A COMPARISON OF NON-EXPLOSIVE ROCK BREAKING TECHNIQUES

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SYNOPSIS

Increasing pressure on mining and related industries has led to the investigation into methods of excavation that will reduce the impacts on the surrounding environment. This may be because of environmental concerns, the proximity of residential areas, areas of cultural heritage or particular sensitivity, such as schools or hospitals. This has led to an escalating number of products on the market claiming to reduce the affects noise, vibration, dust and flyrock, as well as other advantages.

Non-explosive technology is currently experiencing a boom. Three products that have been around for some time, and are now coming to the forefront of the market are Cardox, Nonex and Penetrating Cone Fracture (PCF). These products have been selected to be the focus of this comparison study because of their current popularity and increasingly widespread use for a range of situations. The comparison study is aimed towards quarry and mining personnel intending to use a non-explosive product for rock breakage, but not sure which product suits their situation best.

Each product works on a slightly different principle, but the main similarity is that they all use high pressure gas with which to break the rock. The Cardox system is based on liquid Carbon dioxide being converted to high pressure carbon dioxide gas with ignition. The gas spreads through fissures and microcracks in the rock and breaks it in tension, rather than compression as with explosives. It is this tension breaking mechanism that results in the reduced noise, vibration and flyrock characteristics. Much less energy is required to break the rock in this way, and therefore less must be dissipated on breakage. Both the Nonex and PCF products are based on the burning of a propellant, releasing many gases at high pressures, again breaking the rock along existing fractures to break in tension.

The efficient use of non-explosive rock breaking techniques will make the concept of underground space a more viable option in our cities where underground space will demand a premium in the short term future. Underground space is an increasingly popular option for carparks and storage areas in many highly urbanised areas and these non-explosive methods are one of the most applicable methods to use in its excavation. These areas are usually subject to stringent regulations with regards to disturbance of the area and any products that release very little noise and vibration are welcomed.

Testing has been conducted and various characteristics of the blasts measured and recorded in order to assess the characteristics of the blasts for each product.

1 PRODUCT OVERVIEW

1.1 Cardox

Developed over 60 years ago for use in explosive coal seams in the UK, the Cardox system consists of a high-strength, reusable steel tube filled with liquid carbon dioxide, a chemical energiser, and a rupture disc. When the Cardox tube is ignited, the carbon dioxide is almost instantaneously converted from a liquid to a gas. Pressure is released from the gaseous CO_2 up to 300mpa (3000 bar), it expands through microcracks and fractures the rock. The pressure can be regulated between 1200 and 2800 bar by using rupture disks. Figure 1 shows a schematic diagram of the components which make up the cartridge. The body is filled with liquid CO_2, a safety heater inserted in the firing head, a rupture disk in the discharge end of varied thickness to regulate pressure. A nylon collar is used to hold the cartridge in place so no stemming is required. The chemical energiser is activated by a small electrical charge which causes detonation.

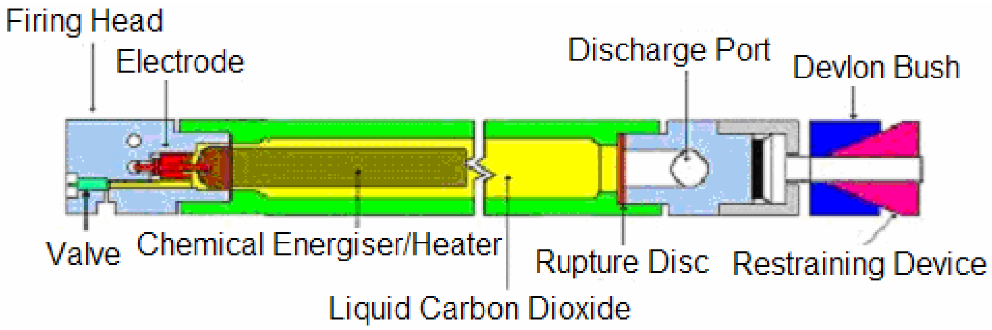

Figure 1: Schematic diagram of Cardox

There is no risk of igniting any gas present in the area of use as all combustion is carried out within the sealed Cardox tube. When the gas is released at such high speeds, it has the additional advantage of a refrigeration affect, which brings the temperature low enough as to ensure that any gas/air mixture could not ignite. Cardox has many specialised applications such as rock and concrete breakage, deep sea excavation, tunnelling and shaft sinking and trenching and excavation. Cardox has been used successfully within a metre of services lines underground with no damage to the services at all. It also has applications in removing hang ups in silos and bin systems.

Cardox is not classified as an explosive, but rather as a high pressure gas generator. As such, it is not bound to the same restrictions as explosive products. Cardox tubes are reusable, by replacing the chemical energiser, rupture disk and gasket, and by refilling with Carbon dioxide the tubes can be reused many times. If the nylon collar becomes worn, it can also be replaced. Reusable tubes save on consumables and help to eliminate the possibility of being caught short without cartridges. The recovery of tubes subsequent to firing must be considered as part of the cycle. Logistically small projects will require either many charged tubes, or nearby location of recharge setup. All Cardox tubes are of a standard size requiring a 57mm diameter hole, differences in pressure are altered by the rupture disks only. The standard tube size reduces the flexibility of hole size, and due to the collar instead of stemming allows very little tolerance in hole diameter. The 57 mm hole size also does not lend itself efficiently where hand drilling is required. The hole depth must be taken into consideration as the discharge points are not located at the end of the cartridge. Cardox provides good fragmentation and breaks the rock into large, easily managed pieces with minimal fines. The product works efficiently in shaft sinking where there is no free face with very little noise or vibration produced.

1.2 Nonex

The Nonex system has undergone extensive research and development in the UK and Spain. In the UK it has a niche market for particular use in slate mines where it is necessary to keep large slabs of the rock intact, and also for the breaking and removal of slate from within the mine shaft. The Nonex system consists of a cartridge which contains a propellant which when ignited produces high volumes of harmless gases such as nitrogen and carbon dioxide are released, providing a pressure increase when the cartridge is sealed in a drillhole. Nonex is particularly suited in situations where the rock is not required to be fractured, but rather, split as it does not cause the rock to shatter. Nonex is classified as a 1.4S pyrotechnic rather than as an explosive. This has a major impact on insurance premiums and they are much lower for sites which use Nonex exclusively over conventional explosives. The product is electrically initiated, and the ignition system is built in to the cartridge. The product is water resistant, which is another advantage over many conventional explosives.

1.3 PCF

The PCF tube is a hollow plastic tube, open at one end which can then be filled with the powdered smokeless propellant and then closed with a small cap. The other end is machined into a wedge to lock into the stemming, and to seal the hole when inserted for ignition. In the cap there is an entry port for insertion of an electric match, which is the means of detonation. This heat ignites the propellant. As there are not the crushing effects of compressive breakage as with explosives, dust and fines are significantly reduced. As the rock requires less energy to break in tension than compression, a much smaller energy input is recquired. A 200 g charge of PCF blasts the same volume of rock as does 1.2 kg of explosive charge, whilst releasing one tenth of the energy. The product has been found to be particularly useful in deep South African mines as it’s low toxicity reduces re-entry time in these hard to ventilate mines thus improving productivity by up to 40 % (Minesite News, 2000). Some gas is produced from the combustion of the cartridge, for PCF, the majority of the gases produced are carbon dioxide, water, nitrogen, carbon monoxide and hydrogen. The main problem gases which are detectable are carbon monoxide, and nitrous oxide which also occurs at low levels. The addition of a very small amount of ANFO prill does increase the toxic fumes from the product, but still below minimal levels in modern ventilation systems. This gives the product a little extra power to fragment the rock. The product also has the ability to enable users to have more control over the accuracy of the excavation profile and drive perimeters. PCF has also been used in floor stripping, back stripping and side wall stripping in a number of mines in Australia, particularly when a larger equipment size is required and minimal disruption to underground operations is essential. By altering the position of the charges in the holes the products flexibility allows for the rock to be fractured or split. PCF can also be used for the clearing of block grizzlies, crushers or chutes, or anywhere else where oversize is a problem. The classification for PCF is 1.4S pyrotechnic, as an added safety precaution, the electric match used for detonation is inserted right before firing.

2 RESULTS

2.1 Test Case 1 – Cardox for tunnelling and shaft excavation

Cardox was used by Millenium Mining and Construction as sub-contractors to McConnell Dowell in the sinking of a 4.5 m diameter (16.5 m length) to 5.5 m diameter (3.1 m length) shaft near the William Jolly Bridge as part of the Heroes Avenue sewerage system. Average advance rates in the 19.6 m deep shaft were 0.9 m per firing and only 23 holes were required for each round advanced (in three stages). Figure 1 shows the results of a Cardox blast in sinking the shaft. Excavation was by a 2t excavator, lowered into the shaft by a crane. Figure 2 shows the completed shaft. Key statistics from the first Australian shaft to be fired with Cardox were:

- 460 tubes fired.
- Average yield for each Cardox tube was 0.75 m^3.
- 7 tubes bent but all were straightened and returned to service.
- Vibration levels very low (claimed 0.002 mm/s at 0.5 m from shaft collar).
- Two shaft doors were placed over the shaft collar during firing.

Improvement of the system for further shaft sinking would include:

- Working continuously on two shifts.
- Use remote drill operation from the excavator.

Figure 1: After firing of the shaft using Cardox

Figure 2: The finished shaft

2.2 Test Case 2 – PCF in controlled testing

- **Concrete**

The block split into four approximately equal larger pieces and four smaller but still significant smaller pieces. There was minimal fines and small fraction produced. The throw on this blast was much greater than on any of the previous blasts, with large fragments landing up to 8.4 m away. One fragment from the blast is shown in Figure 3.

Figure 3: A fragment from the PCF blast of concrete

- **Sandstone**

The throw was not particularly far for this blast with all major fragments staying within 3.5 m from the site of initiation. Three of the blocks were of relatively even size, with another couple of smaller ones that were significant. There was barely any small fraction produced.

- **Greywacke**

Two blocks of Greywacke were blasted simultaneously using a 60 g PCF cartridge for Block One and a 30 g PCF cartridge for Block Two. Block one was larger, and was charged with the larger cartridge, and was split into four pieces. Block Two split in three large pieces, one the size of half of the original block. Block Two also produced four to five small pieces about 20 x 10 cm. Minimal fines were created.

2.3 Vibration and Overpressure

Table 1- Vibration and overpressure readings

At 20m from source

Blast	Cartridge	Vector	Over-pressure	Radial	Transverse	Vertical
PCF Concrete	60g	2.48	129.8	2.12	-1.63	-0.57
PCF Sandstone	30g	-	-	-	-	-
PCF Greywacke	30g + 60g	1.76	136.8	-1.65	0.57	-1.21

At 30m from source

Blast	Cartridge	Vector	Over-pressure	Radial	Transverse	Vertical
PCF Concrete	60g	0.209	101.3	-0.133	-0.209	-0.063
PCF Sandstone	30g	0.879	139.4	-0.734	0.683	-0.443
PCF Greywacke	30g + 60g	0.727	140.1	0.67	-0.658	-0.481

The values in Table 1 are the raw data collected from the Texcel µMX vibration monitors.

2.4 Noise

Table 2 - Noise measurements

At 30 metres from source

Blast	Cartridge	LAmax	Peak	SEL	Leq 60 sec	Leq 1 sec
		dB(A)	Lin	dB(A)	dB(A)	dB(A)
PCF Concrete	60g	83.2	119.3	84.8	67.1	84.5
PCF Sandstone	30g	82.3	119.3	84	66.2	83.6
PCF Greywacke	30g+60g	91.6	122.1	93.3	75.6	90.4

At 60 metres from source

Blast	Cartridge	LAmax	Peak	SEL	Leq 60 sec	Leq 1 sec
		dB(A)	Lin	dB(A)	dB(A)	dB(A)
PCF Concrete	60g	79.9	118.7	82.7	65	81.3
PCF Sandstone	30g	77.8	119.9	79.6	61.9	79.3
PCF Greywacke	30g+60g	86.7	121.5	89.1	71.3	86.8

Table 2 shows the raw data collected relating to noise from the blasts. shows the change in noise level with doubling of distance using the Leq 1 sec data as it is the most accurate to use for comparison. Theory says that a doubling of distance should result in a 3 dB reduction in noise level, these average a 3.4 dB reduction, which is close. There is a possibility that the slight breeze noted on the day was responsible for corrupting some data, as there are some louder noise readings at the further distant site.

PCF seemed to be a flexible product which could be used to split the rock or fragment it by adjusting the depth of hole and stemming methods.

3 CONCLUSIONS

The theory of nine non-explosive rock breaking methods has been reviewed. Two of these methods have been evaluated in practice by monitoring and testing. This experimental work has exhibited the mode of breakage for each of the products and enabled identification of appropriate applications for each.

In general, the products fulfilled expectations as claimed by the manufacturers. The fines produced were minimal which is advantageous where dust is to be minimised for OHS reasons, and has advantages in the dimension stone industry where specific block sizes with minimal fragments are required. Observations indicated that all three products produced significantly less noise, vibration, and overpressure than conventional explosives, though this could be confirmed by further investigation using traditional blasting to compare with the non-explosive methods.

REFERENCES

1 Accurateblasting.com, 2003, http://www.accurateblasting.com/accessories/nonex.html Breaking rock or concrete in enclosed areas is no longer a problem, July.
2 Anon, 1995, ‘Cardox system brings benefits in the mining of large coal’, *Coal International*, 243 (1):27-28.
3 Anonymous, 1993, ‘Surgical Ore Removal’, *Canadian Mining Journal*, pp10 – 13.
4 Brandrill Limited, 2004, RocKracker CD.
5 Brandrill, 2003, http://www.hatch.ca/Mining_Mineral_Processing/Articles/031.pdf, July.
6 Cardox International Limited, 2000, http://www.cardox.co.uk/mining.htm, July.
7 Cardox Systems, http://www.cardox.co.uk/mining.htm, July.
8 Endeco Ltd Cardox Blockage Clearing System, http://www.tmp43915.atomnet.pl/html/uk-cardox.html, July.
9 Flanagan D., 2004, Personal Communication, October – November.
10 Millenium Mining and Construction Services, 2004, http://www.millennium-mining.com.au/, July.
11 Millenium Mining and Construction Services, 2004, MMCS and Cardox CD.
12 Minesite.com incorporating MINEWS, 2000, http://www.minesite.com/archives/news_archive/2000/nov2000/brandrill-12.htm Brandrill goes from strength to strength on non-explosive technology, July.
13 Muehling E., 2004, Personal Communications, July – November.
14 Nairn J., 2004, Personal Communication, September.
15 Nonex Systems Ltd, 2004, http://www.nonex.co.uk/index.html A New Concept in Rock and Concrete Blasting, July.
16 Robertson A., 2004, Personal Communications, March – November.
17 Rockbreaking Solutions, 1998, http://www.brandrill.com/rockm.htm, July.
18 RockTek USA LTd, 2001 , General Introduction to PCF (Penetrating Cone Fracture) Rock Excavation
19 Tennent Isokangas Pty Ltd, February 2004, ‘Cardox Alternatives to Explosives’, *TIP’s Tips*
20 Thorne B., 2004, Personal Communications, August – November.
21 West K., 2004, Personal Communications, July – November.