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Coming of Age for Low-Density Explosives

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ABSTRACT

Low-density explosives have been developed with trials being conducted for over 20 years and yet have still only gained limited market acceptance despite producing some very promising results. The biggest concern with industry acceptance has been disbelief that a product with lower density than the ANFO benchmark could fragment anything but the weakest of strata. Trials have been carried out with products such as diluted ANFO, low-density ammonium nitrate (AN) and various other mixes, although it has been only recently that low-density explosives have been accepted as a serious alternative to traditional products such as ANFO and heavy ANFO.

The recent uptake of low-density products has been the result of several key factors:

- the current resources boom forcing AN supply issues,
- the development of new handling techniques, and
- a far better understanding of the utilisation of such products.

This paper highlights the benefits of low-density products available in the market and focuses on the situations where low-density explosives can provide the end user with benefits that would otherwise be achieved through more time consuming methods.

Through correct implementation, low-density explosives can provide the blast designer with another option when looking at the optimum method of breaking the rock. This while still controlling the other limiting factors such as cost, environmental impacts (noise, vibration, dust and fumes), coal damage and safety (stable walls).

INTRODUCTION

Low-density explosives (LDE) have had a long time in development, with early studies going back to the 1970s. These early investigations focused on reducing the density of the commonly used ANFO product. The widely accepted line of thinking was that ANFO was the lowest density product available at the time and as such, this would be the ideal starting point from which to construct a lower density product. This has led to many different researchers investigating the characteristics of various formulations to try to arrive at a product that would not only be reproducible in the field, but also be commercially competitive with industry accepted products.

While several LDE products have been commercially available for many years, it has only been in recent years that they have been looked at as a viable alternative to ANFO for all but specialised applications. The main hurdle for LDE has been overcoming the perception that it is not possible to break rock with considerably lower powder factors than used with ANFO.

BACKGROUND

Although studies have continually stated the positive benefits of using LDE, the uptake from industry has been slow – partly because of fear of an unknown product, and a perception that LDE were only suitable for 'weak strata.' The main use for LDE has been for niche applications. One of the other main sticking points has been the large-scale handling of the low-density bulking agent. This has effectively led to an impression that although the results are promising, the ongoing use of the product has been put in the 'too hard' basket by mine operators.

If the use of AN as the primary raw material in an explosives is examined, it too took a while to gain acceptance as a standard product. Ammonium nitrate was first discovered as an explosive ingredient when mixed in with nitroglycerine by Swedish chemists Ohlssen and Norrbin in 1867. Literature also makes mention of its ability to form an explosive when mixed with a hydrocarbon. McAdam and Westwater (1958) document how Alfred Nobel realised the potential value of this type of explosive and acquired the patent rights from his fellow countrymen. These early explosives used AN as an ingredient to be combined with nitroglycerine. However, it wasn't until the Texas City explosion in April 1947, along with other developments in the use of AN, that AN as the primary ingredient started being considered a viable explosive in its own right. Hopler (1993) makes mention of the low cost of AN following the end of WWII during which ten ammonia plants were built for the munitions industry to support the war. This, combined with drilling technology that allowed large diameter holes to be drilled rapidly and cheaply, called for an effective explosive product that could be loaded quickly and easily. By mid-1956, ammonium nitrate was being mixed with fuel oil (diesel), and poured from the bag into the drill hole.

Early references to LDE date back to the late 1960s with the Blasters' Handbook from Du Pont (1969) referring to a Du Pont product named 'Nilite ND' with a density range from 0.45 g/cc to 0.55 g/cc as poured (the ND meaning 'no-deck'). This product:

> *… has proven successful in vertical holes when it has been used as a top load. It has successfully replaced decking in quarry shots and is used where the total charge per borehole must be kept below a maximum weight.*

IRECO had its version of a low-density product available named Isanol, which was essentially an ANFO/polystyrene mixture.

During the 1970s, several investigations into the use of LDE were conducted, in particular the use of Isanol. These culminated in a paper by Heltzen and Kure (1980), which showed that a low-density product could be mixed with minimal segregation that was very effective for contour blasting. The main drawback was the additional handling costs associated with the product if there was only going to be minimal application. However, this study did highlight that an effective low-density product could be delivered that sustained minimal segregation along with no static effects and similar CO and NO_x outputs.

Wilson and Moxon (1989) conducted extensive trials diluting ANFO with various low-density bulking agents including polystyrene, bagasse (sugar cane waste) and sawdust. The main aim of these trials was to '… develop a low-shock energy ammonium nitrate based explosive which could be used to fragment weak overburden materials'. They found that ANFO diluted with different products could be easily mixed, could be made homogenous and had detonation pressures that could be controlled. The final point from this study however, was that '… low-density explosives can lead to significant cost savings without compromising fragmentation or production'.

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In the early 1990s LDE received more attention with Hunter, Fedak and Todoeschuck (1993) investigating the use of an ANFO based LDE in wall control applications. This study looked at a range of densities from 0.36 g/cc through to 0.45 g/cc with a view to reducing ore dilution and minimising damage to the final wall. Other techniques considered at the time were pre-splitting, line drilling and decoupling of charges but were ruled out due to the irregular nature of the geology and the size of the blastholes. The other requirement of this product was its ability to be pneumatically loaded. The result of these trials was a low-density product that could be loaded consistently, that performed reliably and resulted in lower levels of blast induced damage and vibration.

At a similar time Jackson (1993) was undertaking field trials of an emulsion based LDE that was a combination of chemical gassing agents, glass micro balloons and polystyrene beads. Various mixtures were tested to determine the most easily field reproducible as well as the most economically viable. The results from these trials found that powder factors could be reduced by as much as 30 per cent, while at the same time producing similar results in terms of fragmentation, breakage, better wall stability and reduced fines. Again, this provides evidence of very good results from the utilisation of lower density products in areas that would traditionally be blasted with ANFO.

This led to a study by Grouhel and Hunsaker (1995) undertaken in the Hunter Valley region of NSW to determine the viability of LDE products similar to that investigated by Jackson. This study found that similar results to that achieved by ANFO could be produced with a low-density product at a density of 0.6 g/cc. The LDE product trialled was deemed a suitable alternative for the majority of medium to large diameter blastholes (>150 mm) where ANFO was the explosive commonly used.

Several trials were conducted in the Bowen Basin with limited acceptance of an ANFO/sawdust mix as documented by Johnson (1996). This saw reasonable quantities of product utilised to replace ANFO in softer geologies. It described significant cost savings over ANFO while providing comparable results. While this process found some acceptance, its use was limited.

Brent and Armstrong (1998) conducted trials primarily looking at the application of LDE for pre-split applications. Using a very low-density product (0.2 g/cc) in large diameter blastholes (311 mm) at depths of 45 m, the half barrel factor was increased from 32 per cent to 62 per cent purely by having a better distribution of the product in the hole (half barrel factor is the percentage of the blasthole visible following excavation of the shot material). Again this showed the benefits of using LDE products in an ongoing application, but without a significant driver behind its use (a clear benefit to the site being economic, safety or environmental), it was relegated to the trial status.

Rowe *et al* (2001) conducted a study with a variable density product to determine its suitability in soft to medium strength rock types. The primary focus was on the ability to load a lower density product into holes regardless of moisture that didn't require blasting with higher density products. They found a range of products that could be tailored to ground conditions to provide the blast designer with a customised system of explosive delivery without compromising results. This has subsequently been finding gradual market acceptance as industry has gained a better understanding of the utilisation of lower density products. This product has achieved greater success due to its ability to utilise current on-bench equipment (Mobile Manufacturing Unit – MMU) without having additional or purpose built delivery trucks.

Further work on an ANFO based LDE was conducted by Beach *et al* (2004) using wheat husks as the bulking agent with an ANFO base. While this paper reported good results in terms of the LDE employed, it required specialised handling equipment and in the words of the authors '…it is suitable for blasting weak ground with dry holes' and '…is suited to weak strata'. Again, this shows that although LDE can be utilised successfully in a large-scale blasting scenario, without significant investment in dedicated equipment, the ongoing use is limited. At the same time Rock (2004) prepared a paper on the merits of LDE based on a bulked out emulsion-based product. This paper highlighted the strengths of lower density products and the techniques to use when designing blasts for such products. It also put forward some of the theory behind the success of LDE and why it works when conventional thinking says it should not.

As highlighted in several of the papers above for a low-density explosive to be viable both operationally and economically, it needs to demonstrate several main characteristics:

- low-density bulking agent – to reduce the density of the product being diluted the bulking agent is ideally lower than 0.15 g/cc;
- ease of handling – product needs to be as easy to load into the blasthole as the higher density product it is replacing;
- non-segregating – product must be homogeneous when loaded into the blasthole (and not segregate while loading);
- equivalent load rate – equipment must be able to reload and load the same number of blastholes as the product it is replacing; and
- lower cost – the use of a LDE must provide an economic or tangible advantage (such as lower vibration or less caprock) to encourage the mine operator to use the product.

PARTITION OF ENERGY

There have been several research papers on the breakage process due to explosives. When an explosive detonates in a blasthole, the sudden and rapid release of energy produces very high pressures which initiate a fracture network around the blasthole. As this network expands, the pressure in the blasthole subsequently reduces according to the P-V relationship applicable for that explosive in that rock type. Singh (1999) proposed that although much of the energy in AN based explosives is interpreted as heave energy, the utilisation effectiveness is dependent upon the preconditioning of the rock and the extent of the fracture network created by the early stages of energy release and pressure application. A simple, idealistic, static energy release model has been proposed by Lownds (1986) in which the zones are partitioned into the commonly known components – shock, heave and losses. As can be seen in Figure 1, the pressure following detonation rapidly drops off as the explosive expands.

The areas and points in Figure 1 are represented thus:

- potential shock energy – area 1,
- strain energy around the borehole – area 2,
- fragmentation and heave – area 3a,
- strain energy in burden at escape – area 3b,
- lost energy – area 4,
- initial detonation pressure – point P1,
- pressure at end of shock phase – point P2, and
- pressure after which no further work is done on the rock – point P3 (cut-off pressure, usually 100 MPa).

As rock is a brittle material, it will break far more effectively in tension than in compression. In the early stages of energy release, some energy is expended crushing and fracturing the area immediately surrounding the blasthole. Energy is also utilised initiating and extending the predominantly radial fracture network away from the blasthole. Energy is then expended opening up both the natural joints and cracks in the rock mass as well as the fractures developed by the earlier high pressures prior to the bulk motion or heave which is manifest as kinetic energy.

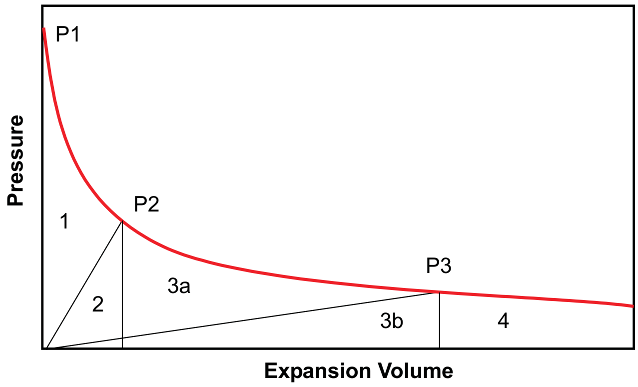

FIG 1 - Partition of energy model (Lownds, 1986).

So whereas conventional thinking has stipulated that higher VOD (and subsequently higher pressure) products produce better results in all but weak strata, this only really holds true for truly massive rock formations with minimal and irregular joint and micro-cracking (such as massive granites). In rock types that display jointing and inherent cracking (such as that found in the majority of coal mining overburden), the requirement for high initial pressures is minimal. As such a more optimal blast in terms of the correct energy for the rock can be provided by products that display significant partitioning towards heave (gas or bubble energy). Figure 2 displays the tapering off of the stress in rock versus volume due to the compression and crushing around the blasthole. This tapering off of the stress in rock is caused by the initial compression and crushing around the blasthole followed by growth of the fracture network and then the movement of the rock mass. The actual interaction point is further along the expansion curve than if it were a purely elastic reaction.

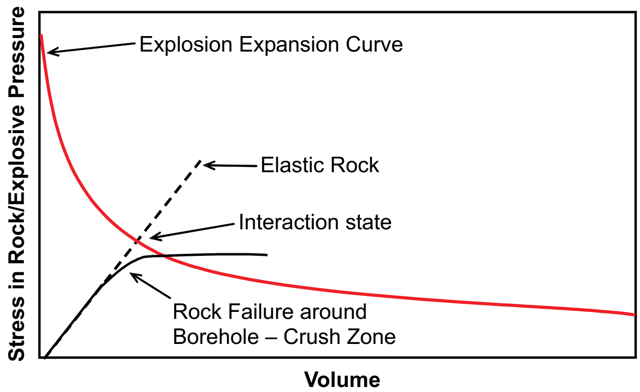

FIG 2 - Plot of pressure in gas and stress in rock versus volume (Lownds, 1991).

Once this interaction point is reached, the heave phase of the process takes over and further fragmentation and breakage is caused by this movement of the rock. As low-density products have a lower VOD, the explosion expansion curve has a lower starting pressure. This lower VOD and initial pressure translates into an increased percentage of the available energy applied during the heave process. A low-density product will still utilise some of its available energy during the initial expansion process, however this is a smaller percentage when compared to ANFO or higher density products.

It should be noted that models such as that proposed by Lownds do not account for the dynamics of blasting. More important than volume expansion, is the rate at which explosive energy is delivered to the rock as this not only controls the stress or strain in the rock, but also the strain rate which can profoundly affect the crack initiation and ultimate fracturing particularly in the near field. Higher strain rates generally lead to more fracturing and smaller fragmentation. Despite having lower detonation pressures, the energy release rate of low-density explosives is very similar to that of ANFO.

CASE STUDIES

Bengalla Mine

Bengalla Mine is managed by Coal and Allied on behalf of Rio Tinto Coal and its partners. It is a low-cost operation in the Hunter Valley producing six million tonnes of coal in 2003 and blasting 19 million bank cubic metres of material. Bengalla is 1.5 km from the township of Muswellbrook and is surrounded by a number of residences as shown in Figure 3. The management of environmental effects including blast induced fumes on its surroundings is of paramount importance to the mine.

FIG 3 - Bengalla Coal Mine with Muswellbrook township in the background.

Historically the mine has used ANFO explosives. However, due to the inherent moisture within its clay based overburden material, suboptimal detonation of ANFO has resulted. If slept for more than 24 hours the deterioration would produce post blast fumes. As a result of this, hole liners were employed to reduce the effect of ANFO deterioration. Although the combination of ANFO and hole liners were cost-effective compared to other conventional bulk emulsion based explosives, issues of reduced on-bench loading productivity and twisted liners within the blasthole resulting in bridged loading were still a concern. There was also a relationship with ANFO and hole liners that had been slept greater than seven days still producing fumes.

The low-density product Flexigel™ CLEAR was highlighted as a suitable replacement product for ANFO and hole liners, to reduce both blasting costs and eliminate fume generation. A series of blasts were conducted between March and September 2004 to explore and demonstrate the suitability of this product at Bengalla Coal Mine. During this period a total of seven shots, 1600 blastholes and 600 tonnes of low-density product were fired successfully. The low-density explosive was used in both partly loaded shots to compare directly against ANFO and hole liners as well as fully loaded shots once confidence in the product was established. Results clearly indicated that Flexigel^{TM} CLEAR did not fume in situations where conventional bulk explosives normally do. In addition to fume reduction Bengalla experienced reduced blast induced vibration and dust generation attributed to the low-density.

With a change in the mining sequence the mine wanted to take advantage of reducing their overburden inventory through the removal of buffer material and to fire their shots with a free face. The buffer material is shot material from the previous blast that slows and dampens the movement of the material thus reducing airblast. A trial blast was fired without the usual safety net of buffer material in front of the shot and the airblast results came very close to exceeding when using ANFO in the front row of holes. Through an investigation involving mine personnel and Orica Technical Services personnel, a design procedure was implemented to reduce the risk of an exceedance.

This investigation highlighted that where conventional explosive products were used, the front row burdens were not insufficient to control the face. This caused a high acceleration rate of the face material, which resulted in an airblast recording close to the site limit.

A design procedure was put in place to reduce the risk of drilling front row burdens that could not be controlled, this involved laser profiling and creating cross sections through every front row hole to ensure that every hole had sufficient burden. However, it was found that with all this in place some holes were still drilled too close to the free face with some burdens being only 2 m. This meant an alternative course of action was required to be incorporated into the procedure to account for small burdens that had already been drilled and were less than design.

When a cross section pinpointed a blasthole or blastholes that had less than the design burden, 0.5 g/cc density Flexigel^{TM} replaced the standard product that was used. Due to the lower Velocity of Detonation (VOD) of Flexigel^{TM} compared with ANFO/other bulk explosives, the face moves at a lower velocity and therefore reduces the chance of exceeding airblast limits.

Hunter Valley Operations

Hunter Valley Operations is an amalgamation of the Howick, Hunter Valley and Lemington mines and is managed by Rio Tinto Coal Australia. The operations produce a total of 12 Mt of domestic and export steaming coal as well as semi-soft coking coal. While the operations are approximately halfway between the townships of Singleton and Muswellbrook, there are still requirements for the blasting program to stay within environmental limits.

As the overburden removal process progresses, blasting adjacent to high voltage overhead powerlines presented dragline scheduling issues due to the size of the shots required and vibration issues. The mining sequence was bringing the shots closer to the powerlines every strip and due to the dip of the seam the depth of material to be blasted was increasing. This resulted in deeper blastholes requiring increased charge weights that limited blast size in order to control ground vibration.

Through the application of 0.5 g/cc density Flexigel^{TM}, the blast lengths were increased from 100 m to 200 m in length while still maintaining the charge weight per delay requirement stipulated by the site. Ground vibration was required to stay below 50 mm/s at he power line towers (150 m at the closest point) to comply with the mining lease conditions. The results from the blast halved the vibration levels compared to previous shots recording 25 mm/s which were the lowest levels recorded in that area.

Newlands Coal Mine

Newlands Coal Mine, owned and managed by Xstrata Coal, is in the northern part of Queensland's Bowen Basin, 130 km west of Mackay, and 32 km north-west of Glenden. The coal is a high quality, medium volatile, low sulfur steaming coal that varies between 5.5 and 6.5 m thickness. It is mined from underground and open-cut operations that together produce seven million tonnes of washed coal per year.

In 2004, Newlands opened its Suttor Creek deposit, mining 16 million bank cubic metres to uncover a total 2.7 million tonnes of coal annually. The overburden material consists of a combination of claystone and siltstone and is mined using a BE1370 dragline fitted with a 37 cubic metre scoop bucket. Blasted material must be both well fragmented and loose to provide optimum digging performance. Historically the mine has blasted this material using ANFO, with Energan 13 (density 1.3 g/cc) toe charges. Blasting in these conditions produced significant post blast fumes. The Suttor Creek deposit was highlighted as a suitable pit for using low-density explosives and in particular Flexigel^{TM} Clear to replace ANFO and Energan explosives to reduce both blasting costs and fume generation.

Blasting with Flexigel^{TM} low-density explosives began in Suttor Creek in September 2004. The mine has reported that the blasted material presented to the dragline has been excellent, dragline productivity was very high for this machine achieving between 50 - 60 thousand bcm per day showing low wear rates on the bucket. This combined with the absence of visible fumes resulted in very favourable feedback from the mine.

BENEFITS OF LOW-DENSITY PRODUCTS

Based on previous work published by various authors, low-density explosives have been utilised in the following situations:

- Reduction of toe in coal mining – being able to drill every blasthole to coal or reduce coal stand-off to ensure all toe material is blasted.
- Protection of coal – minimal shock energy prevents the product from damaging the coal roof.
- Reduction of caprock – lower VOD allows stemming to be reduced, thus placing product in the zone where cap material is produced.
- Protection of walls – using lower VOD products in pre-split can improve wall conditions considerably. Reduced back break allows some pre-splitting to be eliminated altogether.
- Management of environmental results – in side by side comparisons with ANFO, low-density products have reduced both vibration and overpressure by around 30 per cent.
- Cost benefits – by utilising a lower density product, fewer kilograms of explosives are loaded into the blasthole.
- Reduction of fines – because low-density product is heavily partitioned away from shock energy, the area around the blasthole that is normally crushed is reduced.
- Absence of fumes – formulation and lower VOD ensures complete consumption of all components within the blasthole, fumes have been all but eliminated with Flexigel^{TM} CLEAR.
- Density on demand – a continuous mix product such as the Flexigel^{TM} range, has the ability to vary the density being loaded into the hole to allow for changing rock types.
- Moisture resistance – A high emulsion content product such as Flexigel^{TM}, has the ability to withstand moisture where ANFO based low-density products cannot.

DISCUSSION

If the uptake of low-density products is looked at closely, there are several factors that have contributed to its recent increased use:

- Increased understanding of application – with knowledge of the product and how to apply its unique characteristics, the product can be utilised to great advantage.
- Increased investment in capital – with both mining companies and explosives supply companies showing keen interest in the development of this product, capital has been invested to provide the opportunity to deliver at sustainable production rates.
- Current market trends – with current resources upswing, the supply of raw materials have become increasingly stretched. This has led the industry to look for other options to maintain and in many cases increase production. The use of low-density products has largely focused on ground that has typically been blasted with ANFO.

The time between the initial development and large-scale application of LDE has taken some 40 years. If this is compared with the initial recognition of ammonium nitrate as a blasting agent and its application, which took nearly 80 years, the use of LDE has rapidly gained acceptance.

CONCLUSIONS

Low-density explosives such as Flexigel™, offer explosive users an opportunity to enhance their current selection of blasting products. The advantages of reduced product consumption and increased control are significant in themselves. Combine this with moisture resistance and density on demand LDE such as Flexigel™, provide the blast designer with a product that can be used to complement more established products.

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REFERENCES

Beach, F, Gribble, D, Littlefair, M, Rounsley, R, Testrow, I and Wiggin, M, 2004. Blastlite – the practical low-density solution, in *Proceedings Explo 2004*, pp 147-152 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Brent, G F and Armstrong, L W, 1998. Large diameter presplitting improved through two novel techniques, in *Proceedings ISEE Annual Conference 1998*, pp 511-520 (The International Society of Explosives Engineers: Cleveland).

Dupont, 1969. *Blasters' Handbook*, p 57 (E I Du Pont de Nemours and Co, Inc: Wilmington).

Grouhel, P H J and Hunsaker, R D, 1995. An introduction to a revolutionary low density bulk explosive for surface blasting operations, in *Proceedings Explo '95,* pp 67-71 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Heltzen, A M and Kure, K, 1980. Blasting with ANFO/polystyrene mixtures, in *Proceedings ISEE Annual Conference 1980*, pp 105-116 (The International Society of Explosives Engineers: Cleveland).

Hopler, R B, 1993. History of the development and use of bulk loaded explosives, from black powder to emulsions, in *Proceedings ISEE Annual Conference 1993*, pp 177-198 (The International Society of Explosives Engineers: Cleveland).

Hunter, C, Fedak, K and Todoeschuck, J P, 1993. Development of low density explosives with wall control applications, in *Proceedings ISEE Annual Conference 1993,* pp 549-554 (The International Society of Explosives Engineers: Cleveland).

Jackson, M M, 1993. Low strength water gel explosive, in *Proceedings ISEE Annual Conference 1993*, pp 493-499 (The International Society of Explosives Engineers: Cleveland).

Johnson, R J, 1996. 'SANFO' 'The missing link' in explosives technology, in *Proceedings ISEE Annual Conference 1996*, pp 242-252 (The International Society of Explosives Engineers: Cleveland).

Lownds, C M, 1986. The strength of explosives, in *The Planning and Operation of Open Pit and Strip Mines* (ed: J P Deetlefs), pp 151-159 (South African Institute of Mining and Metallurgy: Johannesburg).

Lownds, C M, 1991. Energy partition in blasting, in *Third High-Tech Seminar on Blasting Technology, Instrumentation and Explosives Applications* (Blasting Analysis International: San Diego).

McAdam, R and Westwater, R, 1958. *Mining Explosives,* pp 4-5, 27-28 (Oliver and Boyd: Edinburgh).

Rock, J, 2004. Improving blasting outcomes using Softload low-density explosives, in *Proceedings Explo 2004,* pp 153-158 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Rowe, J L, Goodridge, R, Stow, D and Molloy, K J, 2001. Variable energy explosives for soft ground blasting, in *Proceedings Explo 2001,* pp 111-113 (The Australasian Institute of Mining and Metallurgy: Melbourne).

Singh, S P, 1999. The effect of shock and gas energies on the rock fracturing process, in *Proceedings ISEE Annual Conference 1999,* Vol I, pp 397-406 (The International Society of Explosives Engineers: Cleveland).

Wilson, J M and Moxon, N T, 1989. The Development of a low shock energy ammonium nitrate based explosive, in *Proceedings ISEE Annual Conference 1989,* pp 297-308 (The International Society of Explosives Engineers: Cleveland).