. “Many scientists, blasters, or professors have contributed to finding an answer to modelling the effects of an explosion. Besides, there are many papers, approaches or equations enabling this phenomenon to be described. If these approaches have been, and still are, useful to the profession (e.g. the Kuznam model for fragmentation, or Chapot’s law for vibration), they fail to take into account all the parameters involved in a mine blast or they model the phenomenon in a configuration that is too restrictive to be operational. Thus, for example, the initiation sequence exists in practically none of the models, and yet the use of electronic detonators is widespread today and offers an almost infinite number of combinations.

“...The mechanism that describes the effects of an explosion is complex and is split into a certain number of elementary mechanisms, each one related to the others by links. Therefore, it is possible to describe the overall mechanism modelling each elementary mechanism (called a gene) and the links between them.

“The model, validated by on site measurements regarding fragmentation or vibration, as the case may be, enables a new approach to blast design, in particular thanks to its capability of ‘reverse engineering’ summarised by the expression ‘Objective to Design’, which enables the blast design parameters to be defined in order to attain a given objective.

Without going into great detail, Bernard splits up the description of the effects of an explosion as follows:

1. The charge explodes and is split up into high-pressure, high-temperature gases
2. The gases are applied to the borehole, which contains them and creates a strain field in the rock
3. This strain field, due to its impulsional aspect, creates a strain wave that is propagated in the rock and damages it
4. This damage is the centre of the cracks in the rock
5. Gas pressure is reduced via the cracks thus separating the rock fragments
6. The pressure of these gases applied to the face of the fragments, produces forces that propel the fragments
7. The fragments adopt a ballistic trajectory
8. In areas where the damage to the rock was not sufficient to create fragments, the strain wave continues its trajectory until it runs out of energy that it dissipates by making the rock vibrate.

“When studying the mechanism described above, it becomes obvious that at least with the following genes, it is possible to efficiently model the effects of an explosion:

- A detonating gene (that describes the evolution of the pressure after a detonation)
- A strain wave propagation gene (resulting from a pressure field)
- A wave interference gene (case of several explosive charges)
- A rock damage gene (weakening of the characteristics of the material according to the strain)
- A fissuring gene according to the damage
- A ballistic gene (trajectory of the fragments)

“The contemporary knowledge of these physical phenomena enables us to define these genes easily. All that remains is to model the interaction of the genes. An explosion is a dynamic phenomenon that commences when the blaster depresses the button, and finishes when the rock fragments have hit the ground, and the ground has stopped vibrating. We moved from a pre-blast stable state to a post-blast stable state, having undergone a succession of transient phenomena. The time parameter is therefore part of this overall phenomenon.

“...To take this dynamic effect into account, once the gene interaction has been described, the model works via elementary time stages. At the end of each time stage, the interaction of the genes is updated. Each new time stage takes place, with the initial condition of the state of the previous time stage. This is how the dynamic aspect of the phenomenon is modelled.”

Bernard has validated the model in practice at many mines and quarries around the world. Now, modelling all the effects of a mine blast is a reality today. Thus DNA-Blast Software models the overall effects of a blast, based on a set of elementary mechanisms (genes) interconnected by their common physical parameters, according to time. Consequently, the model offers an approach to the rock fragmentation mechanism, whilst simultaneously modelling the secondary effects, such as vibration, projections or back breaks.

Bernard concludes that “DNA-Blast Software is a unique model taking into account all the key parameters in a mine blast: geology, drill pattern, hole loading, with the quality of the explosive and stemming, and above all the initiation or firing sequence, that is seriously lacking in the present models.

“This opens up new horizons for optimising blasts. Therefore, each blaster, shift supervisor, or manager can now assess the effects of a blasting configuration in terms of the technical result or safety, as well as the financial impact, all with just a few clicks on the Internet. This is also part of the innovation of the DNA-Blast model. (Assessment version, with free access on www.dna-blast.com).

“The final advantage of the DNA-Blast model is its digital feature, linking blasting results with the key parameters of its design, which allows reverse simulations to be carried out. That is to say, starting from the expected results (fragmentation, vibration, fly-rock, etc.), to define the initial implementation parameters (initiation sequence, drilling pattern, stemming, etc.).”

Explosives customers will benefit from the acquisition of Dyno Nobel, one of the great names of blasting, by Incitec Pivot Ltd (IPL) according to
Dyno Nobel President & CEO, Don Brinker.

“Being part of Incitec Pivot will offer our customers the opportunity to be affiliated with a larger organisation offering a broader base and increased security of supply. For Dyno Nobel, the integration will strengthen our ability to provide an enhanced level of service as well as products designed to meet our customers’ needs,” Brinker said.

Dyno Nobel will operate as a discrete explosives business within IPL and the Dyno Nobel brand will be retained along with all products and associated trade names. The global Dyno Nobel headquarters is now located in Salt Lake City, Utah, USA.

Air-decking/plugging

MTi Group, manufacturer and distributor of drill and blast consumables, has released its new Solo BlastBagT borehole plugs. The company says this has “transformed the gas bag market by developing the first ever single-hand deployable, two-speed BlastBag. The fully patented, revolutionary two-speed aerosol latch is the first of its kind and works in all temperatures from extreme heat to extreme cold.” Using the product with one hand requires pressing the trigger with a thumb to the first indent to activate FAST inflation, or press the trigger to the second indent for SLOW inflation. With the cost of explosives sky-rocketing across the globe, air-decking can offer mine’s cost reductions in explosives, improved fragmentation, reductions in backbreak, wall control, reductions in vibration, improved muckpile ‘dig-ability’ and throughput, reduced fines and oversize, etc. (Overall air-deck benefits depend on the application, geology, rock mass, blast design, etc.)

Product marking and branding displays all relevant information pertaining to use, safety and hole size clearly on the outside of every bag. The Solo uses the only completely non-flammable, non-toxic aerosol propellant on the market, and is manufactured with a seamless aluminium aerosol can with a pressure rating of 20 Bar (steel can also available). The Solo is available in eight sizes ranging from 64 through 351 mm. Custom sizes available upon request. IM

References

All papers from the 5th International Conference and Exhibition on Mass Mining, Luleå, Sweden, June 9-11, 2008.

1. Z. X. Zhang, Impact of rock blasting on mining engineering
2. C. Quintero and S. Fjellborg, Measurements of borehole deviation in sublevel caving fans at Kiruna mine
3. E. Arancibia et al, Design of extraction layout for the Chuquicamata underground mine project
4. I. T. Ross, Northparkes E26 Lift 2 block cave – a case study
5. A. van As and G. J. Van Hout, Implications of widely spaced drawpoints
6. Tony Diering, Block cave scheduling with a piece of paper
7. A. Sinuhaji et al, Utilisation of secondary sizing data for improved block cave mine planning
8. E.C. Wellman, D.E. Nicholas and C.A. Brannon, Geomechanics considerations in the Grasberg pit to block cave transition

SEPTEMBER 2008 International Mining 119