Shotcrete in North American Underground Mines: Yesterday, Today, and Tomorrow

by Mike Rispin and John Brooks

Carl Akeley began the process of guniting, or what is now known as shotcreting, sometime around 1907. Since shotcreting subsequently found its way into underground mining operations, it has undergone an evolution through the 20th Century to where we find the process being used today in North America and elsewhere in mining around the world.

As we look at the progress of shotcrete in North American underground mines, it becomes useful to break down the process into five distinct parameters: mix design, equipment, logistics, applications, and operators; for discussion of each.

While some of our current practices have established a benchmark for others to emulate, we also stand to learn from the practices of the rest of the mining world. However, whatever perspective one takes of the current state of affairs, shotcrete is an important part of ground support in modern mining applications, and its use and effectiveness will continue to grow as we tackle the challenges that mining brings us in the 21st Century. Shotcrete, or sprayed concrete if one prefers, has a bright future in underground mining, indeed....

YESTERDAY

Concreting in underground mines has in the past been treated, to a certain extent, more or less as a necessary evil, from operation to operation. The possible exceptions to this generalization have been the mines using block caving, where the ground conditions and mining methods have dictated a more systematic, quality driven approach to placing concrete.

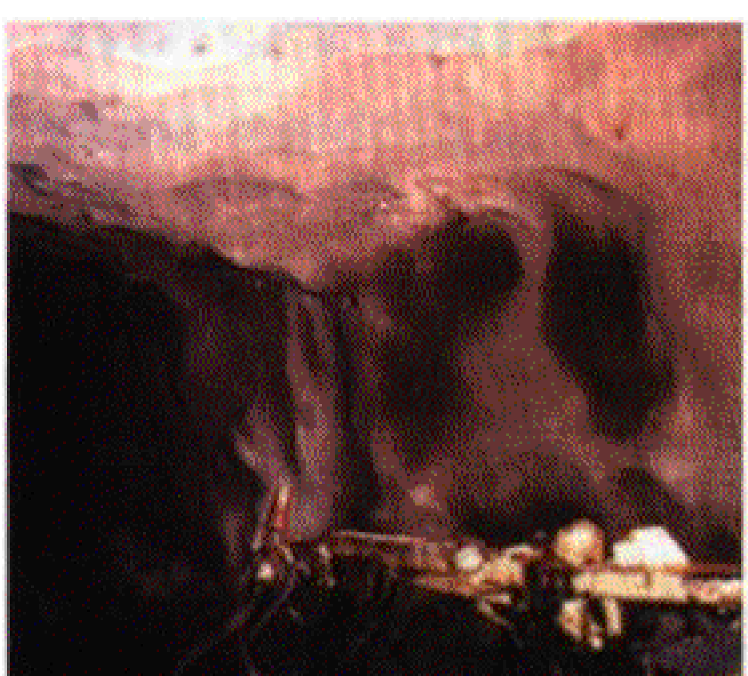

Figure 1. Fiber-reinforced shotcreted heading in a state-of-the-art underground mine.

While differing somewhat from cast-in-place concrete, sprayed concrete or shotcrete has had a similarly shady past in mining.

The history of shotcrete in North American mines reveals an overwhelming use of the dry-mix placement method. The odds are that many mining readers (over the age of 35) first exposure to the process of shotcreting involved a small bowl or rotary barrel gun, "hand bombed" paper wrapped bags roughly 22.5 kg (50 lb) in weight, and a very dusty mining environment replete with ricocheting aggregate rebound anywhere up to and above 10 mm (0.38 in.) in diameter! While this is not true in all cases, war stories seem to indicate a predominance of this experience. It's no wonder that "contracts" for shotcreting among the mining workforce at any particular operation were viewed as being the lower end jobs, and as such often ended up in the hands of the miners with the least seniority or less than exemplary work records.

As the shotcrete applications were typically in ground support rehabilitation, or in some cases, construction projects, they were discontinuous in nature. Combine this with the stigmas attached to shotcreting detail and the pecking order within the workforce, and nozzleman skill development and training logically did not form a key part of the mine's priorities.

TODAY

The use of shotcrete in mining operations increased steadily through the 1980s and '90s to where it is today: a vital part of ground control and an increasingly dynamic construction tool. Annual volumes of shotcrete, both wet-mix and dry-mix, are estimated to be well in excess of 200,000 m^3 (261,000 yd^3) in North American mining.

Materials, Mix Design (Dry-Mix, Wet-Mix)

The majority of the volume of shotcrete placed in North American mines remains, to this day, to be placed by the dry-mix method. The material is typically moved underground, preproportioned in large sacks or "bulk bags" (1000 kg [2200 lb]), stored in central locations, and eventually transported to the workplace for spraying. Applications have expanded to include dry-mix shotcrete being used more proactively as a system in a ground control scheme.

The trend, however, for mines using larger volumes (typically in excess of 3500-4000 m^3 [4575-5200 yd^3] per year) of shotcrete, is to the wet-mix method. This is driven largely by the cost savings that can be reaped from the wet-mix application, principally due to the reduction in rebound, higher volume throughput of material, and savings in materials handling. Other benefits such as consistency of quality and fiber reinforcement efficiency will be discussed in a later section of this article.

This trend to wet-mix in North America emulates that seen elsewhere in the mining world. In Australia, for example, over 95% of the mining industry's shotcrete volumes are wet-mix (Brooks 1998). In addition, in South Africa, even with the logistical challenges of deep mining, mine operations are adopting wet-mix at a rapid rate.

Mix design has essentially remained the same over the years, with the industry seeing refinements in raw material gradation control as well as the addition of silica fume for workability, durability, cohesion, and reduced rebound. The development of admixture technology, however, has played a very significant part in making wet-mix shotcrete highly user friendly in an underground mining environment.

Concrete/cement stabilization technology exists today which allows the concrete to be "put to sleep" at the point of batching, retaining freshness of the concrete and delaying binder hydration until being "reawakened" at the nozzle with an accelerator. Unlike traditional retarders, the stabilizer acts on all four phases of binder hydration (as opposed to one or two) with no detrimental effects on final concrete properties.

Today's powerful combination of ultra-high-range water reducers and alkali-free accelerators allows slump retention and workability in the mix, with true set acceleration at the nozzle, yielding excellent substrate cohesion, layer thickness buildup in excess of 250 mm (10 in.) if required, and high early bond and compressive strengths, without sacrificing ultimate in-situ concrete properties.

Other admixture technologies, such as internal concrete improvers and shrinkage reducers, are available and used today as well. The concrete improvers offset the traditionally poor curing conditions and practices seen in underground mining, improving bond and reinforcement interaction while reducing shrinkage and cracking. SRAs, or shrinkage reducing admixtures, have a more profound effect on shrinkage reduction and cracking, important where watertightness, reduced porosity, and crack avoidance are important.

Equipment

Dry-mix equipment in North American mines consists now largely of rotary barrel guns of various shapes, sizes, and makes, typically spraying shotcrete in the range of 3-4 m^3/hr (3.9-5.2 yd^3/hr). The system placement capacity is not constrained as much by the gun itself as by the manipulation and feed from the bulk bags; 10 of these per hour is generally considered good performance.

While predampeners are highly recommended for effective dry shotcreting, and a number of operations have implemented these into their daily operations, the tendency for mines is to avoid them for reasons of workplace size constraints, the need to maintain an additional piece of equipment, or capital cost constraints.

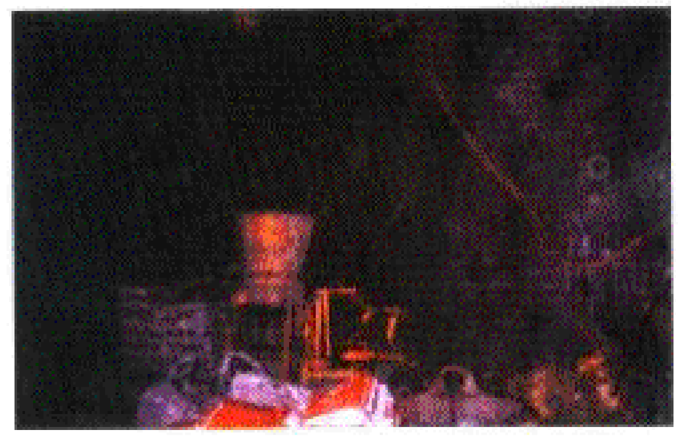

Figure 2. Old-time mining shotcreting: a dry pot and bagged product.

Wet-mix equipment is predominantly a double cylinder swing-tube pump, with a manufacturer's nominal rating between 15 and 27 m^3/hr (20 and 35 yd^3/hr). Given operational constraint in the mines, this equipment will typically produce between 12 and 15 m^3/hr (16 and 20 yd^3/hr). The primary advantage of the swing-tube configuration is to limit the pulsation of the shotcrete at the nozzle.

The preference for wet-mix accelerator dosing systems is either a peristaltic or progressive cavity pump, ideally synchronized to the working of the shotcrete pump so that the concrete receives an even, prescribed dosage of the accelerator of choice.

The trend for both dry-mix and wet-mix systems is to mount the spraying equipment on mine-worthy rolling stock complete with spray boom, accelerator tank, and in many cases, an on-board compressor (recommended). The units are generally electric/hydraulic or diesel/hydraulic, and as self-contained as possible, requiring as few service (power, water, air) hookups in the workplace as possible.

Robotic arms are a key component of today's shotcreting operation as they allow the shotcrete to be placed efficiently on "unsupported" ground, without ever having to put manpower under such ground, which would be a violation of mining principles and regulations.

Logistics

While the progress in equipment, particularly rolling stock, robotics, and now also automation, has been impressive, the evolution of logistics has not been quite as commensurate. As impressive as a spraymobile may be, an operation will not yield all potential efficiencies without being good at "feeding the beast." Getting your shotcrete to the workplace and through the equipment is an art in itself, and due to the nature of underground mining, varies from operation to operation.

Large bags for preproportioned dry-mix have been a tremendous improvement over the small sacks, but it is also typical for a mine to handle such large bags anywhere from seven to nine times from point of arrival on-site to point of placement. While these costs are not easily accounted for, they do add up rapidly and mines are becoming more aware of them. This is translating into a trend to bulk, whether dry or wet-mix.

Shotcrete is an engineered blend of binders,

Figure 3. Underground mining shotcrete spraymobile.

aggregates, water, and admixtures. The terms "dry-mix" and "wet-mix" define the state or process of these materials as they are being shot. How they are proportioned, where, whether in one, or a number of intermediate steps; whether on the surface or in the mine, are just some of the questions pertaining to the permutations in which shotcrete finds its way to the working face. Discussing all the options in depth goes beyond the scope of this article, but suffice it to say that the final method chosen will depend on the configuration of the mine operation, availability of materials, means of transportation, and targeted volumes of material placed.

Options include, in addition to the prepackaged concept mentioned above:

- Bulk containers;
- Transmixers;
- Mobile mixers;
- Cased boreholes;
- Slicklines; and
- Combinations of the above

There is no textbook "right way" but the goal of the operation should be to do it as economically as possible and this usually means to handle it as few different times as possible. For this reason, in mines that don't have surface ramp access, boreholes and slicklines are becoming increasingly popular for transferring the material underground— particularly wet-mix. It has been proven time and again around the mining world that ready-mixed material can be dropped a long way (case studies demonstrate over 1830 m [6000 ft]) with no detrimental effect to the mix, provided that it has been properly designed.

Applications

The most exciting aspect of shotcreting in mines today is the degree to which concrete technology has become much more widely accepted and respected in the underground environment, and the applications in which innovative mining operations are using it today.

Shotcrete has grown from a tool for sporadic rehabilitation and construction projects, to a vital integral component of day-to-day operations, including:

- Rehabilitation;
- Mine floors and roadways;
- Backfill fence construction;
- Shotcrete pillars in large mine openings; and
- Primary or secondary ground support as part of the development process.

It is now being appreciated for its inherent ability as a process to place material quickly, effectively, safely, and with high quality, resulting in durable and functional mine installations that require far less rehabilitation than was heretofore expected and which form environments conducive to productivity for the rest of the mining operation's cycle.

Shotcrete is replacing other more conventional forms of ground support, such as bolts and wire mesh, at a number of progressive operations (O'Hearn, 1997). Fiber reinforcement, whether steel or synthetic, provides requisite ground support for a great diversity of ground conditions, while offering efficiencies in applications such as rapid, single pass ground support application. More and more mines are looking to utilize shotcrete as an integral ground support component of their tunnel development cycle.

Operators

Operator, or nozzleman, skill levels have improved dramatically within the industry. Technical developments in equipment, as well as the proliferation in shotcreting, have led to the position of a nozzleman being a more desirable one on mine property. This has led, in turn, to a more stable shotcreting workforce, where day-to-day experience and systematic training programs have yielded a generation of quality nozzlemen, skilled not only in spraying shotcrete but also in the further "art" of shotcrete ground support in an underground mining environment.

Industrywide training programs, such as the one mentored and sponsored by the ASA, are critical to ensuring that nozzlemen have the shotcrete knowledge required. Further, complementary ground control training is offered by mining industry organizations such that key individuals, from nozzleman to production shift boss to chief mine engineer, receive the blend of practical and theoretical knowledge required to ensure a fuller understanding of shotcrete/rock interaction, and the importance of proper placement of a quality concrete. Apprenticeship and certification programs are in place at both the individual mine level and across the industry.

Suppliers are also a vital part of this equation, having the benefit of being exposed to a variety of operations, and being able to propagate knowledge and good practice across the industry.

TOMORROW

The future for shotcrete in North American underground mines looks even more promising. The economics of sprayed ground support, advances in material and equipment technology, logistical improvements and experience, and a growing list of successful case studies are all driving this trend.

On the mix design side, advances in chemical admixture technology will continue to provide further alternatives to mine operators, including the ability to overcome deleterious characteristics of poorer quality aggregates and less costly binders that may, because of geography or economic factors, be more attractive for use. The trend toward producing the shotcrete as close as possible to the mine operation, in order to minimize rising freight costs to move material, will continue.

Automation in equipment is available today, with computer controlled, laser driven technology available for mapping headings to be sprayed, with the computer subsequently taking over part or all of the shotcrete spraying process (Rispin et al. 1999). Reduction in rebound and more precise control over actual application thickness, as well as an ability to accurately map the applied concrete, are valuable benefits of this technology. One Canadian mining company is working on integrating this technology with tele-operation, using shotcrete as a ground control component in their drive to tele-operate the mining development cycle; that is, operate equipment and drive tunnels from a remote, surface location.

As our technical people learn more about the shotcrete/rock interrelationship, and why shotcrete is as effective a support mechanism as it is, its applications will expand. Noted South African rock mechanic experts have been driving evaluations of shotcrete for their potential as an effective ground support mechanism in highly stressed operations at depths from 1500–4300 m (5000–14000 ft). North American miners are following suit as the depths of our economic orebodies increase.

Synthetic fibers show promise as the reinforcement of the future, either standing alone or blended with high-quality steel fibers. Their energy absorption response to load and displacement shows advantages for the higher deformation environments one finds associated with mining operations, especially at depth.

CONCLUSION

The resultant use of incorporating all of today's available technologies, i.e., materials, equipment, and placement methods, allows the North American mining industry to fully exploit this highly flexible material, whether it is for rehabilitation, or a fully integrated part of the mining cycle. It is up to all involved — suppliers, end users, and industry associations — to ensure that this industry maximizes the benefits of shotcrete.

Figure 4. Computerized, robotic, spraymobile; capable of laser profiling of heading to be sprayed and subsequent computer control of spraying operation.

The set of arguments in favor of modern, advanced, high-performance fiber-reinforced wet-mix shotcrete is today very strong. In all fields of evaluation such as quality, safety, environment, time, and economy, the conclusions are consistently the same.

The key to a successful use of modern rock support technology lies with senior mine management. The whole strategy from rock support design, through correct evaluation of benefits from faster mine development, must be carried through a mining company from "top to bottom." Embracing the concept of this modern rock support technology and embracing its methods, and therefore benefits, is the challenge for mine management in the future.

Bibliography

Brooks, J., 1998, "Wet Shotcreting," *SAIMM School: Shotcrete and its Application.*

O'Hearn et al., 1997, "Boltless Shotcrete," SAIMM.

Rispin, M. et al., 1999, "Shotcrete Research and Development at Inco's Test Mine" *3rd International Symposium on Sprayed Concrete.*

Mike Rispin, P.Eng., graduated with a Bachelor's degree in Mining Engineering from McGill University, in Montreal, Quebec, Canada, in 1985. He subsequently spent 11 years in various sales, technical, and managerial positions in the explosives industry in Canada and the U.S., with a particular emphasis on underground mining. Since 1996, he has held the position of Mining Manager, Underground Systems, with Master Builders, with a focus on the application of concrete and associated technologies in underground mining. He is a member of the Society of Mining Engineers and the Canadian Institute of Mining. At latest count, he has experience underground with over 80 underground mining operations worldwide and is the author of a number of technical papers.

John Brooks graduated with a degree in Civil Engineering from the University of Technology, Sydney, Australia, in 1980. He has been involved in the concrete technology industry since that time, first with a premix concrete producer and then with Master Builders Technologies. He formed MBT Australia's Underground Construction Division in 1993, specializing in the application of concrete and associated technologies for both civil and mining underground construction. In 1997 he was made MBT's Asia Pacific Regional Manager for Underground Construction, based in Singapore, where he worked on many large projects within that region. In April 1999, he was made Director, Underground Construction Americas, based in Cleveland, Ohio. He is a member of the American Shotcrete Association, American Underground Association, Australian Underground Construction & Tunneling Association, and a founding member of the Australian Shotcrete Society. He has presented many technical papers on shotcrete and its application around the world.