Volume 17 | Issue 5 | October 2020

MINING & QUARRY WORLD

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The **FAMUR Group** is a leading manufacturer and supplier of machinery and equipment operating in the mining industry all over the world. The main areas of our activities are underground and open-pit mining, transport, bulk material handling, and the power industry.

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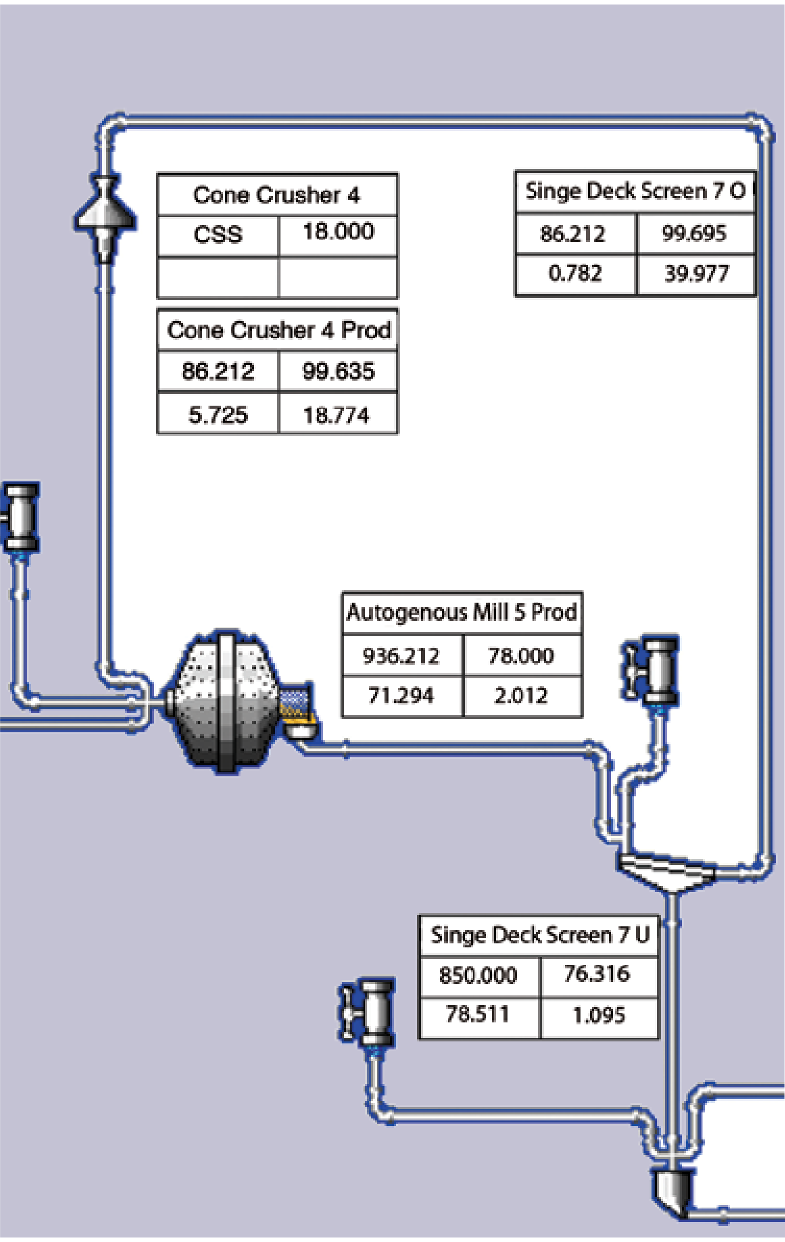

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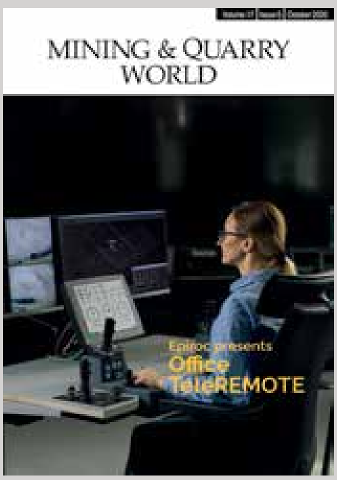

Epiroc

We are a leading global productivity partner for the mining and infrastructure industries. With cutting-edge technology, Epiroc develops and produces innovative, safe and sustainable drill rigs, rock excavation and construction equipment and tools. The company also provides world-class service and solutions for automation and interoperability.

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Hillhead 2021 commits to 'all secure standard' as exhibition industry gets set to resume

The organisers of Hillhead are pleased to announce that trade shows have been given the green light to resume in the UK from 1 October 2020.

As a member of the Association of Event Organisers, the Hillhead 2021 team has already begun planning the event to fulfil the 'All Secure Standard'. This is a programme of enhanced measures, approved by government, that set out industry best practice and guidance for working safely during coronavirus (COVID-19). Set around the cornerstones of Social Distancing, Cleaning & Hygiene, Protect & Detect and Communication, an overview of the Standard is attached.

Show director Richard Bradbury explained: 'Whilst it is likely that some of these measures will be relaxed by June 2021, Hillhead has taken the decision to plan for them at the earliest opportunity, ensuring visitors and exhibitors will be supported in the most effective manner. A comprehensive framework for a safe show is already being put in place, which we look forward to sharing with you in the New Year.'

Meanwhile, Hillhead 2021 welcomes a host of new exhibitors that have signed up during the lockdown, including LiuGong Direct UK, Barford, Fox Brothers, John King Chains, Kelly Tanks and DXB Pump & Power.

Exhibitor enquiries should be directed to Charlotte Stacey. Email: charlotte.stacey@qmj.co.uk; or tel: +44 (0)115 945 4376.

The event will take place from 22-24 June at Hillhead Quarry, near Buxton. To view the current list of exhibitors, visit: www.hillhead.com/exhibitors

MAXAM announces a new large haulage tire – the MS453

MAXAM is excited to present the all-new MS453 53/80R63 open pit mining tire to their range of large mining tires. Manufactured in MAXAM's state-of-the-art radial tire facility, the MS453 is developed through the use of cutting-edge engineering and groundbreaking compounding technology. To meet the most demanding application requirements in the open pit mining, MAXAM has engineered the MS453 to provide the industry with a rugged and long-lasting solution for mining haul trucks.

In order to meet the toughest requirements for haul trucks that require 63" large mining tires, the newly developed MS453 utilizes an enhanced casing construction with advanced compounding technology. The MS453 is the result of advanced engineering, extensive research and global testing. MAXAM designed the MS453 with the goal to provide the best delivered value, greatest productivity and the lowest cost-per-ton value for global mining operations.

Featuring a rugged and aggressive tread design that allows maximum tire life for the most demanding mining applications, the MS453 is built to withstand even most severe challenges on haul roads. Taking feedback from customers and mine sites globally, MAXAM has reinforced the sidewall of the MS453 by enhancing the tread belts and bead construction to provide maximum protection and performance. Similar to the products within the large mining series, the MS453 features a deep tread depth to deliver longer tire life. It also contains a heat resistant undertread for reduced heat built up, increasing the tire's TKPH/TMPH.

In addition, MAXAM has implemented a new naming structure on some products within the Large Mining Series to help broaden their future range of specialty tire programs. To assist customers and mine sites globally, the realignment of the model numbers will allow for easy ordering and program development as MAXAM continues to expand the haulage program. As MAXAM Tire grows, they're ensuring a precise portfolio that provides customers with a clear understanding of their solutions.

The new product model names correlate to specific haulage tire sizes to differentiate tread design patterns within the series. The previous MS403 in size 37.00R57 and 46/90R57 have been realigned as the MS440. All other sizes within the MS403 pattern remains the same. MAXAM believes that this realignment will improve customer communication, allowing for direct access to tread design expectations.

For more information, please contact your local representative or visit us at www.maxamtire.com

Orica's Fragtrack™ Wins international good design engineering award

FRAGTrack™, Orica's innovative fragmentation measurement technology received the prestigious Good Design Award Accolade in the Engineering Design category in recognition for outstanding design and innovation.

The award was won by Orica and design partners, Design Anthology, Newie Ventures and Your Engineer Mechanical Design who supported the development of state-of-the-art technology that captures real-time fragmentation measurement data for optimising drill and blast operations and improves downstream efficiencies in the mining process.

The annual Good Design Awards is Australia's oldest and most prestigious international awards for design and innovation with a proud history dating back to 1958. The Awards celebrate the best new products and services on the Australian market, excellence in architectural design, engineering, fashion, digital and communication design, design strategy, social impact design and young designers.

The Good Design Awards Jury praised FRAGTrack™, commenting: "An innovative design that has the potential to improve commercial and safety outcomes in the mining and extractive industries that use drill and blast techniques. An excellent piece of engineering design using scanning and multi-camera technologies with extensive software engineering in a highly innovative application.

"The robustness of the design and its adaptability are also commended. This is a clever solution to the tedious problem of quantifying fragmentation after blasting. It ruggedises cameras and processors to survive in harsh mining and environmental conditions. Overall, a solid piece of industrial and engineering design that deserves to be recognised and celebrated."

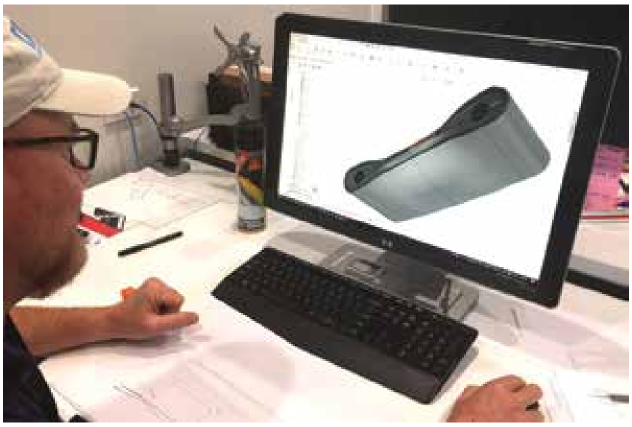
In accepting the award, Orica's Vice President of Digital Solutions Rajkumar Mathiravedu, acknowledged: "We've been able to develop this unique digital solution by combining more than 20 years of customer input, internal expertise and collaborations with market-leading specialists Design Anthology, Newie Ventures and Your Engineer Mechanical Design to make it a reality. This award is recognition of the extraordinary people and partners behind this innovative and value delivering technology.

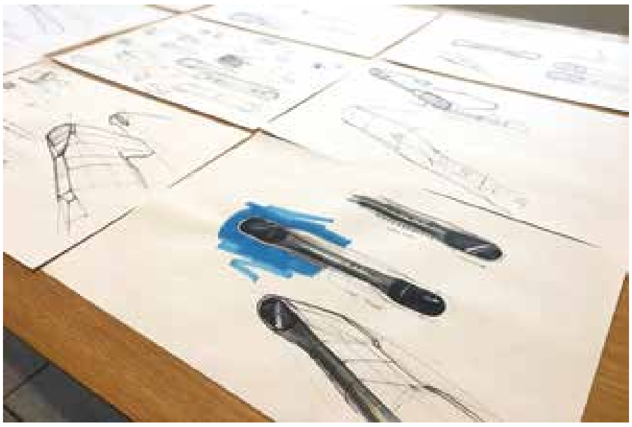
"Throughout the development process we've taken the time to listen to the needs of our customers, and then work with them to evolve the design and engineering to suit harsh mining conditions, delivering real impact and outcomes for them – It's what makes this such a unique and impactful innovation, especially as our customers strive for greater competitive advantage in these challenging times."

More than 55 Good Design Awards Jurors evaluated each entry according to a strict set of design criteria which covers 'good design', 'design innovation' and 'design impact'.

Projects recognised with a Good Design Award must demonstrate excellence in good design and convince the Jury they are worthy of recognition at this level.

Dr. Brandon Gien, CEO of Good Design Australia said: "Receiving a Good Design Award is a significant achievement given the very high calibre and record number of entries received in 2020."





"There's no doubt it has been a really tough year for everyone so it's nice to be able to share some good news for a change. The projects represented in this year's Good Design Awards shine a positive light on our creative and innovative capacity as human beings.

These inspirational winning projects give me hope and optimism that our design community will continue to innovate, no matter how challenging the world around us is," said Dr. Gien.

"Australia's Good Design Award is more than a symbol of design excellence – it represents the hard work and dedication towards an innovative outcome that will ultimately make our lives better. These projects showcase the shear brilliance of design and the potential it has to improve our world," said Dr. Gien.

Following 'Australia's Most Innovative Manufacturing Company' and 'Best Industrial IIoT Application' Awards, this latest recognition further cements FRAGTrack™ as a pioneer product in mining innovation. It is one of the key value-adding technologies that is reinforcing Orica's differentiated position in the marketplace.

Next generation Cat® 6060 hydraulic mining shovel features greater performance and increased durability

The next generation Cat® 6060 hydraulic mining shovel features multiple design enhancements and new components that advance machine performance, durability, serviceability and operator comfort. The new 6060 features updated engines, optimised hydraulics, heavy duty structures and undercarriage, Cat electronics and a state-of-the-art cab. The new shovel is also fully integrated into Caterpillar product support systems for efficient Cat dealer services.

The 600-tonne class mining shovel has a bucket payload of about 61 tonnes (67 tons) per pass in both face shovel and backhoe configurations. The 6060 is an efficient 4-pass match with the Cat 793 mining truck and 5-pass match with the Cat 794 AC mining truck.

Twin Cat 3512E engines are optimised for high performance, fuel efficient operation and increased durability. For North America, the engines are equipped with a maintenance-free diesel oxidation catalyst emissions control system, do not use diesel exhaust fluid (DEF) and comply with US EPA Tier 4 Final regulations. The updated engine design boosts reliability and extends time between overhauls by 10%. The efficient engine and optimized hydraulics enable 10-15% better fuel efficiency compared to the previous face shovel model, with 3-5% greater efficiency for the backhoe configuration. For reduced maintenance, engine oil and filter change intervals are doubled to 1,000 hours.

Structural, undercarriage and slew ring upgrades help maximise uptime and productivity and lower cost per ton. To boost longevity, the Cat undercarriage features heavy duty rollers, idlers and tracks, along with a revised track tensioning system. The superstructure frame, face shovel and backhoe attachment structures have been redesigned to reduce structural repair and extend service life via increased plate thicknesses and geometrical improvements. The slew ring design extends component life with a triple-race roller bearing and sealed internal gearing.

The 6060 features a new, state-of-the-art cab and operator station with industry leading visibility provided by the large floor window and expansive windshield and side windows. Unrestricted lines of sight to the crawler tracks and pit floor aid the operator when repositioning the shovel and when loading trucks.

The pneumatically cushioned operator seat can be heated and ventilated. It has integrated joysticks and is multi-adjustable to offer the optimal ergonomics. The innovative cab design also includes two additional seats: a full-size seat and laptop desk for a trainer and a fold-up seat for an observer. The three-seat cab design is the first in this size class of shovels. Improved sound suppression on the power module keeps spectator sound levels low, while the sound suppressed cab provides a quiet working environment for the operator.

The first of several features within the available Operator Assist suite, Enhanced Motion Control is standard on the shovel. Enhanced Motion Control improves machine controllability and loading efficiency while reducing linkage and cylinder mechanical contact. The machine's five-circuit hydraulics design allows simultaneous control over two cylinder motions, two travel motions and swing to boost digging and loading efficiency.

Enhanced serviceability, technology

The next generation design helps improve service and maintenance efficiency by offering more room inside the service compartment and easy ground-level accessibility to the service station. Integration of Cat hoses in the design allows for local hose sourcing, while improved hose and component organisation further reduces machine downtime.

Sensors located throughout the 6060 monitor operating data, record faults and give audible and visual notifications of issues to the operator. Standard for the first time on the 6060, Product Link™ Elite enables data communication for remote machine health monitoring.

The 6060 comes ready to accept Cat MineStar™ Solutions, a comprehensive suite of mining technologies geared to enhance mine safety, improve efficiency and reduce operating costs.

In addition to the next generation diesel-powered 6060, Caterpillar continues to offer the electrically powered 6060 AC FS (face shovel) for mines optimised for such machines.

For more information, contact the local Cat dealer or visit: www.cat.com/mining

Customised in every detail

BEUMER Group GmbH & Co. KG

BEUMER Group will exhibit its expertise in conveying, loading, palletising and packaging of building materials and (petro) chemical products at POWTECH in Nuremberg from 30 September to 1 October. As a system provider for solutions including complete high-capacity packaging lines, BEUMER Group optimally designs the capacity of the individual machines, components and high-level controls.

However, it will be a little different this year. Due to the effects of the COVID-19 pandemic, this successful bulk material trade show in Nuremberg is now called Powtech Special Edition and takes place over the course two instead of three days and is more compact. At its booth, BEUMER Group will provide information on, among other things, the optimal design of conveying systems and complete packaging lines for both the building material and the (petro)chemical industry.

The overland conveyors and the Pipe Conveyor of BEUMER Group can be used by companies to transport various bulk materials, even over long distances and often through rough terrain. High angles of inclination and tight curve radii enable individual routing adapted to the respective task and topography.

In order to load bulk materials quickly and without dust, BEUMER Group offers bulk loading heads. They are designed according to the double-wall system. The material inlet and the dedusting unit are separated from each other. In order to balance out any minor positional deviations of the vehicle, the bulk loading head can be moved laterally during placement.

In Nuremberg, BEUMER Group will also provide information on its loading and unloading systems for bags, able to handle railway wagons and ships quickly – with minimal dust emissions and without loss of bulk goods. BEUMER Group provides efficient systems for this purpose which take into account both different ship sizes as well as the space available at the unloading points. The modular design of the BEUMER Group systems makes it possible to present a precisely tailored solution for every requirement.

The BEUMER autopac loads bagged bulk materials like building materials or fertilisers automatically onto the truck bed and to simultaneously palletise them – ensuring extremely gentle handling and the desired packing pattern. The BEUMER autopac consumes only little energy and can be easily operated and maintained. The machine is also suitable for paper valve bags, HDPE valve bags and PP valve bags.

For high-capacity packaging lines, BEUMER Group offers different palletising solutions, depending on the packaged items. The BEUMER paletpac is suited best for bagged bulk material. This system palletises even sensitive and valuable products as well as products with special flow characteristics in a gentle and efficient manner. Depending on the product requirements, these palletisers can be equipped with a clamp-type or twin-belt turning device which turns the filled bags quickly into the required position for stacking, ensuring their dimensional stability without any deformations.

Products for the (petro)chemical and consumer goods industries are filled in special bags, barrels, canisters, cartons or buckets. To palletise them, BEUMER Group offers its space-saving articulated robot, the BEUMER robotpac. Depending on the packaged items, BEUMER Group equips the robot with the appropriate gripping tools which can be easily and automatically changed, if the packaged items change. The fork gripper for example was designed specifically for palletising cardboard boxes, the finger gripper for bagged goods. For maximum performance, BEUMER Group offers a double gripper for both types. They also offer parallel grippers for dimensionally stable packed items, suction grippers for items with a smooth surface and many other special grippers and combination tools.

Packaged items stacked accurately on pallets can then be transported successfully to the downstream packaging system – for example, the BEUMER stretch hood. It covers the palletised goods with a highly stretchable film. This ensures that the merchandise is protected reliably against environmental influences such as sunlight, dirt, and humidity during transshipment and outside storage.

Wirtgen 220 SMi 3.8 Surface Miner – high-performance chalk mining in France

On behalf of the HeidelbergCement Group, Wirtgen conducted a performance test with the 220 SMi 3.8 surface miner at a chalk quarry in Couvrot. The goal was to increase production output compared to the current mining method using a crawler dozer while simultaneously reducing operating costs.

During the demo, several tests were conducted to convince the customer that the smallest Wirtgen surface miner is a viable and more efficient alternative. To do so, the surface miner's cutting performance, turning time, and fuel consumption were recorded, among other parameters.

WIRTGEN'S 220 SMI 3.8 VALIDATES HIGH EXPECTATIONS

Up until now, the company has used a bulldozer to break up the chalk in Couvrot, before a scraper loads the material into the hopper (also known as the bowl) and transports it to a temporary storage facility. From there the chalk is transported to the adjacent cement factory, where it is immediately processed.

Since the pieces of rock mined by the dozer are relatively large, with a grain size of up to 80 cm, this mining method causes several problems at once. On the one hand, it creates an uneven surface that must first be leveled by the dozer so that the scrapers can be used to load the material in the first place – an additional, extremely time-consuming task. On the other hand, the coarse grain means that the scrapers require considerable energy and force to load the mined material. This primarily causes considerable traction issues for the scraper, which results, among other negative effects, in an extremely high level of wear and tear to the machine's tires. As a result, two to three dozers are currently required per shift to level the excavated area and push the scrapers. In addition to the customer's expected output of at least 500 m³ per hour, the objective was to eliminate the aforementioned problems with the help of the surface miner.

The 220 SMi 3.8 surface miner is capable of selectively mining raw materials at cutting depths of up to 350 mm and a uniaxial compressive strength of up to 35 MPa. Thanks to its 3.8 m wide cutting drum designed specifically for soft-rock mining, the surface miner achieves maximum productivity at low operating costs, making the compact 220 SMi 3.8 perfect for use in small to large mining operations – a fact that it impressively demonstrated in France.

During the performance test in Couvrot, cutting zones with a length of 150 m and 300 m as well as a width of around 40 m were first mined using the 3.8 m wide cutting drum. The drum was then replaced with a 2.2 m wide drum and tested for one more day.

220 SMI 3.8 SURFACE MINER PROVES ITS SUPERIORITY UNDER DIFFICULT CONDITIONS

According to the customer, the Couvrot region receives significantly more rainfall between October and April than in the summer months. Huge puddles make it difficult to mine the chalk and the moist material has a negative effect on further processing. These conditions were simulated at the beginning of the tests. The 220 SMi 3.8 had to perform a variety of cutting tasks in muddy and wet terrain. Needless to say, the machine also mastered this challenge without any loss in performance. All of Wirtgen's surface miner models feature adjustable longitudinal and cross slopes, which ensures that rainwater drains off and keeps the working surface dry.

Even when cutting on slopes with a gradient of up to 16%, the production output of the 220 SMi 3.8 remained high. The machine achieved a peak cutting performance of 1400 m3 per hour. This represents an outstanding result for the customer, since most of the quarry's mining areas are located on such steep slopes.

The fact that Wirtgen's surface miner can easily handle the average rock hardness of 20 – 30 MPa was clear even before the tests began. After all, it is designed for rock with a compressive strength of up to 35 MPa. But how would the machine perform under even harder rock conditions? Some areas of the quarry contain deposits of blue marl with a hardness of up to approximately 40 MPa. Another challenge for Wirtgen's miner that the 220 SMi 3.8 mastered with an advance rate of 5 – 10 m/min.

WIRTGEN SURFACE MINERS INCREASE PRODUCTION OUTPUT

In the final and probably most important test, the surface miner was used for an entire shift at the quarry. As part of a fleet with three scrapers and one dozer, the 220 SMi 3.8 cut at two cutting depths of 20 cm and 30 cm. Thanks to its powerful cutting drum and an engine output of 963 PS at a weight of 59,000 kg, the miner was able to produce significantly smaller and more uniform grain sizes than the dozer. The advantage of this is that the material cut smaller is easier to load than the large pieces of rock, so the scraper and dozer need less power to load the scraper hopper. In addition, the milled material lies flat on the surface, which means it no longer needs to be leveled with the dozer, saving additional time and therefore cutting costs. In addition, the surface miner produces level surfaces that make it easier to load the scraper and provide stable road surfaces for fast material transport. Thanks to the level haul roads, tire wear can also be reduced.

After completing the test, the quarry operator was more than satisfied with the results achieved by the 220 SMi 3.8. The surface miner far surpassed the target output rate of 500 m³ per hour. In fact, at times the machine was able to extract almost three times the specified amount of chalk per hour.

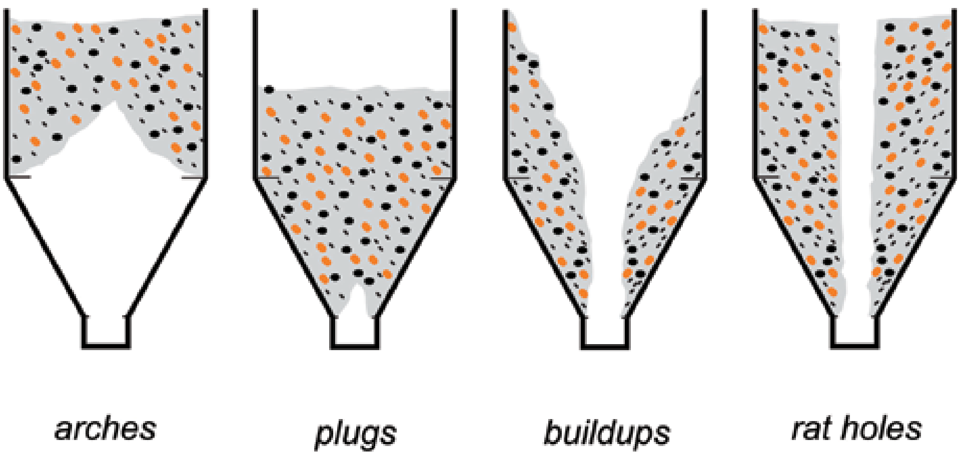
Due to its outstanding cutting performance and its production of fine grain sizes and flat surfaces, the operator no longer needs to use a dozer, which increases output and reduces costs at the quarry. In addition, the flat surfaces reduce traction problems and scraper tire wear. Since the chalk is pre-crushed by the 220 SMi 3.8 at the quarry, further costs resulting from the use of crushers can be saved during further processing at the cement factory. In other words, the smallest surface miner delivers what it promises: "maximum performance and cost-effectiveness."

Preventing accumulation in mining hoppers and chutes

Air cannons can help prevent accumulation, while minimizing the need for downtime and manual labor.

Efficient material flow is a critical element of wet mining processes such as stoping, hydraulic mining and wet dredging. Accumulation or blockages in storage systems and build-up in process vessels can impede material movement, causing bottlenecks that interfere with equipment performance, reduce process efficiency and put a choke hold on an operation's profitability. Poor material flow also raises maintenance expenses, diverting manpower from core activities and in some cases introducing safety risks for personnel.

"Most systems suffer from some amount of accumulation on vessel walls, which can rob plant owners of the storage systems in which they've invested," observed Brad Pronschinske, Global Director of Air Cannons Business Group for Martin Engineering. "These buildups reduce material flow, decreasing the 'live' capacity of the vessel and the efficiency of the bulk handling system overall." Pronschinske said the accumulations tend to take one of several forms: arches, plugs, build-ups or "rat holes."



"If they become severe enough, flow problems can bring production to a complete stop," Pronschinske continued. Although many plants still use manual techniques to remove build-up, the cost of labor and periodic shutdowns has led some producers to investigate more effective methods for dealing with this common production issue.

BUILD-UP VS. THROUGHPUT

Even well-designed processes can experience accumulations, which have a significant impact on output and profitability. Changes in process conditions, raw materials or weather can all have an effect on material flow, and even small amounts of accumulation can grow into a serious blockage.

Beyond moisture content, there are many causes of raw material buildup on vessel walls. Some metals contain naturally occurring magnetic properties. Nearly 90% of the earth's crust contains silica, and the sharp crystalline structure can contribute to buildup. Other factors can include the surface friction of the silo walls, the shape of the vessel, the angle of the slope and the size of the material being loaded.

Lost production is probably the most conspicuous cost of these flow problems, but the expense can become apparent in a variety of other ways. Shutdowns to clear the restricted flow cost valuable process time and maintenance hours, while wasting energy during re-start. Refractory walls can be worn or damaged by tools or cleaning techniques. When access is difficult, removing material blockages may also introduce safety risks for personnel. Scaffolds or ladders might be needed to reach access points, and staff can risk exposure to hot debris, dust or gases when chunks of material are released.

Many of the most common problem areas for accumulation are classified as confined spaces, requiring a special permit for workers to enter and perform work. The consequences of untrained or inexperienced staff entering a silo or hopper can be disastrous, including physical injury, burial and asphyxiation. Disrupted material adhered to the sides of the vessel can suddenly break loose and fall on a worker. If the discharge door is in the open position, cargo can suddenly evacuate, causing

unsecured workers to get caught in the flow. Cleaning vessels containing combustible dust – without proper testing, ventilation and safety measures – could even result in a deadly explosion.

GETTING PROFESSIONAL HELP

"While some large facilities choose to make the capital investment to purchase their own cleaning gear to clear process equipment and storage vessels – as well as train personnel – others are finding it more sensible to schedule regular cleanings by specially-trained contractors," said Pronschinske. "Given the costs of labor, lost time and potential risk to employees, this can often be accomplished for less than the total investment of in-house cleanouts."

At one location, for example, the blockage was so severe in one silo that it had been out of use literally for years. While it took the outside contractor almost two weeks to fully evacuate the vessel, the process restored 3500 tons of storage capacity. At another facility, the crew was able to remove enough "lost" product that the value of the recovered material actually paid for the cost of the cleaning. In short, regular cleaning of storage vessels can quickly turn into an economic benefit – not an expense, but rather an investment with a measurable ROI.

Safe, effective cleaning requires tools that work inside the silo from the top, controlled by personnel outside.

THE COSTS OF CLEANING

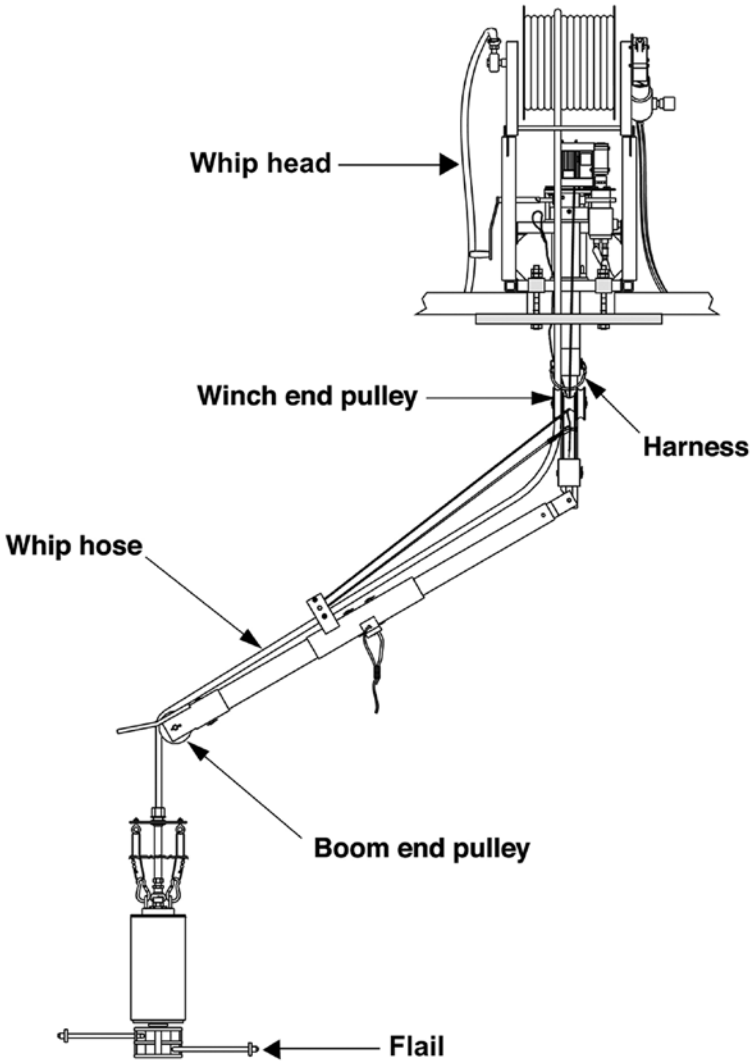
There are a few types of equipment used for this purpose. One operates like an industrial-strength "weed whip," rotating a set of flails against the material in the vessel. This approach eliminates the need for confined space entry and hazardous cleaning techniques, typically allowing the material to be recaptured and returned to the process stream.

The whip can be set up quickly outside the vessel, and it's portable enough to move easily around various bin sizes and shapes. Typically lowered into the vessel from the top and then working from the bottom up to safely dislodge accumulation, the pneumatic cutting head delivers powerful cleaning action to remove buildup from walls and chutes without damaging the refractory. Technicians lower the device all the way down through the topside opening, then start at the bottom of the buildup and work their way up, undercutting the wall accumulation as it falls by its own weight. In extreme cases, a "bin drill" can be used to clear a 12-inch (30.5 cm) pathway as deep as 150 feet (45 meters) to start the process.

FLOW AIDS

Regular cleaning is one approach to keeping materials flowing freely by removing buildups from silo walls, but there are other flow aids which may reduce the need for cleaning or even eliminate it. One method is through industrial vibrators designed for bin and chute applications.

Electric vibrators are generally the most efficient, delivering the longest life, low maintenance and low noise. The initial



A pneumatic whip rotates a set of flails to dislodge material, eliminating the need for confined space entry.

Industrial vibrators for bin & chute applications can reduce or even eliminate the need for cleaning.

cost for an electric vibrator is higher than for pneumatic designs, but the operating cost is lower. Turbine vibrators are the most efficient and quietest of the pneumatic designs, making them well suited to applications in which low noise, high efficiency and low initial cost are desired.

Air cannons are another approach to maintaining good material flow, particularly in larger vessels. Also known as an air blaster, the air cannon is a flow aid device that can be found in mining, coal handling and many other industries. Applications vary widely, from emptying bulk material storage vessels to purging boiler ash to cleaning high-temperature gas ducts.

In the mining industry, air cannons are frequently specified to eliminate build-ups in hoppers, storage vessels, transfer chutes, bins and other production bottlenecks. They can also be found in mineral processing plants where metals are extracted using processes creating slurries and other wet, tacky tailings.

Air cannon technology has been used in mining and material processing for many years, helping to improve flow and reduce maintenance. The timed discharge of a directed air blast can prevent accumulation or blockages that reduce process efficiency and raise maintenance expenses. In underground mines with potentially explosive dust, manual firing of cannons without the use of electrical solenoids is an option. By facilitating flow and minimizing build-up, air cannons help bulk material handlers minimize the need for process interruptions and manual labor.

The two basic components of an air cannon are a fast-acting, high-flow valve and a pressure vessel (tank). The device performs work when compressed air (or some other inert gas) in the tank is suddenly released by the valve and directed through a nozzle, which is strategically positioned in the tower, duct, chute or other location. Often installed in a series and precisely sequenced for maximum effect, the network can be timed to best suit individual process conditions or material characteristics.

"The core message for mines and material processors is that they don't have to put up with accumulation problems and the additional expenses they can cause," Pronschinske concluded. "There are a number of approaches that can help resolve those issues before they turn into expensive downtime, lost material and safety hazards."

Weir Minerals saves OceanaGold $800,000 per annum with Cvex® Hydrocyclones at Didipio Project gold and copper mine

Replacement of competitor cyclones with Cavex® 400CVX10 cluster reduced grinding mill recirculation by 246%.

The installation of 19 Cavex® 400CVX10 hydrocyclones at OceanaGold's Didipio Project gold and copper mine in the Philippines has led to savings of more than US$800,000 annually through a dramatic reduction in grinding circuit recirculation.

The Didipio mine, which employs more than 1,500 workers (drawn predominantly from the local community) expanded its production capacity, which increased the incumbent cyclones' feed density beyond what they could effectively manage, leading to a circulating load of up to 700%.

The Cavex® 400CVX10 hydrocyclones significantly improved separation efficiency due to their finely tuned spigot liner diameter, and the strength and corrosion resistance provided by its cast housing.

Thanks to these qualities, the introduction of the Cavex® hydrocyclones reduced the circulating load from 620% to 374%. The direct savings in power consumption, ball consumption, cyclone and pump maintenance costs exceed US$815,000 per annum.

A Cavex® 400CVX10 hydrocyclone.

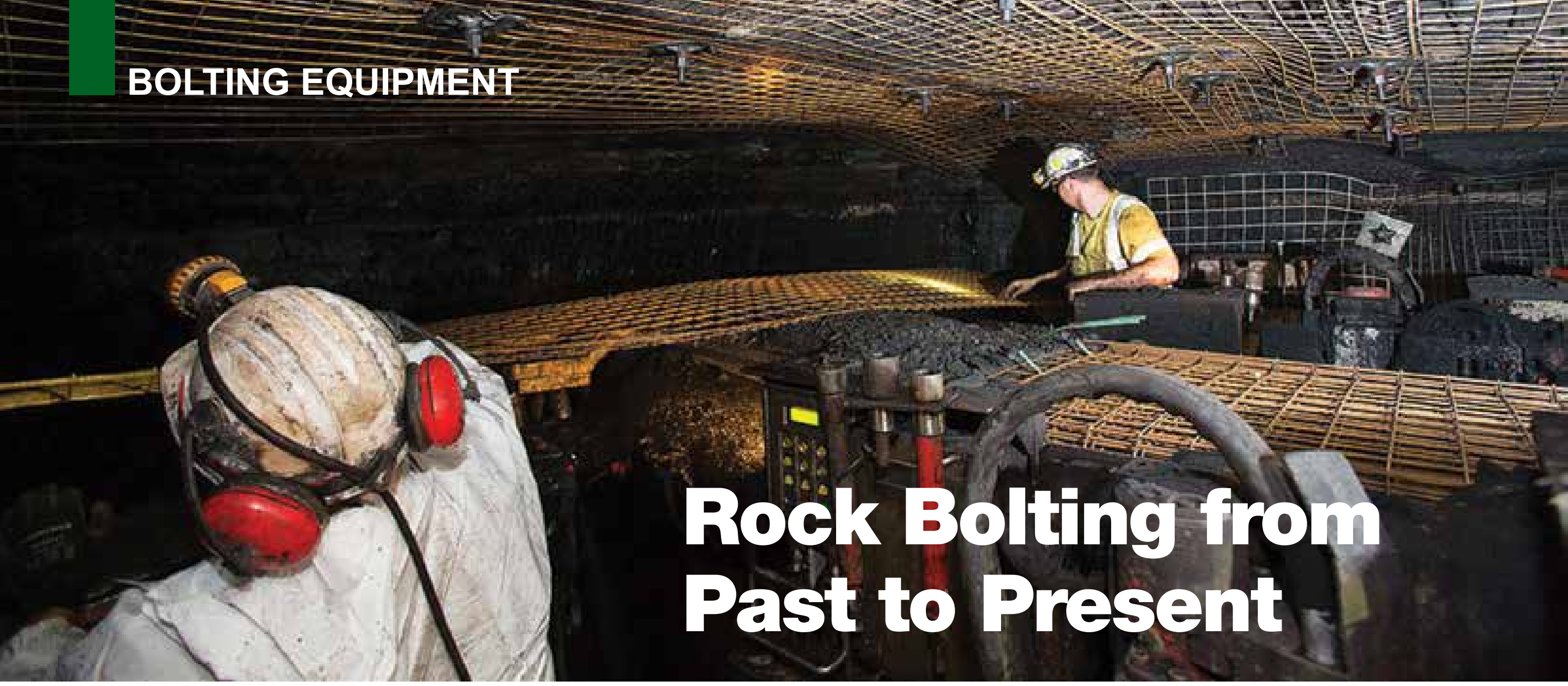
"Having had good performance from Cavex hydrocyclones at our New Zealand sites, we were confident that retrofitting Cavex hydrocyclone cluster at Didipio, with an increased number of smaller cyclones than we had at the time, would help reduce our problematic circulating load and lever multiple benefits in doing so," says Gary Webb, Processing Manager, OceanaGold Didipio Project. "The changeover to Cavex hydrocyclones has exceeded our expectations, enabling higher throughput and lower consumable costs without being penaliSed in grind size."

The superior performance of Cavex® hydrocyclones can be attributed to the unique 360° laminar spiral inlet geometry design, which provides a natural flow path into the hydrocyclone. This shape allows the feed to blend smoothly with rotating slurry inside the chamber, reducing turbulence.

"Working with customers across the globe, our expert engineers are constantly looking at how they can maximise separation efficiency, hydraulic capacity and extend the wear life of not just the hydrocyclone, but our customers' overall processing plants," says Mike Arakawa, Philippines Country Manager, Weir Minerals. "I'm proud of the results we've achieved together with OceanaGold. Reduced circulation means reduced power draw, fewer balls consumed and less equipment wear, creating a more sustainable mine."

Mike Arakawa is available for comment.

Cavex® 400CVX10 hydrocyclone cluster at Didipio Project gold and copper mine.



Rock Bolting from Past to Present

The use the rock bolt was invented more than one hundred years before, its usage has increased in mining and tunneling industries since the 1930s. Then, the steel rock bolts have become one of the most widely used tunnel supports since the third quarter of the 20th century, which was a time of changing strategies regarding supports and many challenges faced concerning the use of new support materials. Twenty inventions in the rock bolt history from its start of usage to nowadays are briefly explained in this paper. It can be inferred from the listed matters in this paper that many of the important developments in the rock bolt history were because of the need for use of new materials like contemporary grout materials increasing the load bearing capacity or rock bolts made with engineering polymer materials having good resistivity against the ground water. Also, developments in the mechanical science have made rock bolting an effective support method due to improvements such in the drilling technology or new anchoring mechanisms developed to overcome the problems in rock bolting. As a result of growing applications during 20th and 21st centuries, new challenges have come into being as in the energy-absorbing rock bolts being improved for the rock burst problem since 1990.

INTRODUCTION

Although the first date for use of rock bolts is not clear, the first rock bolt patent application is known to be done in 1913 by Stephan, Frohlich and Kltipfel who introduced their invention used in German coal mines as grouted steel rebar type of rock bolt (Stephan *et al*., 1918). In 1930's, the rock bolts also known to be applied in USA in early 20th century systematically started to be used in US mining industry (Gardner, 1971; Tully, 1987).

As a result of invention of the contemporary support systems, tunnel excavations have been able to be carried out with lower costs. Principally, the background of the contemporary support strategy had been made for long years. One of the most important improvements for having the opportunity to excavate underground openings with large-cross sections in weak rock zones can be accepted to be new materials use in rock support. Before the invention of use of steel materials in the rock engineering, the main support material was wood that caused many of different rock mass properties which are able to be supported in today's conditions impossible to perform engineering applications in history.

Many of the important civilizations in ancient times like Romans, Babylon's, Egyptians, Persians, Aztecs, Incas excavated tunnels for different aims such as mining, transportation, drainage, hiding and living, fighting in wars. Egyptians and Romans are known to excavate mining tunnels at the depths reaching 200 meters in the ancient times. The Roman Empire was the first country to have a special ministry on water transportation (Sandstrom, 1963). Therefore, many of the Roman tunnels were excavated under the official inspections of the empire. Some of the Roman tunnels excavated in the ancient times can be still considered big engineering applications in today's conditions.

Findings for the 6th Century BC refer that people could excavate tunnels in hard rocks with the rate of 9-10 meters per a year (Fukushima, 2012). One of the three wonders of the Hellenistic world was a water transportation tunnel with 1 km length whose excavation was completed in 530 BC. The name of tunnel considered as a wonder of Hellenistic world is Eupalinos which was excavated in the Samos Island of Greece. Then, the excavation rates and the length of tunnels increased by the Roman Empire

Figure 1: (a) A view of the Titus tunnel, (b) excavation tool marks.

that excavated the biggest tunnels of the ancient times. A Roman tunnel excavated for draining the water of Fucino lake in Italy was the longest tunnel until 1876. Excavation of the tunnel with 5.8 kilometers length and depth reaching 120 meters was started by the Emperor Claudius (a.d. 11-54) and completed in 11 years. For excavation of the tunnel, 30000 people worked to excavate the total length of over 10 km including the shafts (Parry, 2013). Another important Roman tunnel was excavated to divert the floodwaters threatening the harbor near the ancient city of Seleucia Pieria in Turkey nearly before 2000 years. The tunnel with the name of Titus tunnel was started to excavate by Emperor Vespasian (a.d. 9-79) and also excavated during the time of Emperor Titus (a.d. 39-81). Considering the cross-section area of tunnel excavation of over 50m2 and length of 1.4 kilometers, it can be said that the 2000 years old Titus tunnel is an important heritage from the ancient times and still an important tunneling project in today's conditions.

It was a quite tough job to manually excavate tunnels in history. For making rock masses be excavated with an easier way, fire was made on face and quenched by pouring water for an immediate change in temperature which causes cracking. After the quenching, it was easier to excavate rock using metal tools (Wahlstrom, 1973). An example of ancient excavation marks from the Titus tunnel is given in **Figure 1**. Although excavation rates could be increased significantly as a result of the developments in the excavation tools due to the improvements in metallurgy, it should be noted herein that the human power was the main need to have a success in the tunneling in the ancient times.

Although the metal tools were used to excavate rock since early times, metals were not used to support rock masses until the 18th century. In terms of economical use of metals as support material, developments in the metallurgy during the 18th century have made an important back ground for important inventions. Steel material being widely used as support material in todays was firstly used for an aim except making weapon, tools, and some goods in 1778, as being the construction material of the Coalbrookdale Bridge in England (Baugh and Elrington, 1985). For the start of steel material use as construction material, the Abraham Darby's invention to make coke from coal was an important milestone which caused to produce steel materials with cheaper costs. English ironmaster Henry Court's invention of puddling process was also an important milestone for having high strength steel materials.

The first time to use steel support material for rock supporting was just 17 years after the first steel construction of the Coalbrookdale Bridge. In 1795, steel lining support was firstly applied to support a coal mine shaft in England. A prefabricated steel lining shaft support from 1850's that was used in another coal mine of England is shown in **Figure 2**. Prefabricated steel liner sup ports had become a widely used support and started to be applied as tunnel lining in addition to being shaft support in 19th century. The first prefabricated steel lining tunnel support was used in a subway tunnel construction

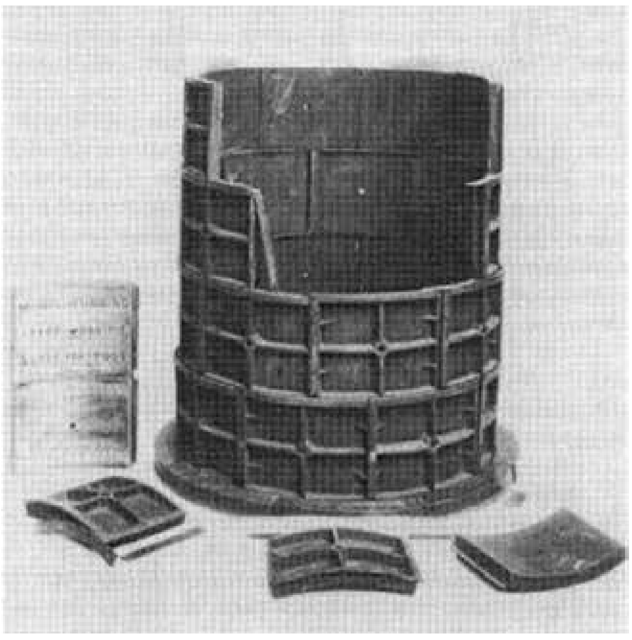


Figure 2: Steel shaft liner support produced in 1859 (West, 1988).

in London. Because of the development in concrete science, cheaper prefabricated concrete liners have taken the place of steel lining supports. However, steel ribs are being still used and most widely seen conventional support in tunnel constructions. By using steel support, higher strength and more practical supports with lower prices could be set in comparison with the previous support methods such as timbering and bricking. Until shotcrete material became wide in tunneling, steel ribs were used with wood support. Steel ribs had started to be used in several European countries in the second half of the 19th century (Merivale, 1888).

There were notable developments in the 19th century which established tunneling as a modem industry. As a result of inventions of drilling machines and effective explosives with nitroglycerin, the excavation rates in tunneling have been increased significantly in the 19th century. As drilling machines have made rock bolts possible to be applied practically, frontiers of rock excavation in the 19th century also had an important role on the development of the rock bolt supports in addition to the entrance of the steel supports into the rock engineering applications.

In the 19th century, numerous tunnel projects were needed to set network for the reason of increasing transportation requirement resulting from the industrial revolution. Different European countries developed their own tunneling methods in 18th and 19th centuries (English method, German method, Belgian method, Austrian method, etc.). However, the most important revolution can be accepted to be in the 20th century with the new Austrian tunneling method (NATM). The most important difference of contemporary support strategy of the NATM firstly introduced in 1950's was considering rock mass to support itself which can be supplied using rock bolts and shotcrete (Muller, 1990).

TWENTY MILESTONES IN HISTORY OF ROCK BOLTING

The first rockbolt

The first time to use rock bolts is not definite and believed to be late 19th century. Although the first patent for the rock bolt support was applied by Stephan, Frohlich and Kliipfel in 1913, the patent in rock bolt history was got in 1918. The long delay in the time for getting patent was probably because of the 1st World War (Kovari, 2003b). Stephan *et al*. (1918) reported that two different locations in ground can be linked using the grouted rock bolts inserted in drill holes. Therefore, it is explicitly understood that the firstly patented rock bolt was the grouted rebar type bolt.

Some examples

MAKING ROCK BOLT USE POPULAR IN EUROPE AND NORTH AMERICA

Although rock bolts could not become a widely used support in 1920's, they have fastly grown up in tunneling since 1930's and become popular in 1960's (Kovari, 2003a). The 20th century was the century of changing support strategies and many challenges based on using new support materials. The New Austrian Tunneling Method (NATM) named in the second half of 50's was developed as a result of using rock bolts with shotcrete in tunnel supporting (Muller, 1990). Some important examples which made rock bolting widely applied can be listed as follows:

- In 1930, rock bolts were applied in tunnels of Keyhole dam in USA
- Rock Bolts started to be used in a Canadian mine of Melntyre in 1934
- In 1942, rock bolts were firstly applied in Europe for transportation (motorway) tunnels excavated in England.
- From 1948 to 1950, rock bolts were applied in underground coal mine galleries with a total length of 1400 km in USA.
- In 1950, rock bolts were used in a water carrying tunnel excavated in Manchester.
- In 1950's, rock bolts were applied in several dam constructions in Canada, Norway, Sweden, and France.

From 1958 to 1962, rock bolts were applied in a motorway tunnel with a depth reaching 2200 meters and length of 11,6 km, between France and Italy.

PORTLAND CEMENT

Grout quality is one of the most important issues in rock bolt support performance. In terms of having a better grout material, invention of Portland cement which is the most widely used cement material all through the world is a significant improvement in the rock bolting practices. The Portland cement was invented by an English chemist Joseph Aspdin in 1824. As the color of the cement is close to that of limestone of the Portland island in England, it is called as Portland cement. The first Portland cement was introduced to market selling it as a modern binder material in 1845 (Eckel, 1913).

SHOTCRETE

In terms of the success of contemporary support strategies, use of rock bolt with shotcrete has a capital importance because of bettering the performances of each other. Shotcrete has important advantages to control deformations of the bolted ground. Before the use of

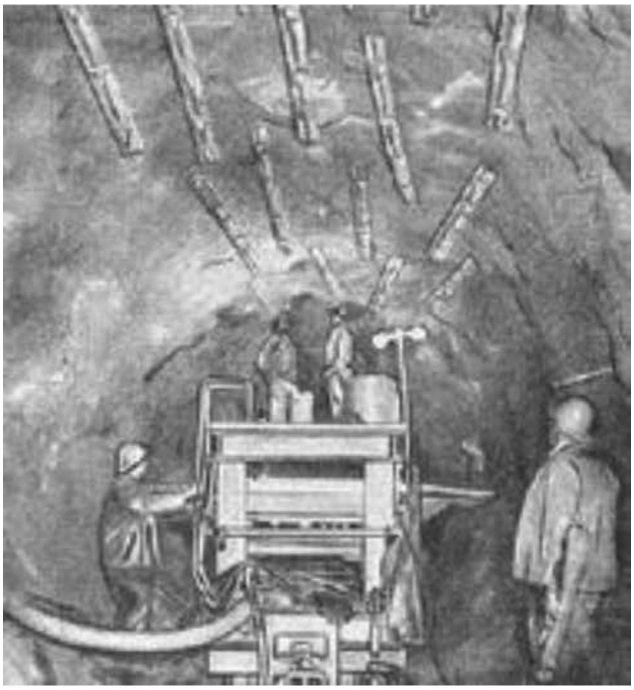


Figure 3: A rock bolt application in I 950's (Perez, 1952).

shotcrete in tunnel ling, iron plates were used to link bolts each other and supply support pressure on the wall which results from the load bearing by the rock bolts (**Figure 3**). The invention of shotcrete and its use with rock bolts were the main reasons for realising the contemporary support mentality firstly detailed with the NATM (Rabcewicz and Golser, 1973).

The first spraying concrete called gunite was found by an American taxidermist of Carl Akeley to be used with animal models in early years of the 20th century. In the first system, solid was being carried by air and water was being mixed immediately before spraying from the nozzle. Carl Akeley got the patent of his invention of the cement gun in 1911. The most important

difference of the Akeley's method in comparison with the typical shotcrete applications is using no mixer to make the sprayed concrete. The first mixer machine was invented by Chester A. Beach in 1910, just a year before the invention of Akeley (Bicik, 2012). Therefore, it can be inferred that all the concrete materials were manually mixed in 19th century.

First shotcrete application performed in an American mine is known to be in 1914. In 1930's, American railway engineering association (AREA) firstly used the name of "shotcrete ". Early shotcrete applications were performed as dry mix that water and solid were mixed in a mixer used in application area and sprayed with air pressure. Wet mix shotcrete which is mixed outside of application area and generally transported by the mixer trucks has started to apply in 1950's.

THE FIRST FRICTIONAL ROCK HOLTS (SPLIT SETS)

The frictional rock bolt was invented by an American Engineer, Dr. James Scott in 1972 (Scott, 1974; Davis, 1979; Scott, 1981). Because the system is quick and simple to install, it fastly gained acceptance by miners all through the world. As it is installed by pushing into a hole with slightly lower diameter than that of the rock bolt, the radial spring force is generated by the compression of the tube with cross-section of C shape, which provides the frictional anchorage. Although increase in the normal forces applying on the drill hole surface is an advantage in terms of the frictional load bearing capacity, having a high ratio of tube diameter to drill hole diameter is a disadvantage for the insertion performance of the rock bolts. Split set type of rock bolts generally has similar load bearing capacity with the load level reached during the insertion. Although the load bearing capacity increases due to increase in the split set tube wall thickness and/or diameter, insertion practicality of the rock bolts is affected as a result of increase in the split set tube wall thickness and/or diameter. Furthermore, the corrosion problem getting worse by scratching of the steel surface contacting to the drill hole should be payed attention with the increase of tube diameter (Li and Lindbald, 1999; Hassell ve Villaescusa, 2005).

ANOTHER FRICTIONAL ROCK BOLT: SWELLEX

Atlas Copco invented the swellex type frictional rock bolts in 1980's. Because the swellex type rock bolt tubes have smaller diameter than the drill hole diameter before insertion, it needs to be expanded in the drill holes to supply frictional load bearing capacity. One of the most important advantages of the swellex type rock bolts is having no significant scratching problem during their insertion which limits the frictional load bearing capacity as in the split sets' application. Therefore, higher stress applying on the hole surface from the swellex type tubes can be supplied in comparison with those in the split set applications.

RESIN TYPE GROUTS

The first resin grout product was developed in Germany, in 1956. The resin grouts which need short time for curing reactions are usable for the rock bolts that start to carry load in short time as insertion is done. The first application carried out in 1959 to use resin grout cartridges was also in Germany. Nowadays, many different resin grout materials having a significant variety can be found in the market. Mechanical properties of resin grouts can change using chemical additives. Resistivities against the ground water and dynamic load resulting from the blasting applications are important issues making the resin grouts advantageous in comparison with the conventional cement grouts (Hoek, 2006; Komurlu and Kesimal, 2013a).

THE FIRST MECHANICALLY ANCHORED ROCK BOLTS

The first rock bolt having expansion device at the front of the shank for the mechanical ancho ring was firstly used in construction of an Australian dam called "Snowy Mountains Scheme" in 1947 (Meacham, 2007). The first application carried out in Australia was an important milestone for the invention of the modern pre-tensioned rock bolts being able to supply active support pressure without the need for the ground deformation.

CABLE BOLTS

Hoek *et al*. (1995) reported that cable bolts were firstly applied in underground mining in Canada in 1963. In 1964, cable bolts were also started to use in South African mines. Because cable bolts were able to be inserted for support of deep rock masses, they were found convenient to use in rock engineering and became a widely used support in Australian and Scandinavian mines in 1970's. During 1980's and 1990's, cable bolts became a typical mine support all through the world, support reaction of cable bolts have been well understood and different kinds of cable bolts were produced (Yazici and Kaiser, 1992; Kaiser *et al*., 1992; Hyett, 1992; Windsor, 1992; Hutchinson and Diedrichs, 1996).

POLYMER COMPOSITE ROCK BOLTS

For the aim of eliminating the effect of ground water, composites of engineering polymers having no corrosion problem and proper mechanical properties were started to use in 1985. The first application of the polymeric rock bolts was carried out in Switzerland (Firep, 2013). Light density of the polymer composite rock bolts is another advantage in terms of the application practicality. Polymer composite rock bolts are generally made with glass or carbon fiber reinforcement used in the matrix of polymer materials such as ABS (Acrylonitrile Butadiene Styrene), epoxy, polyester, vinylester (Komurlu and Kesimal, 2013b). Depending on the production details and additives, it is possible to find the polymer composites being much stronger material in comparison with the steel widely used in rock support applications.

CONE BOLTS

To combat rock burst problem in deep mines, many challenges have been faced concerning the use of new rock bolts. The first rock bolt developed to use in the

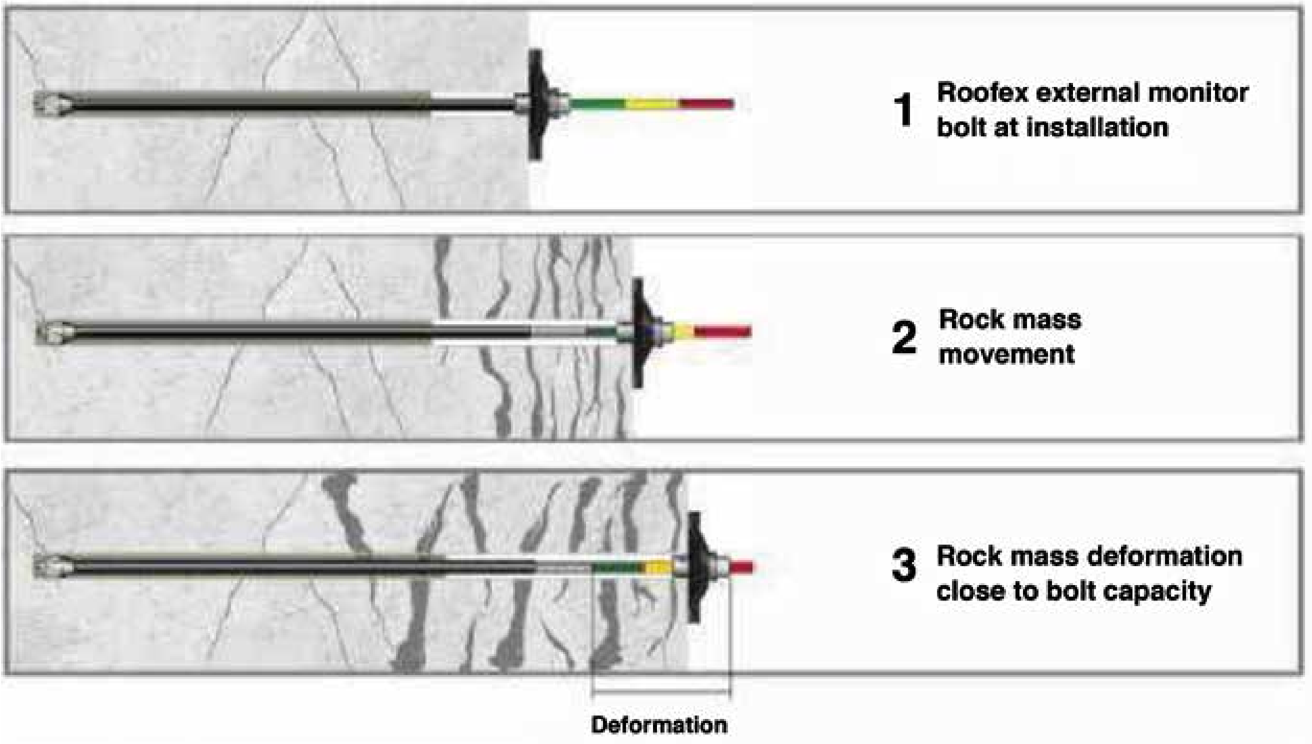


Figure 4: Deformation let by Roofex bolts (Atlas Copco, 2015).

mines having rock burst problem is the cone bolts having increased energy absorbing capacity resulting from the anchoring of cone end of the shank. The cone bolts firstly used in 1992 have a simple design with an expanded front end which can increase the anchoring performance in the grout material, were developed in South Africa (Jager, 1992).

ENERGY ABSORBING ROCK BOLTS WITH SLIDING BODY (GARFORD, ROOFEX)

In 2008, Garford bolt (Australia) and Roofex bolt (Sweden) were developed to increase the energy absorbing capacity against the dynamic load resulting from the rockburst problems, consisting of a solid steel bar sliding in polymeric materials, an anchor and a coarse-threaded sleeve at the far end of the bolt. The Garford and Roofex bolts have a high deformation limit, ductile support reactions and also high static load bearing capacity which make the support effective to combat rock burst problem (Li *et al*., 2014). As the increase of mining depths make miners face with the rock burst problem, the energy absorbing rock bolts seem to be used more widely in future than being in todays. **Figure 4** illustrates the high deformation let by the Roofex type energy absorbing rock bolts.

THIN SPRAY-ON LINER COATED ROCK BOLTS

The deficiencies of tunnel supporting lead up to be improved by including the use of new mate rials. Corrosion problem can be considered as the most important problem of steel support usage. Underground water can substantially affect steel support material and decrease the load bearing capacity especially for long terms and acidic underground water conditions (Ranasooriya *et al*., 1995; Li and Lindblad, 1999; Komurlu, 2012; Hassell and Villaescusa, 2005).

The polyurea-type thin spray-on liner was firstly applied to be water resisting coating for the steel rock bolts in 2013 (Komurlu *et al*., 2014; Komurlu and Kesimal, 2014). Polyurea is an isocyanate-based copolymer used for surface treatment applications, such as liners for truck beds, tanks, ships, buildings, pools, and waste deposition isolation plants, because of its good water-resisting performance (Komurlu and Kesimal, 2012). Polyurea is being used as spraying membrane in tunnelling and a support called thin spray-on liner (TSL) (Holter, 2014; Ozturk, 2012). It has good adhesion with rock, concrete, and steel surfaces (Ozturk and Tannant, 2010; Tannant, 2001; Komurlu and Kesimal, 2013b; Jain and Gupta, 2012; Ozturk, 2012; Komurlu and Kesimal, 2012; BASF, 2009).

A Turkish copper mine with acidic underground water condition was the first area to apply the polyurea coated rock bolts. Rebar and split set types of rock bolts were easily coated with polymer spraying method. It was found that material and workmanship costs for the surface treatment method are quite low; two people can easily coat more than 100 rock bolts in one hour. Long and short terms pull-out tests were separately performed on polyurea coated and uncoated rock bolts to examine the effect of the surface treatment method on rock bolt corrosion and load bearing capacity. It was confirmed by the tests applied on the grouted rebars that polyurea has excellent adhesion with steel and cement mix injections. In addition, the substantial increase in pull-out test results for the split-set-type frictional bolt showed that the polyurea coating adheres well to the hole surface. The results indicated that polyurea coat significantly increases frictional load bearing performance of the contact between the bolt and the rock surface. It was observed from the field study that polyurea type TSL prevented steel corrosion economically while bolt load bearing capacity was being increased significantly (Komurlu and Kesimal, 2014). **Figure 5** shows the polyurea type thin spray-on liner coating and the surface of polyurea coated rock bolts.

FRICTIONAL ROCK BOLTS WITH PLASTIC BODY

Komurlu and Kesimal (2015) have started to investigate the use of fiber reinforced engineering polymer tubes as frictional rock bolt, obtained proper load bearing capacities with tests applied using the plastic frictional bolts. The plastic frictional bolts developed by Komurlu and Kesimal are plastic type split sets which have thicker tube wall in comparison with typical steel split sets. The fitting devices, material handling and application details for the plastic split-sets are still being developed with laboratory and field studies performed in Turkey and Australia. Some field studies showed that frictional load bearing capacities of steel split sets applied in a mine with acidic underground water problems resulting from sulphuric ore content can decrease by 400% only within several months, although they are galvanized (Komurlu and Kesimal, 2015). New, economical, and high strength polymeric split sets with high chemical resistivity are expected to be helpful for improving the rock bolt performance especially for the corrosive ground conditions.

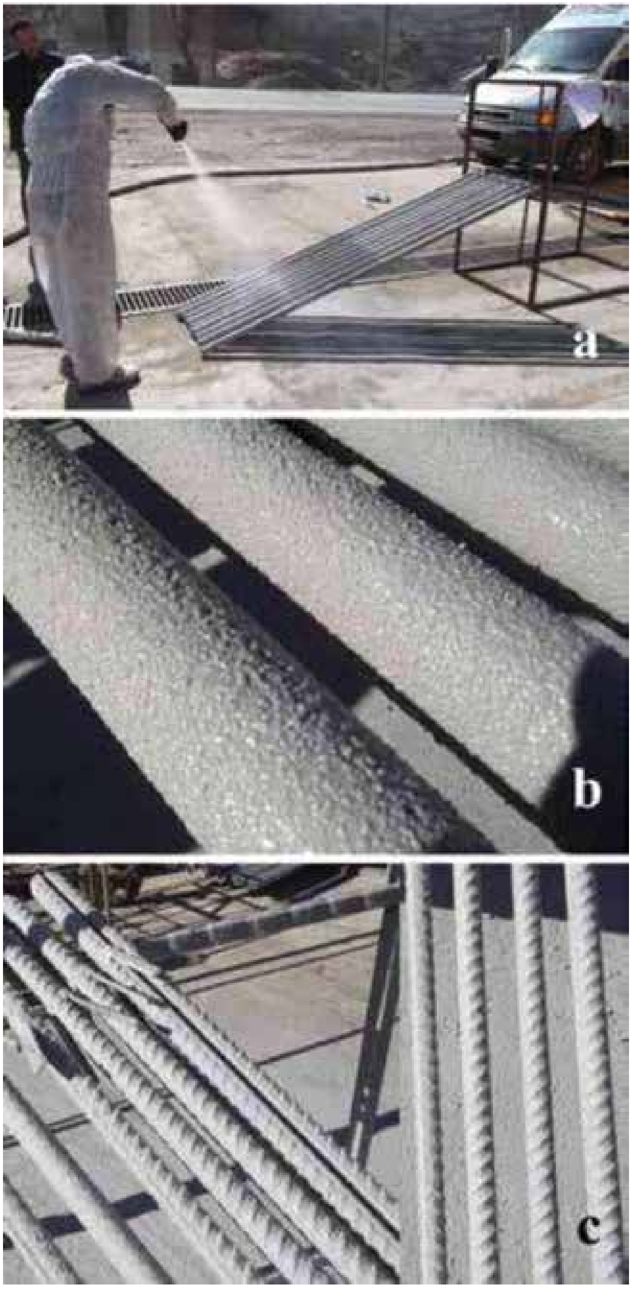


Figure 5: Polyurea coating on rock bolts, (a) s ray-application of polyurea coating, b) polyurea coated split set bolts, (c) polyurea coated rebar bolts (Komurlu and Kesimal, 2014).

TUNGSTEN CARBIDE DRILL BITS

The improvements in the drilling technology were not only increasing the rate of excavation, but also made rock bolt application easier and more effective. The invention of drill bits with tungsten carbide tips can be accepted to be one of the most important inventions of drilling in rock engineering

The invention of the electric furnace in 19th century opened the way for experiments on the reactions of elements at extremely high temperatures which could make tungsten carbide possible to be produced. The tungsten carbide alloy firstly produced in the late 19th century was an important milestone in rock engineering which was firstly produced in France. In 1920's, a German firm took over the production of sintered tungsten carbide products and introduced hard metal alloys made from sintered tungsten carbide which were marketed under the name "Widia" meaning "like diamond". In 1928, the manufacture of sintered tungsten carbide tools began to be sold in outside of Germany. The production of sintered tungsten carbide in Germany rose from 1 ton per month in 1930 to 40 tons per month in 1944 (West, 1988).

Indeed, results of the idea of using rock drill bits with early tungsten carbide tips were not desired because of brittleness and brazing difficulties. The idea was taken up in the early 1940s as a result of co-operation between Atlas Diesel (Atlas Copco today) and Luma which was a firm making electric light bulbs. Atlas designed the sintered tungsten carbide bits and Luma manufactured them. Later on, Luma's tungsten carbide manufacturing operation was taken over by Sandvik, but Atlas and Sandvik continued with the joint development work. In 1947, many of the difficulties to produce economical and effective drill bits with tungsten carbide tips had been overcome and the world-famous drill steels tipped with sintered tungsten carbide came onto the market (Gardlund *et al*., 1974).

COMPRESSED AIR ROCK DRILLING MACHINES

Before the 1850s, the method of driving tunnels was same with that used for the previous 200 years. The heading was advanced by drilling a number of holes into the face. The drilling was done by a man holding the drill steel and two other men hammering to penetrate the drilling steel into the face. The basic features of the method are illustrated in **Figure 6**. A drilling steel would only drill about 0.3 m because of becoming blunt. A procession of men, or boys, carried sharp drill steels to the face and took the blunt drilling steels to bring them for resharpening. Drilling rates for a single hole were as slow as a meter per three hours (Stauffer, 1906). After having the enough number of holes drilled into the face, the holes were charged with gunpowder also called "black powder".

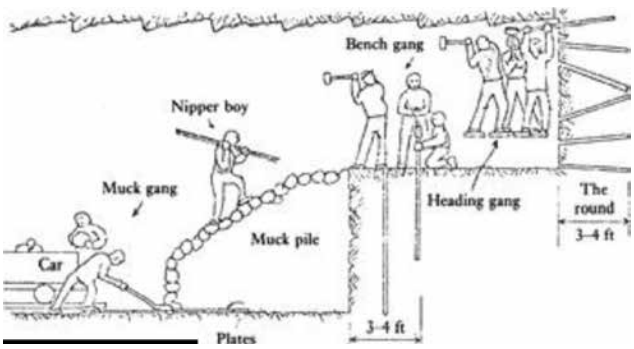


Figure 6: Tunnel driving in the 19th Century (West ,1988).

From the 1850s, tunnelling was revolutionised by extremely important innovations such as the compressed air rock drilling machine use in 1850s, the use of nitroglycerine explosive in 1860s, the tungsten carbide drill bit in 1940s, the hydraulic rock drilling machine in 1970s.

Although the steam engine was available as a source of power for operating a rock drill in 1840 and 1850s, a steam boiler could not be operated in the space of a tunnel as the exhausting steam was a big disadvantage making the working atmosphere intolerable. A solution to the problem was using compressed air rock drilling machines for driving holes into the face. Air compressed drilling machines was used in 1850s in European mining industry. The first time for use of air compressed drilling machines in tunnelling industry is known to be 1861. The Mont Cenis Tunnel was built to provide a railway connection between Chambery in France and Turin in Italy. Construction started in 1857 and the tunnel was constructed by manual drilling until 1861, with the advance rate of only 7 meters per month. Germano Sommeiller was responsible for the design of the rock drilling machines to increase the efficiency in the tunnel excavation. He introduced air drilling machine to be used in the Mont Cenis Tunnel in 1861 (West, 1988). As mechanised rock drilling in the Mont Cenis Tunnel had become to be a routine operation by the middle 1860s, the rate of advance increased to 70 meters per month.

The first use of compressed air rock drilling machine in USA tunnels was at the Hoosac tunnel in 1866. During the 1860s, different rock drilling machines were being fastly developed in United States of America, an engineer, Charles Burleigh worked on and produced an efficient compressed air rock drilling machines to be used in tunnelling industry. The Burleigh drill machine was started to use in Hoosac tunnel and significant improvements in the machine was carried out with new works (Andre, 1876). A sketch of the Burleigh's compressed air drilling machine produced in 1870 is shown in **Figure 7**.

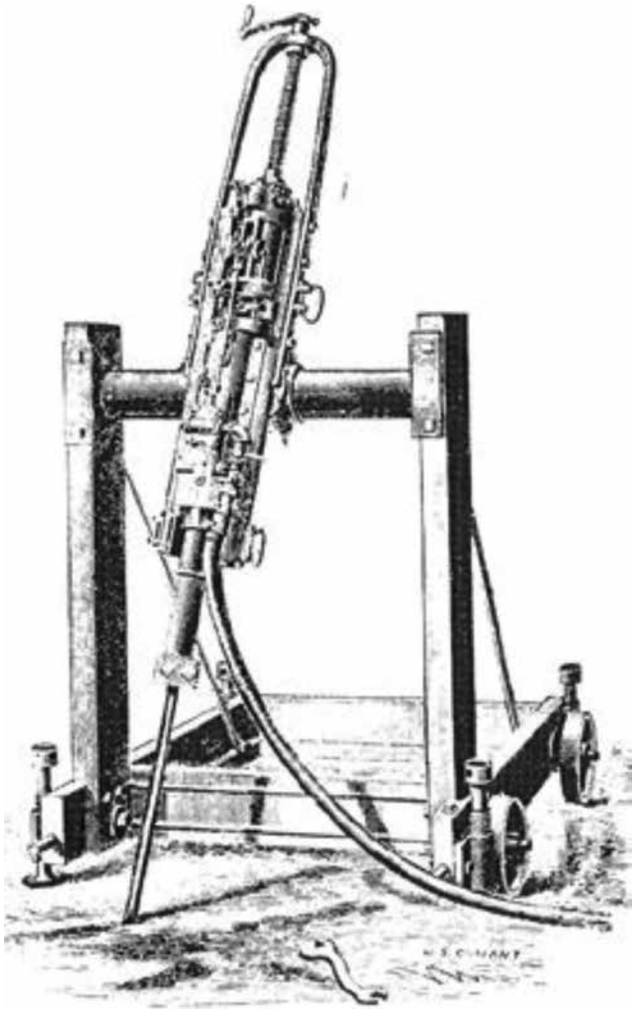


Figure 7: A primitive rock drilling machine used in 19th century (Andre, 1876).

HYDRAULIC DRILLERS

In 1876, the first hydraulic rock drilling machine was invented by a German engineer, Alfred Brandt (1846-98). Brandt had the idea of utilising the waterpower directly for avoiding the energy loss involved in compressed air method. He firstly developed a percussive type rock drill machine similar to the compressed air rock drills except that it was driven by water pressure instead of compressed air. Although the first machine was unsuccessful, it was important milestone for the second drilling machine of Brandt which was successfully used in rock drilling applications (Sandstrom, 1963). The second machine was operated with the water consumption of 1.8-2.5 m3 per hour. Its hydraulic engine developed 8-15 hp and run at 200-300 revolutions per minute. (Stauffer, 1906) By the development in hydraulic rock drilling machines, oil was started to use instead of water, and modern drilling machines used in nowadays have been shaped.

JUMBO DRILLER MACHINE

Because heavy driller machines and devices being able to drill holes with high lengths has to be hold and controlled effectively, proper mounting equipment's were needed to use. Invention of the jumbo drillers can be accepted to be an important stage in development of modern drilling machines. The first working hydraulic percussive rock drills with hydraulically controlled articulated arms were pioneered by Montabert which is a major drilling equipment manufacturer situated in France. The first machine was introduced in 1969. Then, the jumbo machines were quickly developed in different countries. Six European and two American drill machines manufacturers had their own versions of the new hydraulic rotary percussive rock drilling machine in 1974 (West, 1988).

Jumbo driller has made easy to drill holes in rock engineering and significantly increased the excavation rates. As well as excavation, modern jumbo drillers have significantly bettered the practicality of the rock bolting applications. Before the invention of jumbo driller machine, it was not practical to drill rock bolt holes especially for the roof. The increase of drilling efficiency due to the developments in machinery science is illustrated in **Figure 8**.

ROCK BOLTER MACHINES

Jumbo drillers have been modified to be able to insert rock bolts in addition to drilling the holes rock bolts are inserted in. The machines called as rock bolter also have devices to grout the hole. Therefore, they have made rock bolt application more practical and significantly decreased the time needed for carrying out the rock bolt applications. The rock bolters are known to use in 1980s (Nelson, 1986)

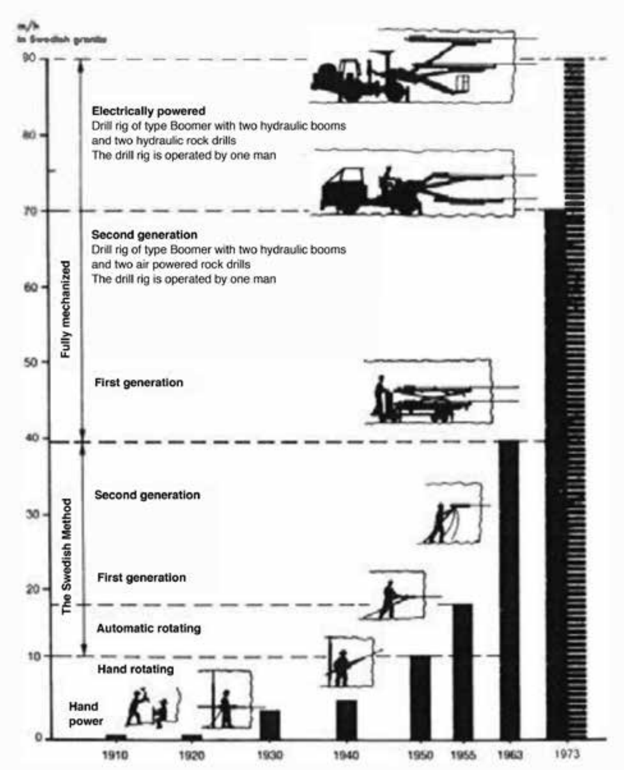


Figure 8: Increase in drilling rates (West, 1988).

SELF-DRILLING BOLTS

The self-drilling bolts used since 1980's have front part with drill-bit and enable high rates of installation good directional stability and also help to consolidate the grout within the borehole. Self-drilling rock bolts provide a unique bolting solution for unstable drill-hole conditions as in drilling in highly fractured rock masses. The technique of the self-drilling can be accepted to supply an important contribution to the rock bolting. **Figure 9** shows a self-drilling type rock bolt.

CONCLUSIONS

The invention of the rock bolts can be accepted to base on the improvements of material and engineering sciences in 18th and 19th centuries. Because of increasing demand for new transportation networks which mostly resulted from the industrial revolution and finding opportunity to start using steel support materials due to the developments in the metallurgy, the second half of 19th century was a time for significant leaping forward of the tunneling industry to change into a modern industry. However, the most important development in understanding the ground reactions and realizing the contemporary support strategies were because of the new supports of rock bolts and shotcrete entering in tunneling industry in 20th century.

The entrance of the new materials in applications caused not only many of the important improvements in the rock bolt support history to come true, but also all the topics in the rock engineering. The main idea of contemporary support is use of rock mass to support itself, which could be supplied by using rock bolts and shotcrete, preventing to carry dead load of rock mass. In the 20th century, many of the ground conditions which were quite difficult to excavate and support have become possible application areas as a result of using new materials, support methods, machines, and new systems in rock engineering.

Although steel materials have caused big advantages in rock support applications, it has some lacks which need to be improved by use of new materials. New engineering polymers have been started to use as support materials because of their chemical resistivity, light density, high load bearing capacity especially against the dynamic loads. Nowadays, high strength new engineering polymers and composites are being produced and derived. To have better solutions in support practices, new polymeric materials and their composites should be assessed in comparison with other engineering polymers, which may have even better effects on support performance.

The success in today's rock bolting applications is result of many developments in different scientific disciplines and technology. A better focusing on the history of tunnel supporting would be helpful for new developments and enlarging the frontiers of the rock engineering.

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Figure 9: Self-drilling rock bolt (URLI).

Epiroc Office TeleREMOTE Pushing the boundaries, in more ways than one

This brand-new product is designed to control SmartROC DTH drill rigs*, MK I (based on RCS 4 platform) from a remote location. Office TeleREMOTE has been designed to address the need for increased safety, efficiency and productivity and removes the operator completely from the potentially dangerous mine environment. SmartROC rigs are controlled safely and efficiently from an office located on the same local area network (WLAN) as the quarry or mine. This dramatically improves the working conditions for the operator, boosts safety and ramps up efficiency.

Mining Quarry World interviews Mayya Popova Product Manager Automation for Epiroc about the Office TeleREMOTE, its performance, capabilities and her role within Epiroc, asking the questions centred around the mining industry and if it perpetrates prejudices that women cannot handle technology or be part of a worldwide mining community. Mayya Popova speaks passionately about her involvement in this great industry of ours.

This smart product enables the operator to access and run multiple rigs from a control centre located inside an office. You have the option to select the stand-alone Office TeleREMOTE solution or to update any existing BenchREMOTE to a teleremote operations by connecting it to a Wireless Local Area Network (WLAN).

"With Office TeleREMOTE, a single person can control multiple drills in a productive and efficient manner", says Mayya Popova, Product Manager Automation at Epiroc.

One of the biggest benefits of Office TeleREMOTE is its ability to effectively increase the number of productive hours in a day. It will optimize time as it reduces operator transports and idle time due to shift changes. Remote drilling, together with AutoDrill and Auto-Rod Handling System features, boost productivity as the drill rigs can work almost continuously without breaks.

"Office TeleREMOTE drastically increases efficiency as it improves how the work site utilizes the equipment. For many customers, the balance between capital investments and any expected return is critical", clarifies Mayya Popova.

The safety aspect is always a top priority. The Office TeleREMOTE operator can run the rig without taking any risks thanks to multiple onboard systems. The operator uses the Hole Navigation System for accurate positioning and a geofence function ensures that the rig stays within the predefined area. The remote rigs are also fitted with multiple cameras which provides the Office TeleREMOTE operator with a 360° view all around the machine.

Office TeleREMOTE consists of a suitable work desk with adjustable height and ergonomically designed operator controls mounted on it. The two controls and operator display are the same as in the drill rig cabin, so the operator will immediately feel familiar with this setup. The product also includes a server rack with Epiroc Automation Common Machine Server (ACMS), a video system and a safety system capable of handling one remote drill rig, with an option to be extended up to nine drill rigs, in increments of one, if required.

"The Office TeleREMOTE operator is less exposed to the harsh work site environment. The operator spends every single workday running equipment in an improved working environment with increased comfort", Mayya Popova explains.

Office TeleREMOTE is designed to remotely operate surface drill rigs in open pit mines or quarries only.

*The SmartROC models currently compatible with Office TeleREMOTE work desk are: SmartROC D50 MKI, SmartROC D55 MKI, SmartROC D60 MKI and SmartROC D65 MKI.

Interview with Mayya Popova of Epiroc: Product Manager Automation

MQW: How did you get into mining, was this by chance or a pre-conceived career path?

MP: "I studied Mechanical Engineering at University in Novosibirsk in Russia gaining many of my qualifications at this educational institution. I was one of only two females within this cohort, which for this University was considered a novelty as this area was mostly dominated by men. My original intention was to direct a career towards the car industry, however, my father (at the time) worked for an international mining OEM company, which subconsciously could have guided me and my thoughts towards another area of engineering".

***MQW*: How long have you been with Epiroc?**

MP: "I started my career with Atlas Copco in 2015 as sales engineer and consequently pursued and worked with various types of equipment, products and services sales, both from a surface perspective and underground".

***MQW*: Where do you think your strengths are in relation to working for Epiroc and as a woman in mining?**

MP: "My strengths within the family of Epiroc undoubtedly lay within the customer focus having worked with and had to liaise with customers from a variety of backgrounds and equipment emphasis. These experiences have led me to develop an understanding and synergy of the customer requirements, needs and problems associated when purchasing and using a product. It is these experiences that have developed my problem-solving skills and approaches, ensuring that the customers achieve the absolute best from their product purchases".

***MQW*: What are your aspirations for yourself and where do you see your career heading in the next 5 years?**

MP: "I have a loyalty towards Epiroc as my career has progressively been developed from my introduction at Atlas Copco and then through to Epiroc, however, in terms of areas to personally develop, I would prefer to remain with the automation side of products as I feel this is the future and where mining is heading, allied to this direction I also truly enjoy my work; even if this means taking a sideways move as opposed to an upward move/promotion".

***MQW*: What is a typical working day for you and what does it involve?**

MP: "Most of my day is product specific and involves meetings and decision making about my products with colleagues from different departments. One of my roles is always to take the customer perspective when we have discussions around 'best fit' technologies and engineering solutions, ensuring that the decisions we make will be economically effective for all parties concerned".

***MQW*: How passionate are you about your product?**

MP: "I have always given 100% behind a product I have been linked with and truly believe that whatever product I am promoting is one of the best on the market at that time and fits the customer's needs in every possible way".

***MQW*: How do you think the Office TeleREMOTE compares with other products on the market today and what makes it stand out from other products?**

MP: "Currently the market shows quite a few products with the same sort of technology via our competitors, however, it's important to note that our product highlights increased time and equipment utilization. In addition, it is a truly scalable solution that allows operating from one up to nine remote drill rigs. For many customers, the balance between capital investments and any expected return is critical".

"Some of the main benefits to our system are: Enhanced safety. Mines and quarries can be dangerous places. The Office TeleREMOTE allows the operator to be totally removed from the work-site – this drastically increases safety".

"Improved working conditions for operators. SmartROC rig operators can sit together in the office control centre away from noise, danger and dust".

"Increased utilization, productivity and efficiency. Each Office TeleREMOTE controls a single SmartROC rig as standard – with an option of extending to nine machines using the same server rack. This represents a massive increase in equipment utilization and return on investment for each rig".

***MQW*: How reliable do you think this product is in terms of signal and remote location?**

MP: "It Is quite common for our customers to already have an infrastructure that supports various types of equipment they run on their work site. Consequently, Epiroc always provides a list of minimum wireless network requirements and recommendations that should be met thus allowing the utilisation of the Office TeleREMOTE product.

This means that the control centre can be located a distance away, so long as it is on the same network. For safety reasons, if the network connection between a drill rig and an Office TeleREMOTE station is lost, the drill rig safety system will trigger the emergency stop to shut down the engine and place the I/O modules in a safe state".

***MQW*: How do you ensure the reliability, function and efficiency of the Office TeleREMOTE for a customer?**

MP: "Even the best equipment needs to be serviced regularly to make sure it sustains peak performance. An Epiroc service solution offers peace of mind, maximizing availability and performance throughout the lifetime of your equipment. We focus on safety, productivity, and reliability. By combining genuine parts and an Epiroc service from our certified technicians, we safeguard productivity – wherever you are".

***MQW*: What are your thoughts about women in mining?**

MP: "I am quite clear about my role within Epiroc and I have nothing but praise for the way in which Epiroc have developed and given me the opportunities to progress in this industry, however, from a 'women in mining' perspective I believe that irrespective of the role or product there should always be an opportunity for both men and women, Epiroc have in the past launched several initiatives to promote women in engineering, and specifically in mining, which can only be a good thing. When a position becomes available it should always be given to the best person for that particular position with no bias towards male or female".

***MQW*: If there was one thing you could change (with reference to your career at Epiroc) what would it be?**

MP: "On a personal note I'm not sure how I could answer that as I am quite satisfied with the way my career has progressed, especially with Epiroc, however, in relation to other 'women in mining' I wish I could have encouraged more to come into this profession as it is quite a challenging environment".

***MQW*: Are you a member of any organisations for 'women in mining'?**

MP: "I have followed the path of women in mining but myself I have not been an active member of any organisation that promotes women in mining and have never seen myself as somebody who could lead these type of group activities, I have been more of a follower than a leader of this type of role".

***MQW*: How does Epiroc support you and your role?**

MP: "I receive lots of support from my colleagues when situations arise, e.g. technical questions, software related challenges, etc. With my manager we openly have discussions about the way forward, I think it's important that we can freely discuss ideas and options on an open-ended basis".

Mining & Quarry World would like to thank both Mayya Popova (Product Manager Automation) and Anders Bromsjo (Project Manager – Brand Communication) for their time and co-operation in allowing this interview and article to be published.

Platinum well positioned in hydrogen economy's sweet spots

The upcoming platinum demand of Hyundai alone could come close to taking up the total annual production of one of South Africa's biggest platinum mines.

Hyundai has stated categorically,that it will be making 700 000 fuel cell stacks a year by 2030.

While Hyundai has not given exact platinum loadings for the fuel cell stacks, it is estimated that each fuel cell stack will require about 1 oz of platinum, which would total 700 000 oz of platinum per year, just for Hyundai alone.

"That's almost equivalent to what Rustenburg produces annually, so it's a significant amount of demand," World Platinum Investment Council director of research Trevor Raymond commented recently.

"If you talk 2030, there's a debate on whether you'll have either one-million or five-million fuel cell passenger vehicles on the road, and that's ten years out. What Hyundai is saying is 700 000 stacks of which a third will go to trucks and they will have two stacks per truck, or about 2 oz per truck, that still leaves 500 000 oz going into cars.

At the moment Toyota's Mirai and Hyundai's Nexo also use about an ounce, which should come down with mass production over time.

"So, what Hyundai is saying is that they probably believe that they'll be somewhere between 300,000 or 500,000 vehicles that will be fuel cell Hyundais as part of a larger global fleet, and that fleet is growing quite aggressively in China," said Raymond.

The likely demand for platinum in the short term comes from heavy duty trucks. Hyundai Xcient fuel cell trucks are being rolled out in Europe.

Toyota has put the Mirai content into Class 8 fuel cell trucks and these are being trialled at the Port of Los Angeles, in the US. There are many bus fleets around the world, particularly in Shanghai and Beijing and in the north of China, that are converting to fuel cell.

"That demand is quite good but from heavy duty trucks, you're probably looking at 100 000 oz to 300 000 oz of platinum demand in the next three years, so that suddenly becomes material to short-term interest," he added.

Reclaiming tailings sustainably with a Weir Mobile Pumphouse

Inside our engineered to order, innovative mobile pumphouses for managing intensive tailings.

Water requirements for intensive applications such as hard rock mining and oil sands processing have historically been supplemented by local water sources. Today, these applications face new challenges as the focus shifts to how operations can minimise their environmental footprint, but continue to improve productivity while also complying with new regulations. This global shift in focus reveals the need for increased sustainability in tailings processing.

The way forward is not only installing energy-efficient products that offer improved reliability, but also working directly in partnership with companies such as Weir Minerals that can design engineered-to-order solutions tailored for optimised and sustainable results.

One of the ongoing challenges for customers is tailings reclamation. The question of how best to reduce dependence on tailings ponds, yet expedite reclamation of both water and product in the process, was top of mind for one Weir Minerals customer.

Pumping stations are a critical element of tailings management, providing the energy needed to drive the downstream processes. Static slurry pumphouses have until now been the norm, but they are costly and present many limitations when considering alternate tailings processing techniques.

A NEW APPROACH TO TAILINGS RECLAMATION

When the customer approached the Weir Minerals Canada dewatering team with a vision to mobilise the pump system for their new tailings treatment process, initially they didn't even know if it was even possible.

"The sheer size and energy requirements of the equipment needed for the application meant that this was a huge undertaking from the beginning. You don't normally think of 3,500HP pumps and 160 tonnes of equipment as mobile," explains Kris Kielar, Product Manager for Dewatering Engineered to Order Solutions at Weir Minerals Canada.

The Weir Minerals team worked directly with the customer to design an innovative booster pumphouse, engineered especially to manage the Non-Segregating Tailings (NST) on site. The proposed solution was an integral piece to reduce the tailings pond footprint on site through accelerated fines capture and decreased fluid tailings production, thus releasing more water for recycling thereby reducing necessary water intake from local sources. This

in turn would expedite reclamation to create landforms that support wetlands and self-sustaining forest ecosystems.

The standard tailings processing model takes time, but this solution dramatically reduced tailings residence time with a total solution realised through Weir Minerals equipment. Multiflo® pump barges mounted with Hazleton® submersible slurry pumps extract the target fluid tailings that feed high-powered, land-based, Weir re-locatable pump houses. Inside the pump houses, Warman® slurry pumps boost recovered tails from the pond to drive the new tailings treatment process plant.

Kielar continues, "By working directly with the customer, we understood not only their desired outcome, but also the existing capabilities on site. We stayed close and were able to proactively tweak our design based on the customer's needs, so when it was time to present, we were already prepared with the ideal solution."

ENGINEERING FOR EXTRA VALUE

The Weir Minerals dewatering team designs solutions using highly engineered and reliable equipment that isn't just efficient, but also adds value to a customer's site process. For example, the entire module of the Weir mobile pumphouse can be built offsite at a much lower cost than traditional pumphouses, which are built in-situ. Building a pumphouse in-situ is time-consuming and expensive, as the method requires skilled trades to work for extended periods of time in remote locations.

"Competitor pumphouses built using in-situ construction methods can more than double the construction time and costs compared to the steel fabrication methods we have used," states Peter Pavlin, Weir Minerals' North America General Manager of Engineering. "When faced with a complex problem from a customer we always evaluate the situation holistically and strive to develop a new approach. That's the beauty of engineering, the possibilities are endless, and the Weir Engineering Team have the expertise and tenacity to go against the norm and develop novel and cost effective solutions," states Peter Pavlin.

The Weir mobile pumphouse is an innovative solution that provides a variety of pumping possibilities for intensive tailings applications. It's designed to relocate across the site using especially engineered, military-style skid and "jack-and-roll" elements and a novel patent-pending pump/motor suspension system, providing a unique advantage in mobile pumphouse technology. These advances provide operators with distinct advantages over traditional fixed-in-place designs, creating a more agile and cost-effective solution.

"Our ground-breaking design sets a new standard for tailings management applications. Other pumphouses in the market are static and often cause difficulties for operators when they wish to expand into new areas, as they must discontinue service, resulting in a large capital expenditure. Our solution has overcome these limitations by providing the customer with the tools to rapidly reconfigure a changing pumping network and move it to other sections of the tailings pond," explains Pavlin.

The Weir mobile pumphouse incorporates an integral gland water supply system and a separate eHouse for power control and remote communication. A patent-pending, three-point pump base mounting system allows the base and skid to act independently, minimising the risk of pump and motor shaft misalignment during operation and the relocation process.

OPTIMISING YOUR TAILINGS OPERATION

"Establishing relationships with our customers is just the beginning," Kielar explains, "By working closely together over several years, we learn the ins and outs of their operation. We hear feedback directly from the people who work with our equipment, and that helps us create even better solutions."

No matter the application, Weir Minerals' tailings reclamation solutions put partnership and efficiency first.

Having in-house engineering expertise means that we work directly with our customers to create solutions that consolidate waste to recover more product more easily, while also extracting reusable water and sending it back into the process plant more quickly than other standard solutions.

To find out more about this offering and how it could optimise your site, contact your local Weir Minerals representative.

NEWS, PLANT AND EQUIPMENT

New Cat® Durilock™ Shroud System for underground loader buckets cuts maintenance time and allows fast adaptation to application needs

Caterpillar has developed the new Durilock™ Lip Shroud System for underground loader buckets. The fully integrated bucket system features hammerless installation and maintenance-free retention of GET with Cat Infinitite™ elastomer compression retainers. Three interchangeable shroud styles enable a mining operation to quickly remove one type and replace with the type that is best suited to the loader application – without changing the base edge or retention system.

The Durilock system delivers 50% faster installation and removal of GET compared to legacy, mechanically attached systems, and, because there is no need to re-torque bolts periodically, maintenance time for GET is reduced by more than 50%. Additionally, integral corner guards extend bucket in-service time by about 30%.

The Durilock Shroud System is available for Cat R1700 to R3000 loaders and most buckets of 5 to 10 cubic meters capacity.

Innovative, adaptable GET

The Cat Infinitite retention design provides superior retention reliability without time spent performing re-torque procedures. The elastomer compression retainer installs in seconds to allow fast installation and removal. There is no complex hardware to fail, handle or tighten.

The Durilock system offers three different shroud styles to enable matching the GET to the application and conditions in the mine. The D50S Standard is a traditional wedge shape used in most production and development applications. The D50A Abrasion has a contoured design and repositions more material on the shroud base, and the D50P Penetration has less leading-edge material to deliver easier penetration in dense material.

The lip assembly provides the mounting surfaces for the shrouds and corner protectors, which balance corner and center station wear rates. Cast corners are welded to the base edge assembly to create the lip assembly. The corners incorporate a stepped design that eliminates corner shroud torsional loads and delivers superior reliability. The integral corner design boosts corner life by 15% and improves penetration as compared to systems that experience corner erosion and shortened bucket life due to corner rounding.

With the addition of Durilock, Caterpillar has a complete portfolio of GET products that are designed to meet the unique and challenging requirements of any underground mine. For more information about Durilock and Cat GET offerings for underground loaders, contact the local Cat dealer.

Voith successfully implements first BeltGenius ERIC system

The mining industry is facing serious challenges, including declining ore concentrations, harsh weather conditions at remote locations and a growing interest in environmental protection. Voith is responding with new digitalised solutions to meet these challenges and to permanently increase mine productivity. Voith has been successfully running a first prototype of the digital twin BeltGenius ERIC at a renowned European mine operator for some time now.

The project has now reached a relevant milestone, with all the key figures announced at the beginning of the prototype run having been realised for the customer since the start of the project. BeltGenius ERIC analyses and compares on the basis of standardized values how respective belt conveyor systems of a mine perform. By means of these key figures, Voith is able to identify physical deviations of the belt system, which serve as an early indicator of failures. In addition, the mine operator is given a starting point for determining how efficiently the respective system transports material. With the help of this key figure, conveyors can be compared with each other.

In this case, the newly defined data made it possible to take measures that led to improved uptime and reduced energy consumption. The prototype is used in a belt conveyor system with a capacity of 37,500 tons per hour and a speed of 7.5 meters per second. The belt of the system is 2.2 kilometers long and 2.7 meters wide and is completely digitally mapped by the system.

"BeltGenius ERIC has achieved all planned key figures at the customer's site," says Dr. Manfred Ziegler, Business Development Manager of Belt Conveyor Systems at Voith. "The exact image of the belt conveyor system generated by the digital twin enables us to create further added value for our customers and thus maximise productivity."

Next level of condition and efficiency monitoring

Voith BeltGenius is the product family used for monitoring, benchmarking and optimising belt conveyors and conveyor systems. BeltGenius ERIC is a digital twin of the conveyor belt. It processes sensor data in real time to calculate the Performance Indicator of the respective conveyor belt and to point out possibilities for performance improvement.

Find more information online: www.voith.com/beltgenius

Zyfra installs drill management system at 50th location

Zyfra has completed the 50th installation of its high-precision drill management system (Zyfra Precision Drill), which increases productivity and quality of drilling operations in open-pit mines based on high-precision navigation and real-time monitoring of drilling parameters.

The 50th Zyfra Precision Drill installation happened at the Berezovskiy open-pit mine, one of the leading coal producers in the Kuznetsk Basin (Kuzbass) in southwestern Siberia, Russia. The mine is owned by the Stroyservis company.

Zyfra Mining (formerly – VIST Group), a division of Zyfra, has a successful record of work in the mining industry for over 30 years with 100+ mines using the company's products, including mine fleet management systems and autonomous mining dump trucks.

“By 2022 we plan to add our drill management solutions to 30 more locations across the globe. The next step in our continuous technology development would be the upgrade to autonomous drilling, which can include tele-operation,” said Liana Meliksetyan, chief operating officer at Zyfra.

The implementation of the system allows to significantly improve the drilling process, replacing the physical control points with automated high-precision navigation on the blast hole grid.

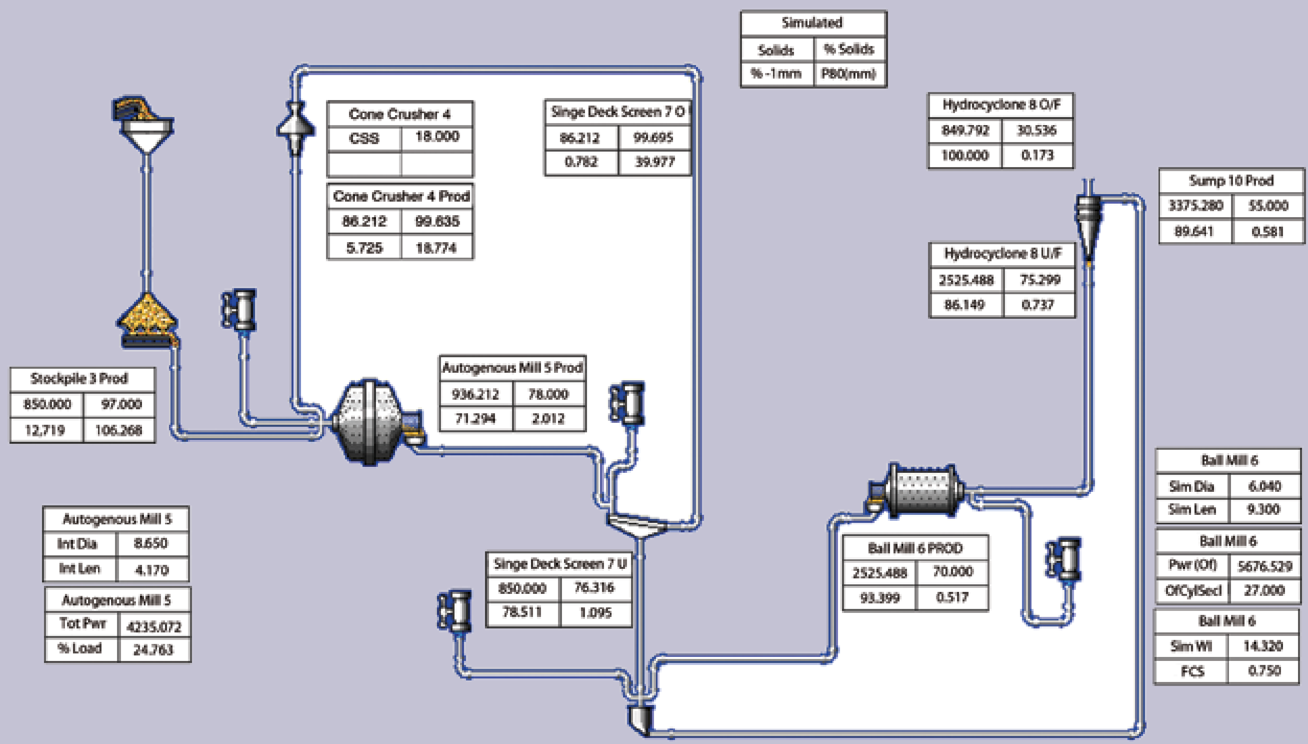
Information received from drill rigs in real-time can be reported in various ways, that allows quick monitoring of the drilling parameters from the machine cabin and on mobile devices, as well as to analyze the hardness of rocks when planning the blast site.

Zyfra Precision Drill can also increase the quality of blasting through automatically collected information about the hardness of rocks.

According to EuroChem, one of the world’s leading mineral fertilizer producers, implementation of the Zyfra Precision Drill reduced idle times on average by 12 machine hours a week.

According to GV Gold (also known as Vysochaishy), one of the fastest growing Russian gold mining companies, the Zyfra Precision Drill implementation has significantly improved the drilling process. With the same number of drills, the blast volume has increased by 20%. There was also a 15% increase of drill rig productivity and a 10% reduction of re-drilling volume among the expected results of the system implementation.

Zyfra Precision Drill can run in the Cloud or on mine servers, and can provide easy data exchange between the various parties involved with the drilling.



Comminution of critical metal ores

Over the last decades, several reliable mathematical models have been developed for simulating ore comminution processes and determining the Work Index. Since Fred Chester Bond developed the Work Index standard procedure in 1961, numerous attempts have been made to find simpler, faster, and economically more advantageous alternative tests.

In this paper, a Bond test simulation based on the cumulative kinetic model (CKM) has been checked on a spreadsheet. The research has been accomplished by conventionally determining the kinetic parameters for some Ag and Au ores and for three pure minerals and one rock that are common constituents of the gangue rock. Analysis of the results obtained allowed to develop a simplified procedure for calculating the kinetic parameters and their application to Work Index determination through simulation.

INTRODUCTION

Energy consumption during the comminution stage has a severe impact on the operational costs of ore processing plants, being a key factor in operation planning and optimization. This situation has drawn the interest of researchers on early stages of ore processing, who tie the amount of energy consumed with the work done in the comminution of the mineral species involved.

The First Law of Comminution or Rittinger's Law[1] dates back to 1867 and postulates that the energy required in the mineral breakage is directly proportional to the new surface area produced. Later, in 1885, the Second Law of Comminution was postulated by Kick[2], who stated that the energy supplied is proportional to the particle volume, regardless of the original size. In 1952, Fred Chester Bond[3,4] postulated the Third Law of Comminution (also known as Bond's Law). It states that the energy required is proportional to the length of crack initiating breakage. However, as mentioned by Jankovic *et al.*[5], the application of Kick's and Rittinger's laws has been met with varied success and are not realistic for designing size reduction circuits, while Bond's Third Law can be reasonably applied to the range in which ball/rod mills operate. In spite of its empirical basis, Bond's Law is the most widely used method for the sizing of ball/rod mills and has become a standard.

Nevertheless, despite being unrivalled, it has an error range of up to 20%. Besides, determining the Work Index (wi) for a given mineral or ore composition is a time-consuming procedure that requires qualified personnel and a significant quantity of sample[6-8]. These drawbacks were resolved to some extent by several researchers, who developed alternative methodologies to determine energy consumption during crushing and grinding[9-15]. Some methodologies[7,16-20] employed mathematical simulations based on tested mathematical models. In all cases, they involve an adequate characterization of the material in the laboratory, followed by the simulation of the grinding and sorting operations of the standard test to determine the Work Index (wi). The cumulative kinetic model (CKM) was developed by Laplante *et al.*[21], and it represents a simple solution to the basic equation proposed by Loveday[22]. As Menéndez-Aguado[8] pointed out, it possesses several advantages, the main of which are that the model is defined by two parameters, simplifying the interpretation of the results and that the parameters determined in the laboratory can be applied at industrial scale[23].

THEORETICAL BACKGROUND

The Cumulative Based Kinetic Model

The CKM is based in a first-order kinetic equation, in which the particle breakage rate for a given particle size interval is proportional to the mass existing in that interval. It has the particularity of being defined in terms of only two parameters, which may be determined in laboratory batch tests and then directly applied to the model. The kinetic parameter (k) is defined as the oversize disappearing rate for a given size class, either at continuous or discontinuous grinding under a piston flow regime, and can be described as shown in **Equation 1**.

Equation 1

$$W_{(x,t)} = W_{(x,0)} \exp(-k\,t)$$

where:

$W_{(x,t)}$ = cumulative percent of oversize for size class *x* in time *t*.
$W_{(x,0)}$ = cumulative percent of oversize for size class *x* at the feed.
k = breakage rate constant (min^{-1})
t = time (min).

The relationship between breakage velocity and particle size is shown in **Equation 2**:

Equation 2

$$k = C\,x^n$$

In **Equation 2**, *C* and *n* are constants depending on the features of the mineral and the mill, as described by Ersayin *et al.*[24]. They are CKM model parameters and can be determined experimentally. Provided that size distribution in the feed stream is known, *C* and *n* allow to calculate the size distribution of the product through **Equation 3**.

Equation 3

$$W_{(x,t)} = W_{(x,0)}(\exp(-C\,x^n\,t))$$

Determination of the CKM Parameters C and n

Parameters *C* and *n* may be calculated simply and quickly from a small amount of sample in a laboratory mill[8]. In our case, since the objective was simulating the Bond tests to obtain w_i, the standard mill designed by Bond was used for characterization purposes.

Keeping the same feed quantity as in Bond test (700 cm^3), successive grinding cycles were done at predefined time intervals. After each cycle, a representative sample of the mineral load was extracted, and its particle size distribution (PSD) was obtained. The part of the sample above the reference size was then conveyed back to the mill and new feed was added up to the initial load before resuming the test.

The *k* values are calculated for several monetizes through linear regression of the retained mass accumulated for each grinding time, using the **Equation 1** linearized:

Equation 4

$$\ln\left(W_{(x,t)}\right) - \ln\left(W_{(x,0)}\right) = k\,t$$

Linearizing **Equation 2** and performing a new linear regression for each monosize, *C* and *n* are obtained:

Equation 5

$$\ln(k) = \ln(C) + n\,\ln(x)$$

Taking into account that **Equation 5** is the equation of a straight line, ln(*C*) is the intercept on the y-axis and *n* is the slope. Thus, the parameters are set for applying **Equation 3** to obtain the size distribution as a function of grinding time.

Simplified Procedure to Grinding Kinetic Parameters Determination

Figure 1 shows the outcome of **Equation 4** as a function of grinding times for monosizes of 840, 420, 149, and 53 µm of a pure quartz sample. It can be seen that the slope *(k)* remains rather constant irrespective of the time considered, from intermediate values to the end (5 min) of the test. A reduction of the test duration would be important to obtain the kinetic parameters through this procedure.

METHODOLOGY

To check this procedure, this work was aimed at validating the proposed methodology to determine the grinding kinetic parameters. The modelling was then used to determine the Work Index through simulation, and finally, those results were compared for eight different samples with the w_i obtained through the Bond standard test.

Sample Preparation

Eight samples were selected, of which four, namely, M1S1, M2S1, M2S2, and M2S3, were critical metal ores (Ag and Au) and the rest consisted of minerals (feldspar, quartz, and calcite) and a rock (pure limestone), being usual constituents of gangue rock.

It must be taken into account that critical metal ores have commonly an exceptionally low grade, and thus, it is the gangue composition that defines their grindability behaviour.

Heretofore, M1S1 stands for a hydrothermal low sulfidation mineral ore, consisting of veins and veinlets of silica (quartz, chalcedony, and opal) containing free gold, electrum, and

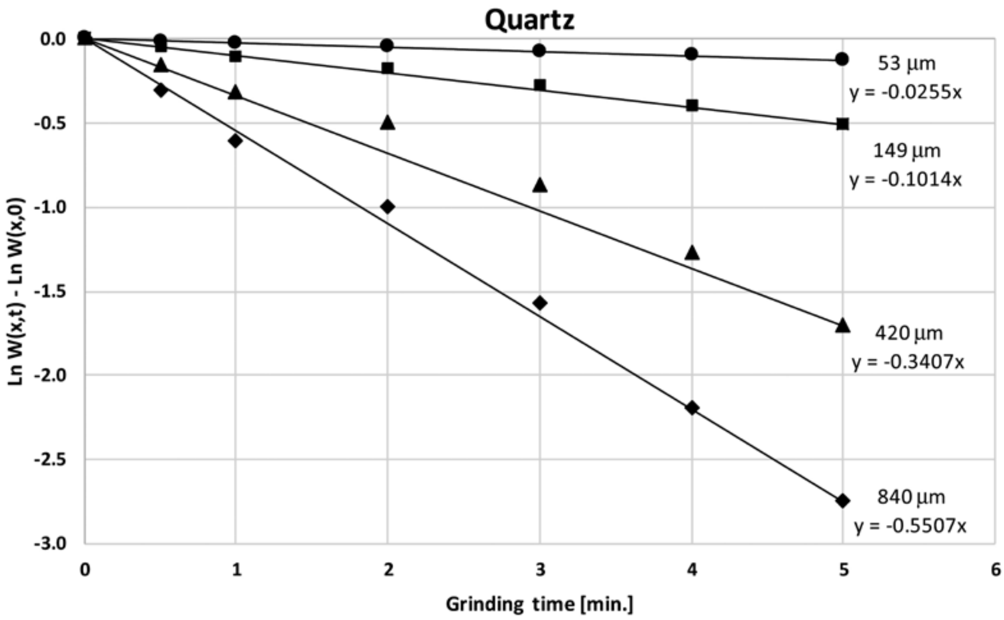


Figure 1: Determination of the kinetic constant, k, for a quartz sample; the lines are drawn from the starting point to the 5 min measurement.

Ag sulfosalts, in addition to cassiterite, galena, pyrite, and chalcopyrite. M2S1, M2S2, and M2S3 stand for an interpreted medium-sulfidation epithermal system, containing quartz, carbonates, and, to a lesser extent, Ag-, Au-, Pb-, Cu-, and Zn-bearing sulphides and sulfosalts.

Sample preparation was done following the usual procedures for the standard Bond test[4]: progressive comminution through several steps in jaw crusher, cone crusher, and roll/roller mills, until a final product finer than 6 mesh (3.35 mm) is obtained, avoiding an over-representation of the finest fraction.

The samples finer than 6 mesh were then subsampled with a rotary splitter. The resulting subsamples, 1 kg each approximately, were used in mineralogical, chemical, and grain size characterisation and also constituted the feed and the fractions for the Bond and grinding kinetic tests.

Grain size analyses were performed after sieving, approximately 300 g of each sample in a RO-TAP Sieve Shaker using a series of ASTM sieves.

Work Index Determination

The Bond test for ball mills was performed for each sample following the abovementioned Bond standard procedure[4]. The resulting value was later used as a reference to compare with the Work Index obtained through simulation. An initial feeding sample with a volume of 700 cm^3 was weighed and then fed into the standard mill filled up with the ball load defined for the test. After a grinding period of an arbitrary number of revolutions (e.g., 100), the mill was carefully dumped, recovering the maximum possible of the fines from the ball charge and the mill liners to minimize sample losses. The material was sieved to the reference size (P_{100}), and the undersize was weighed. An equal mass of new raw material was then added to the oversize feed to compensate loss of the fines.

The process was repeated, weighing the newly produced undersize (G) concerning the reference mesh. This undersize (G) was divided by the number of revolutions resulting in the grams per revolution (Gbp). Once Gbp is known, a new grinding cycle was performed after calculation of the needed revolutions to reach the steady state. The cycle was repeated until the undersize produced per revolution (Gbp) came to an equilibrium and the circulating feed approached 250%. The Gbp of the two last cycles was then averaged to obtain the grindability index of the test. The P_{80} of the undersize to the reference size was obtained allowing the calculation of the Work Index with **Equation 6**.

Equation 6

$$w_i = \frac{44.5}{P_{100}^{0.23} Gbp^{0.82}\left[\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}}\right]}$$

where:

- w_i = Bond Work Index (kWh/sht).
- P_{100} = test reference size (µm).
- Gbp = Grindability Index for the mineral (g/rev.).
- F_{80} = grain size corresponding to 80% of the feed undersize (µm).
- P_{80} = grain size corresponding to 80% of the final undersize (µm).

Regarding w_i units, although the original Bond formulation uses short tons (sht), results from this work are given in metric tons, after applying the corresponding conversion factor.

Determination of the Kinetic Parameters

As mentioned before, the kinetic parameters (C and n) were determined in a Bond standard mill with its corresponding ball charge to avoid variability. According to Ersayin *et al.*[24], the parameters C and n are a function of both the mineral and mill features. The test feed was a 700 cm^3 representative sample with known particle size distribution. Several grinding runs were performed with different cumulative times (0.5, 1, 2, 3, 4, and 5 min). Size analysis was done between runs, the analysed sample being reintroduced into the mill before resuming the process. Size analyses were then used first to determine the constant k and then the parameters C and n for each time and size class, using **Equations 4** and **5**.

Simulation Based on the Cumulative Kinetic Model

The cumulative kinetic model provides the size distribution of the product from the size distribution of the feed and the grinding times, using **Equation 3** and the parameters *C* and *n*, determined in the laboratory.

As in the Bond test, an arbitrary initial number of revolutions was set and converted into time units (provided that the mill speed is 70 rpm). Then, using **Equation 3**, the quantity of product for a reference particle size was calculated. By comparing with the weight of the feed, the resulting undersize and the *Gbp* were determined for the cycle.

The simulator calculates the new feed (weight and PSD) from the reference size reject of the previous cycle plus the fresh feed that replaces the undersize product of the previous cycle. Next, it calculates the number of revolutions for the following cycle and the grain size distribution of the reconstituted feed. The cycle is repeated until *Gbp* stability is reached and a circulating load is close to 250%. Finally, the simulation ends after calculating the simulated Work Index value (w_{is}).

A spreadsheet for performing the simulation is available as Supplementary data.

RESULTS

Simulation of the Work Index, Obtaining the Kinetic Parameters through the Conventional Procedure

Table 1 displays the results obtained for the studied usual components of the gangue. It includes the kinetic parameters, the Work Index for the Bond standard procedure, and the Work Index obtained through simulation. The latter two were obtained for a reference size of 100 µm

Table 2 displays the results obtained for the critical metal ores studied. It includes the kinetic parameters and Work Indexes obtained through Bond standard procedure and simulation (reference size of 100 µm).

Bond index values were also determined, with a 150 µm reference size, for feldspar and quartz and then compared with those determined through simulation using CKM. **Table 3** compares the results obtained through the standard procedure and the simulation for both minerals. It was noted that the differences between w_i and w_{is} for 150 µm were within the range obtained in the previous cases for a reference size of 100 µm.

Table 1: Comparison between Work Indexes for pure gangue components and reference size 100 µm, obtained through the standard procedure and the simulation (w_i = Work Index; w_{is} = simulated Work Index).

Ore	Kinetic Parametrs		R^2	w_{is} (kWh/t)	w_i (kWh/t)	Difference (%)
	C	*n*				
Feldspar @100 µm	0.000586	1.07	0.98	11.67	12.41	6.0
Limestone @100 µm	0.001789	0.87	0.97	9.66	9.98	3.2
Calcite @100 µm	0.000973	1.09	0.95	6.41	6.30	-1.7
Quartz @100 µm	0.000448	1.07	0.99	13.77	13.88	0.8

Table 2: Comparison between Work Indexes for metal ores and reference mesh of 100 µm, obtained through the standard procedure and the simulation (w_i = Work Index; w_{is} = simulated Work Index).

Ore	Kinetic Parametrs		R^2	w_{is} (kWh/t)	w_i (kWh/t)	Difference (%)
	C	*n*				
M1S1 @100 µm	0.000792	0.89	0.99	19.56	19.25	1.6
M2S1 @100 µm	0.000451	1.03	0.98	15.55	14.83	-4.9
M2S2 @100 µm	0.000486	1.03	0.98	16.61	15.98	3.8
M2S3 @100 µm	0.000303	1.10	0.99	17.06	17.35	-1.7

Table 3: Work Indexes for feldspar and quartz (reference sizes 100 and 150 µm) obtained through the standard test and the simulation (w_i = Work Index; w_{is} = simulated Work Index)

Ore	Kinetic Parametrs		R^2	w_{is} (kWh/t)	w_i (kWh/t)	Difference (%)
	C	*n*				
Feldspar @150 µm	0.000586	1.07	0.98	11.67	12.41	6.0
Limestone @150 µm				14.19	14.69	3.4
Quartz @150 µm	0.000448	1.07	0.99	13.77	13.88	0.8
Quartz @150 µm				17.34	17.88	3.0

Table 4: Compared results between wi and wis using the simplified procedure to obtain the kinetic parameters

Ore	Kinetic Parametrs		R^2	w_{is} (kWh/t)	w_i (kWh/t)	Difference (%)
	C	*n*				
Feldspar @100 µm	53	840	0-4	14.69	13.38	8.91
Feldspar @150 µm	53	840	0-4	12.41	11.20	9.76
Quartz @100 µm	53	840	0-5	17.88	17.82	0.33
Quartz @150 µm	53	840	0-5	13.88	14.63	-5.37
Limestone @100 µm	53	840	0-4	9.98	9.41	5.72
Calcite @100 µm	53	840	0-4	6.30	6.24	0.96
M1S1 @100 µm	74	840	0-3	19.25	21.11	-9.68
M2S1 @100 µm	53	840	0-3	14.83	15.40	-3.85
M2S2 @100 µm	74	840	0-3	15.98	17.01	-6.47
M2S3 @ 100 µm	53	840	0-3	17.35	16.79	3.21

Work Index Determination by Obtaining the Kinetic Parameters through the Simplified Procedure

From the results of the tests carried out to determine the kinetic parameters for each sample, it the product size distribution of the longest grinding time test was selected. Then, the slope was determined from the starting time to the end time of the test to obtain k for all the grain size populations involved.

To calculate *C* and *n*, the condition was set of using the widest grain size range, with an upper (coarsest) limit of 840 µm and including the finest possible populations without distorting the outcomes significantly. For most cases, this resulted in a lower (finest) limit of 53 µm. **Table 4** displays a comparison of the Work Indexes obtained through the Bond standard test and the simulation using the kinetic parameters provided by the simplified procedure. It can be seen that Work Indexes from the simulation using the simplified procedure differ from those from the Bond standard procedure by less than 10%.

DISCUSSION

The simulation of the Work Index test applying the cumulative kinetic model proved to yield results that differ by less than 10% from those from the Bond standard test. This figure agrees with results by Ahmadi and Shahsavari 2009[25], who proposed a two-step simplified procedure. They applied a simulation based on the cumulative kinetic model and validated their results over three samples of iron ore and one of copper ore. Their results differed by less than 7% from those yielded by the standard procedure. Previously, Aksani and Sönmez 2000[7] determined the Bond indexes by means of the cumulative kinetic model with values differing by less than 4% with respect those determined with the standard test.

As to determining the kinetic parameters, the possibility of reducing the procedure to only one grinding test with the greatest possible estimated time to obtain the grain size distribution over which the *k* index and then the parameters *C* and *n* could be calculated was evaluated.

As it can be observed in the graph of **Figure 1**, illustrating the tests performed with quartz, the slope for each particle size class does not vary much over the time span recorded. This suggests that the determination of the constant k would not require obtaining grain size data at intermediate grinding times.

The graph of **Figure 2** shows that k values vary for different particle sizes over the grinding time. For grinding times longer than 3 min, the curve is straight for the grain size class between 595 and 840 µm (20 and 30 mesh), and then after a break in slope, a straight line continues again. It can also be noticed that, with grinding time, the different curves adjust and merge into a new slope.

The similar situation occurs for the remaining studied minerals, as the graph of **Figure 3** depicts. This graph shows the variation of *k* with particular size according to grinding times of feldspar. Similarly, **Figure 4** displays the results for the ore M2S2.

The graphs show that the curves display a stable shape after a given grinding time. In all cases, a change in slope takes place for particle size coarser than 700 µm. That is the reason why the simplified procedure should not be extended for particle sizes coarser than 840 µm. (20 mesh). This condition does not involve an important limitation since this is the usual particle size range employed in ball mill grinding.

Indeed, it was decided to use the maximum time employed in for each mineral grinding, highlighting the convenience of using a grinding time of at least 5 min to calculate the kinetic parameters with this procedure.

It can be considered that the simplified procedure permits to determine the grinding kinetic parameters *C* and *n*, after carrying out one grinding test and two PSD analyses. This can be done rapidly in the laboratory once the sample is prepared. It is considered a valid procedure for a particle size range between 840 and 53 µm with a grinding time of 5 min, using the standard Bond mill with the standard ball charge. The procedure can be summarized as follows:

1. Feed preparation 100% passing a 3350 µm (6 mesh) sieve followed by gradual crushing to avoid the overproduction of fines.

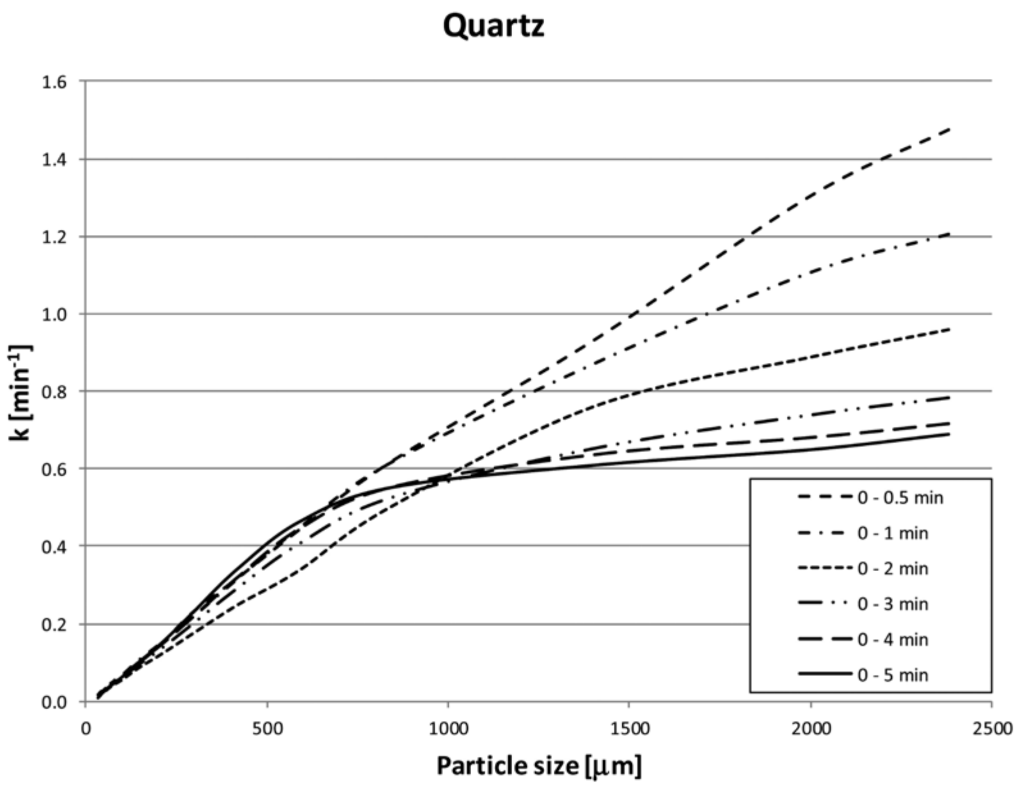


Figure 2: Graph showing the variation of *k* with particle size for different grinding times in the case of quartz.

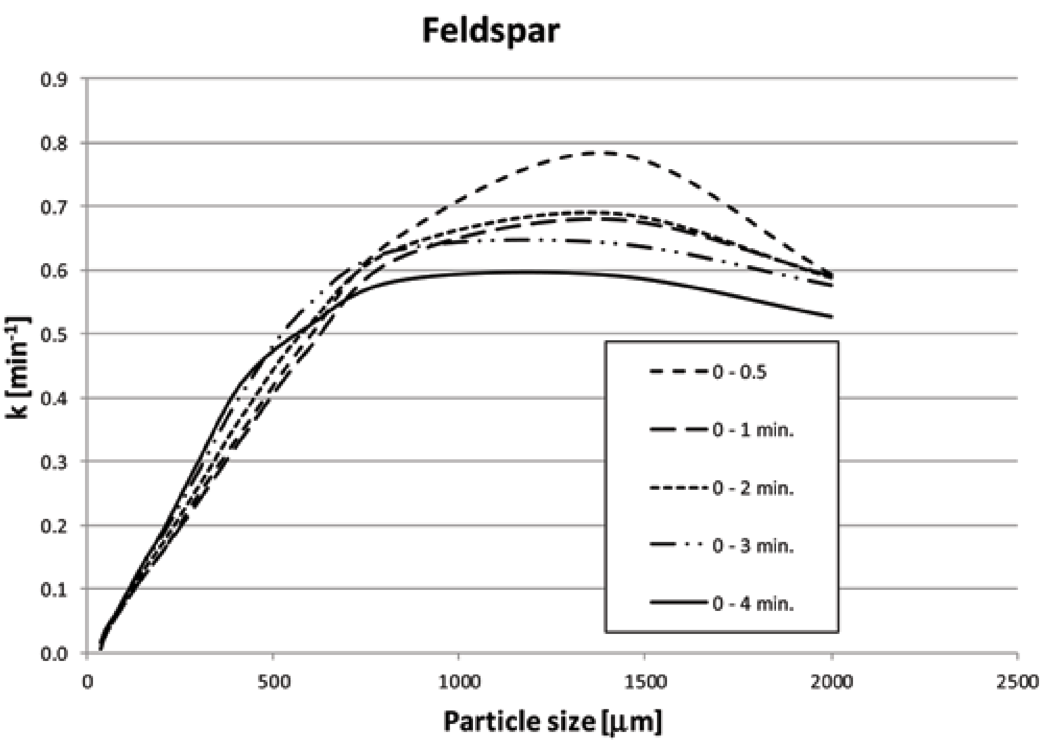


Figure 3: Graph showing the variation of *k* with particle size for different grinding times in the case of feldspar.

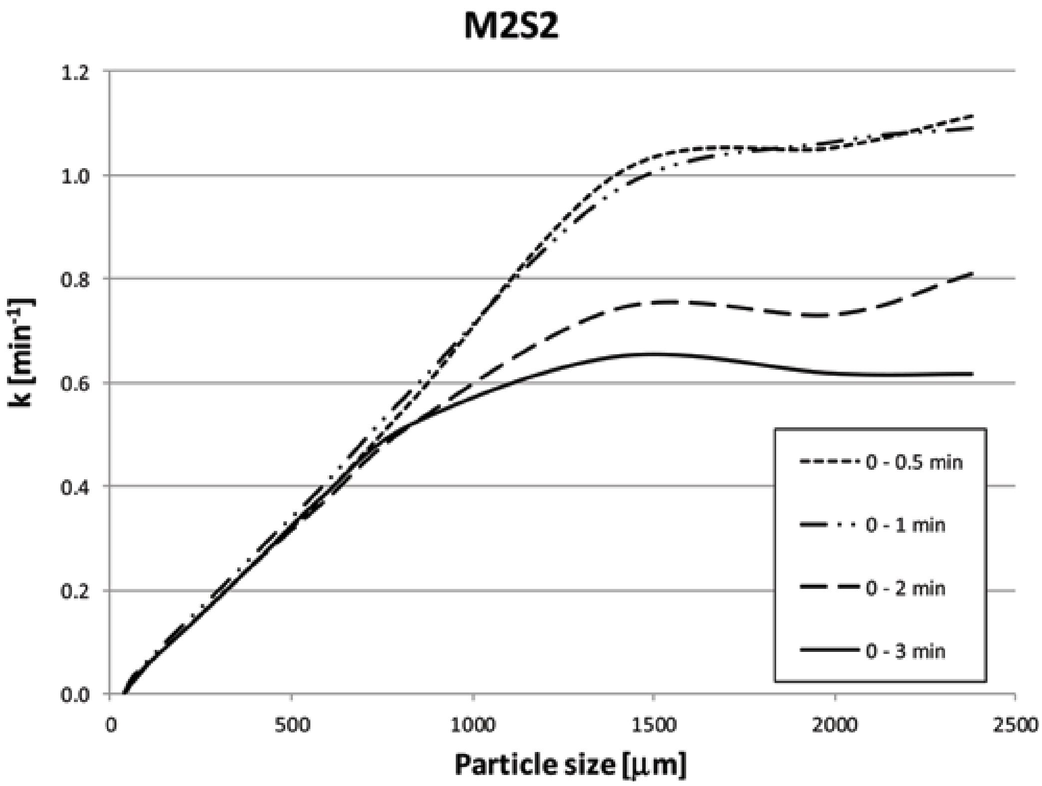


Figure 4: Graph showing the variation of *k* with particle size for different grinding times in the case of M2S2 sample..

2. PSD determination with sieves between 3350 and 37 µm, and determination of the feed characteristic particle size (F_{80}).
3. Grinding of a quantity equivalent to 700 cm^3 for 5 min.
4. PSD analysis to determine the product characteristic particle size (P_{80}).
5. Determination of *k* for each particle size class (slope from 0 to 5 min).
6. Determination of the slope (*n*) and the intercept on the y-axis (*C*) of the logarithmic-scale graph of *k* as a function of particle size (*k* vs. particle size).

Once the kinetic parameters are determined, the Bond test can be simulated, and the PSD can be obtained until reaching the grindability value (*Gbp* or grams per revolution) for a load of 250% and for the reference size (P_{100}). Once the feed characteristic grain size (F_{80}), the product characteristic grain size (P_{80}), and the grindability index (*Gbp*) are known, the Work Index can be calculated with **Equation 6**.

CONCLUSIONS

The experimental work done and its further analysis permit to draw the following conclusions:

- The conventional cumulative kinetic model (CKM) is a tool that allows determining the Work Index (w_i) for ball mill grinding, simulating the standard procedure of F.C. Bond. The respective results provided, according to literature, differ from less than 7%.
- A simplified procedure has been proposed to obtain the CKM parameters. It is based on determining *k* with one grinding time since *k* variation with particle size is rather constant for times less than 5 min. This makes it valid for simulating batch grinding with residence times on the order specified.
- The proposed simplified procedure has been proven to be valid for using the CKM to simulate the F.C. Bond's standard test. It permits to obtain the Work Index in ball mill grinding for a reference size range between 840 (20 mesh) and 53 µm (400 mesh), yielding results that differ by less than 10% with respect to real values. This considerably reduces the involved laboratory work, thus being enough with one grinding run and two PSD determinations.

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NEWS, PLANT AND EQUIPMENT

Ultimate in power and performance: Sandvik presents the world's first 18 tonne battery loader, the LH518B

Sandvik is introducing its new battery-electric loader, the 18 tonne LH518B. The all new loader is the result of Sandvik's decades of engineering expertise, matched with Artisan Vehicle's innovative powertrain technology and battery system expertise.

Rethink the machine, not the mine

The LH518B from Sandvik has been designed, ground-up, entirely around the loader's Artisan™ battery system and electric driveline to best utilize the possibilities that the battery technology brings. It was not enough to replace some components or redesign only a part of the equipment: the designers were compelled to rethink the whole machine. For the customers, when the OEM rethinks the machine, it means that the mine doesn't need to rethink its whole infrastructure. In practice, changing the loader battery does not require any cranes or forklifts, thanks to the patented AutoSwap feature.

Unmatched productivity

The new LH518B battery-electric loader comes with an exceptional capacity for its size: its design solutions allow the loader to fit in a 4.5 x 4.5 meter tunnel and carry 18 tonne loads. In addition to an innovative boom and bucket system, the LH518B features independent front and rear drivetrains, allowing high payload capacity while keeping a low overall height.

For superior productivity, the LH518B is equipped with three 2000 Nm permanent magnet motors. With no torque converter, transmission or engine to rev up, the loader is fast and agile. There are no emission restrictions based on installed power to limit the electric motor selection, which enables the use of the most powerful motors available that are suited for the underground conditions.

Fast and easy battery AutoSwap and AutoConnect

The LH518B is equipped with AutoSwap, a patented self-swapping system for the Artisan™ battery pack. Battery swapping is made fast and easy with minimum amount of manual handling: changing the battery only takes about 6 minutes, and it can be done in a passing bay or old re-muck bay with no overhead cranes or external infrastructure needed. The brand new AutoConnect feature available for the first time on the LH518B is making swapping even easier and faster by automatically connecting and disconnecting the battery pack to the machine. Aside from unplugging and plugging in the charger, the operator doesn't need to leave the cabin, which saves minutes on the swapping procedure and decreases effort and risk in the swapping process.

The purely battery-powered loader helps to reduce heat and emissions underground, helping mines reach their sustainability targets and reduce ventilation costs. The robust battery pack uses Lithium Iron Phosphate chemistry ($LiFePO_4$) and is purpose-designed for use in underground mining.

From innovation to globalization of battery-electric vehicles

Currently, Sandvik is expanding the BEV loader and truck offering and prepares to enter new market areas, which will happen in phases and model by model. When the battery loaders and trucks are introduced to new markets, Sandvik will be ready to offer full product support and aftermarket services for its customers.

Hardfacing products for mines, quarries and mineral processing facilities

The generation of abrasive wear and friction can not only cost an industry a considerable amount of money because of downtime and product replacement, but these common nuisances within the mining industry can also result in reduced life of various parts, increased need for replacement parts, greater operating costs, greater maintenance costs, higher staffing levels for maintenance workers and increased downtime.

It is therefore crucial for the mining industry to utilise validated analytical techniques to estimate, predict, and analyse friction and abrasive wear that is generated on all relevant mining equipment, machinery, and products.

TYPES OF WEAR

In mining operations, there are four different types of wear: abrasion, erosion, adhesive wear and surface fatigue. Abrasion wear is caused by hard bits of material being pressed against and grinding along a softer surface. The particles responsible for abrasion typically have sharp angular edges that cut into the softer surface. Erosion is caused by the mechanical interaction between a surface and a fluid that may or may not contain particles. We typically associate erosion with acts of nature, but in mining operations, erosion can be seen when exhaust fans blow dirty air against surfaces.

Wear due to adhesion is caused by the localised bonding between two contacting surfaces. Often, adhesive wear can lead to abrasive wear as particles from the contacting surfaces break off. Surface fatigue is caused by the breaking off of a material due to cyclic stress generated by rolling or sliding action. This type of wear can be aggravated by high temperatures and mechanical wear qualities.

THE COST OF WEAR

In general, wear costs every industrialized nation approximately 1-4% of their gross national product (GNP). In addition to being economically costly, wear also increases global energy demand. Currently, the mining and minerals industry accounts for up to 7% of the global energy output, which is largely attributed to the vast amount of electricity used throughout the mine.

The use of other energy sources, including diesel oil fuel, coal, natural gas, and gasoline, also play a significant role in the energy output generated by the mining and minerals industry. The presence of abrasive wear on mining equipment can further increase the energy consumption within this industry, as mining machinery will often require a greater amount of energy to overcome significant friction losses.

NUMERICAL MODELS

Several different numerical models have been used to approximate the wear generation of machinery when used for several different mining processes, including excavation, comminution, and the transportation of ore.

The methodology behind these numerical models shares a similar foundation where both the particle motion is stimulated and ultimately used to assess and analyze the potential wear that will be generated during the process.

The discrete element method (DEM) and Archard's wear rule is a unique combination of numerical models widely used throughout the mining industry to predict wear generation on machinery. For example, the DEM-Archard approach has been used to assess and analyze the wear profile of mill liners, which was achieved by obtaining a simulation of the operation of the mill liners to obtain precise experimental values.

Similarly, the DEM-Archard approach was further enhanced by adding a finite element method (FEM) to predict the failure of roadheader picks under a simulation of brittle rock cutting. Smoothed particle hydrodynamics (SPH) has also been used to enhance the DEM-Archard approach to understand the behavior of particles and their contribution to the wear in a dumper truck body.

MICROSTRUCTURE ANALYSIS

In a recent study investigating the impact wear resistance of a novel modified medium manganese steel (MMAS), researchers conducted impact abrasive wear tests to examine wear behavior. Additionally, the morphological features of the impact wear surface were observed by a scanning electron microscope (SEM), whereas the martensitic transformation of the material's surface was studied by X-ray diffraction (XRD). Transmission electron microscopy (TEM) also allowed the researchers to analyze the microstructure of the impact wear layer.

The SEM, XRD and TEM observations made in the aforementioned paper allowed the researchers to confirm the existence of deformations and dislocations within the microstructure of the MMAS material.

Furthermore, numerical studies were a highly useful and accurate method of predicting wear generation on mining products. Taken together, these two classes of wear generation analytical techniques can provide the mining sector with a plethora of useful information capable of reducing this industry's energy demand, while simultaneously improving their ability to preemptively overcome the effects of wear on mining products.

WEAR PROTECTION MEASURES

Lubrication and wear protection measures are critical to just about every mining operation. Some basic examples of wear protection measures include rubber lining for conveyor belts, open gear lubricants, wire rope lubricants and lubrication systems.

Tightly attached to a conveyor belt, rubber linings are designed to resist abrasion and prevent corrosion. Due to the extreme conditions of typical mining operations, these linings should be heat and fire-resistant.

Lubricants can be either penetrating, which contain a solvent that delivers lubricant deep into a part or surface, or coating, which seal the exterior of a surface with a thick film. Effective open gear lubricants have significant load-bearing, vibration reduction and water resistance qualities; while wire rope lubricants are made to form a dense film that protects draglines and drag robes from abrasion and corrosion.

Automatic lubrication systems are often used in mining operations to provide localized lubricant in precise amounts at exact moments. Typically made up of a timer, reservoir, pump, lines, pistons and valves, these systems are strategically set up to minimize friction and resulting wear. Valves and pistons allow the system to deliver lubrication at the various necessary locations.

Metal parts and equipment often fail their intended use not because they fracture, but because they wear by abrasion, impact, metal-to-metal contact or some other form of wear, which causes them to lose dimension and functionality. Hardfacing, also known as hard surfacing, is the application of a build-up or wear-resistant weld metal onto a part's surface by means of welding to extend the life of the part. The weld metal may be applied as a solid surface or in a pattern, such as a waffle pattern, herringbone or dot pattern, etc.

Hardface Technologies by Postle Industries, Inc. has a variety of hardfacing wires, tubular electrodes, tungsten carbide products and other solutions including chrome carbide and tungsten carbide wear plate to provide wear protection to this industry. These products are used to reduce high maintenance costs and prevent unwanted shutdowns.

Applications include:

- Crusher rolls and parts
- Dragline bucket teeth
- Grizzlies
- Screw conveyors
- Augers and auger points
- Tamper tools
- Manganese dragline chain wear parts
- Bulldozer blades
- Dragline bucket teeth
- Tractor driving sprockets
- Mixer blades
- Bucket sides and bottoms
- Pan conveyors
- Tractor rollers
- Scraper blades
- Hammers
- Bulldozer end bits and plates
- Manganese shovel track pads
- Pulverizing rolls

At Hardface Technologies we have solutions to address the many abrasive wear, impact, corrosion and maintenance repair challenges that face Mines, Quarries and Mineral Processing facilities. Our experienced welding professionals along with engineering and metallurgical experts can evaluate and recommend realistic solutions.

Throughout our history servicing this industry, Hardface Technologies has developed a complete line of hardfacing products and solutions for wear protection. As an added technological advancement many of our hardfacing products utilize our proprietary RCT™, Reactive Core Technology.

REACTIVE CORE TECHNOLOGY (RCT™)

During welding, components in the core of the tubular wire or electrode require energy to react and melt together to form the hardfacing alloy. Postle's Welding Products with *Reactive Core Technology (RCT™)* contain special "Reactors" in the core to assure a controlled reaction between alloys and other elements, improving weldability, as well as the matrix of the finished hardface product, resulting in optimum wear properties.

Benefits of RCT include:

- Improves weldability
- Promotes strong arc transfer
- Promotes the distribution of alloy ingredients to more effectively control the microstructure
- Promotes carbide formation
- Refines the grain structure to improve toughness

HARDFACING CHEMISTRIES

Geological conditions along with the type of wear will determine the chemistry of the hardfacing product required to solve a customer's wear issue. There are Chromium carbides, Complex carbides, Tungsten Carbides and combinations of Other Carbides available. In addition, build-up or buffer alloys may be needed to provide the best solution.

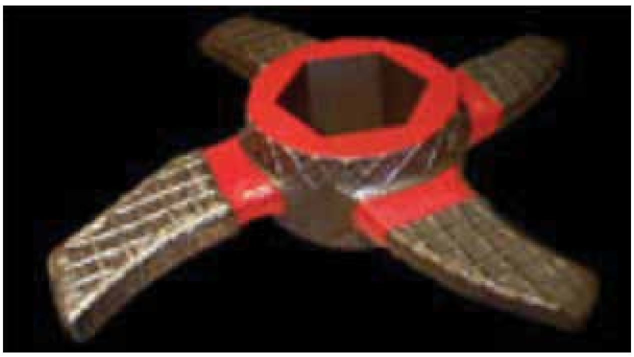
Also available, is the Tungsten Carbide Embedding process.

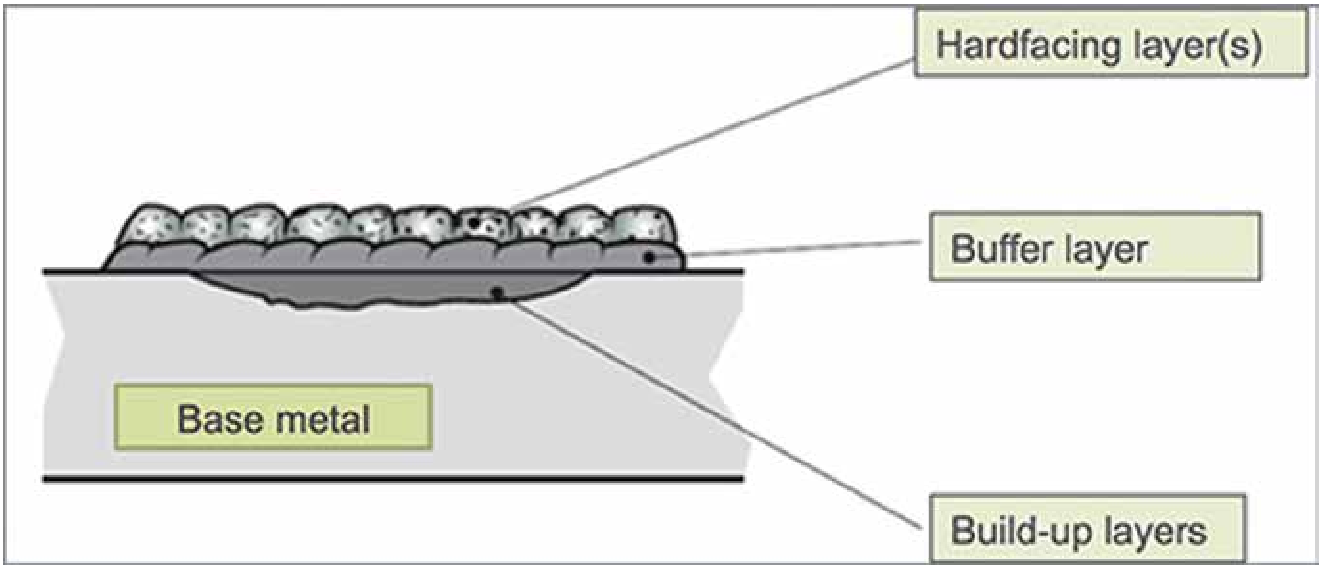
1. **CHROMIUM CARBIDES** are iron-based alloys that contain high amounts of chromium (greater than 15%) and carbon (greater than 3%). These elements form hard carbides that resist abrasion. The deposits frequently check-crack about every ½ in., which helps relieve stress from welding. Their low friction coefficient also makes them desirable in applications that require material with good slip. The abrasion resistance increases as the amount of carbon and chromium increases, although carbon has the most influence. Hardness values are 40 to 65 HRC. They may also contain other elements that can form other carbides or borides that help increase wear resistance in high-temperature applications. These alloys are limited to two or three layers.

2. **COMPLEX CARBIDES** generally are associated with the chromium carbide deposits that have additions of columbium (niobium), molybdenum, tungsten, or vanadium. The addition of these elements and carbon form their own carbides and/or combine with the present chromium carbides to increase the alloy's overall abrasion resistance. They can have all these elements or just one or two. They are used for severe-abrasion or high-heat applications

3. **TUNGSTEN CARBIDE** Hardfacing can help increase service life of equipment by 300% to 800%. Tungsten Carbide Hardfacing wires are specially engineered to ensure maximum service life of hardfaced surfaces. Tungsten carbide hardfacing wires are alloyed with various metals such as nickel, chromium, silicon and boron to create products that ensure maximum protection of your equipment in virtually any environment.

4. **COMBINATIONS OF OTHER CARBIDES** are engineered using multiple alloys and carbides. These carbides can include such alloys as niobium, boron, vanadium, titanium, molybdenum, manganese, nickel, zinc or a combination of these alloys.





5. **BUILD-UP or BUFFER ALLOYS** are similar to the parent metal alloy in hardness and strength, with two main functions.

   - They are applied to severely worn parts to bring them back to dimension where machining must be used after welding. Hardness ranges from 30Rc to 45Rc.

   - They are applied as a buffer for subsequent layers of a more wear-resistant hardfacing deposit. If the hardfacing alloy produces check cracks, such as a chromium carbide alloy, then it's wise to use a tough manganese product as the buffer to blunt and stop the check cracks from penetrating into the base metal.

   A mild steel electrode, or wire such as 7018 or E70S6, should never be used for build-up or as a buffer layer. While mild steel welding products are great for joining and fabricating, they do not have the strength and hardness to support hardfacing. A soft mild steel buffer layer will collapse under the hardface layer, causing the hardface layer to spall off and fail.

6. **TUNGSTEN CARBIDE EMBEDDING PROCESS** offers the ultimate in wear ans abrasion protection. It consists of a vibratory feeder and a standard semiautomatic MIG Gun, that delivers metered Tungsten Carbide particles to a molten weld pool at precisely the right moment prior to the puddle freezing. The result is a weld deposit filled with Tungsten Carbide (70 Rc particles) surrounded in a 58 Rc tool steel matrix.

Hardfacing will extend the life of your equipment but it's important to select the correct product to optimize performance and cost. Contact your hardfacing specialists to assist you in solving your wear and abrasion issues.

HARDFACING PATTERNS

When working in rocky earth, ore or slag, the goal is to NOT trap the soil on the surface, but to protect the surface underneath from abrasion caused by the movement of the rocks over the surface. This can be done by applying a series of ridges or weld beads parallel to the flow of material, like rails. This will prevent the rocky soil from coming in c When working in dirt or sand, apply hardface weld beads spaced from 1/4" (6.4 mm) to 1-1/2" (38 mm) apart and perpendicular or against the flow of an abrasive material. Forcing the material to compact between the weld beads works well for finely grained sands and soils.

Apply a dot pattern to areas that do not see heavy abrasion, but are subjected to wear, or when weld areas are hard to reach. A dot pattern is also used on thin base metals, when distortion and warpage may be an issue ontact with the surface. from overheating of the base metal.

When working in soil with some clay content, the goal is to use a hardfacing pattern that traps the soil on the surface, forming a layer of trapped soil that will protect the surface underneath. This is best done with a crosshatch or waffle pattern. This pattern also works well when there is a combination of fine and coarse soil.

Conveying advice

Conveyor belts are critical components within the mining and quarry industries. They are surprisingly complex and their reliability and efficiency can make or break an operation. At the same time, they are a very significant overhead. For more than 50 years, Netherlands-based Dunlop Conveyor Belting have been one of the leading and most well respected manufacturers of high-performance conveyor belting in the world. Who better, therefore, to provide a regular feature that helps to unravel the technical complexities and provide some expert advice and guidance? Here, Rob van Oijen, Dunlop's manager of application engineering looks at a common problem affecting mining and quarry belting, which is ripping, tearing and impact.

THE MOST DESTRUCTIVE FORCE

Even the strongest, heaviest multi-ply and steelcord belts can be punctured and ripped by a foreign objects and sharp rocks becoming trapped. A belt can quite easily be ripped apart longitudinally over its entire length in a matter of minutes. In one incident, a wooden broomstick became trapped at the conveyor head, penetrated a steelcord belt and ripped 4 kilometres of belt from end to end. The cost of repairing and replacing belts, both in monetary terms as well as lost production, can have very serious consequences indeed. Despite this, most manufacturers make little or no mention of the rip and tear resistance of their belts.

RIP AND TEAR RESISTANCE – TESTING

The ability to withstand the forces that rip and tear belts is often more important than any other physical attribute. This is especially true when it comes to quarrying and mining. A 'rip' is best described as what happens when a sharp object punctures the belt and cuts the belt lengthwise as it is pulled against the trapped object. In contrast, a 'tear' is what happens when a section of belt is pulled apart in opposing directions, much like when a telephone directory is torn apart by hand as a feat of strength.

Rip and tear strength should be regarded as important KPI's

Surprisingly, despite its significance as a key performance indicator, there are currently no internationally accepted test methods or standards for testing rip resistance, which is perhaps one reason why belt manufacturers rarely mention the subject. However, in Dunlop we regard rip and tear strength as very important KPI's. What our laboratory technicians do is pull sections of belt through a right-angled piece of metal under extreme force and carefully measure and record the level of force exerted. The technicians have nicknamed the specially designed equipment they use for this harsh treatment 'Jack the Ripper'.

Dunlop's 'Jack the Ripper' rip test in action

Unlike rip resistance, an international standard for tear strength does exist. The ISO 505:2017 test method measures the propagation resistance of an initial tear in textile conveyor belts, either in full thickness or of the carcass only. The test is intended for application to multi-ply (fabric) belts in installations where there is a risk of longitudinal tearing.

Although it is a defined method of testing there are no standardised performance requirements. The test, often referred to as the 'trouser test', basically consists of mounting two cut ends of a test piece of belting in the jaws of a tensile testing machine. An initial tear made in a test piece, which is then pulled apart in opposing directions. The force necessary to propagate the tear is then measured. Examination and analysis of the multi-peak tear resistance test traces is made in accordance with ISO 6133.

FINDING THE BEST SOLUTION

Because of the huge disparities between the types of materials being conveyed, the design of the conveyor systems and their working environments, there is no 'silver bullet' answer to the damage caused by ripping, tearing and impact. In my experience, it is probably easier to start with what will almost certainly NOT be the answer to the problem. The most common misconception is that making the belt thicker by increasing the cover thicknesses and/or the number of plies will help. The fact is that belts that are too thick for the design of the application can cause problems such as excessive rigidity (lack of troughability) and steering and handling difficulties. The same applies to increasing the tensile strength. Especially in Eastern Europe for some reason, it is not uncommon to see belt specifications of 1000/6 10+4 or even heavier. Whenever I see specifications like these, I can be pretty confident that there is an underlying problem with ripping and tearing.

To the uninitiated, another answer might seem to replace the multi-ply belt with a steelcord belt, but this is also extremely unlikely to provide the solution. Conveyors using steelcord belts have to specifically designed. Because of their innate tensile strength and low elongation (stretch), steelcord belts are really only suited to conveying over longer distances. In any case, their Achilles heel is that although the actual steel cords themselves are very strong, they cannot prevent a trapped foreign object from penetrating through the rubber covers, between the cords and ripping the belt longitudinally.

ENGINEERED FOR THE TASK

For multi-ply belts on conveyors where ripping and tearing is a problem the only genuinely practical solution is to fit a conveyor belt that has been specifically engineered for the purpose. Such belts can have several times the resistance against ripping and tearing and cope with the impact of heavy objects falling from a high drop height much more effectively compared to belts that use a conventional fabric ply construction.

Belts that have been engineered to resist ripping, tearing and impact use uniquely designed fabric plies that allow the nylon strands to stretch. As the trapped object is being pulled through the belt, the strands of the special ply construction gather together into a bundle that can eventually become strong enough to stop the belt.

Strange as it may seem, special synthetic plies are usually more effective than steel when it comes to actually minimising the length of a rip. I am an engineer, not a salesman, but I can tell you in all honesty that the two best examples that I have ever come across are Dunlop UsFlex and Dunlop Ultra X. They are both totally unique to Dunlop and both belt types have at least three or more times the resistance to ripping and tearing compared to conventional belt. To find out more simply go to: https://www.dunlopcb.com/cover-grades/rip-impact/

USING BREAKER PLIES TO INCREASE RIP RESISTANCE

For steelcord belts, the best solution tends to be the use of breaker plies, which provide a significantly increased resistance against longitudinal ripping. Ultimately, the use of breakers is one of damage limitation.

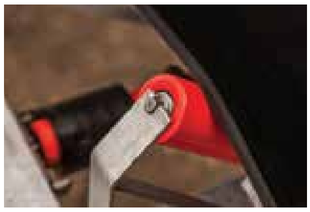
The breaker ply performs two functions – firstly it can help prevent the penetration of the belt by a foreign object. Secondly, the breaker ply acts as a barrier if an object does actually penetrate between the steel cords and starts to rip along the length of the belt. Breaker plies are embedded in the rubber covers during the manufacturing process. There are numerous types and strengths of breaker used. The lighter weight versions are designed to simply absorb and dissipate energy whereas stronger, heavier weight breakers can actually stop the belt and limit the amount of damage stop the belt, thereby limiting the extent of the damage. These are commonly referred to as 'Rip Stop' breakers.

NOT WORTH THE SACRIFICE

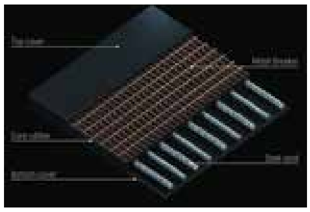
Rather than look for belts that are capable of handing the demands, many operators decide to opt for what they see as the cheaper option by fitting low grade, 'sacrificial' belts that are then repaired and replaced with frightening regularity.

But when you add the cost of incessant repairs, the fitting labour costs and, most of all, the lost production, to the cost of replacement belt after replacement belt, it very rarely proves to make economic sense.

ISO 505 tear testing



Belts that are too thick can cause problems such as excessive rigidity



Steelcord belt cross section with Ripstop breaker ply

Ripping, tearing and impact – the best solution is to fit a conveyor belt specifically engineered for the purpose.

Sacrificial belts rarely make economic sense

Rob van Oijen is Manager Application Engineering for Dunlop Conveyor Belting in The Netherlands. Rob has specialised in conveyors for some 14 years, supporting businesses throughout Europe, Africa, the Middle East and South America.

Technology options and innovation for copper heap leaching

The metallurgical heart of the majority of copper oxide processes is the heap leaching operation. Fresh low grade sulfide ores is a far greater challenge. The success of this unit operation is so important that operators need to understand the ramifications of their decisions or non-decisions and how they could affect the downstream processing. Heap leaching is an operation that can be described as a scientific art whereby principles of science can be used to guide experienced personnel in attaining their goals. Recent advances have been made based on better understanding the ore characteristics. The success of a heap leach operation, or otherwise, is dependent upon a number of factors, notably:

- The type of ore to be treated
- The extent of testwork completed to define the process
- The interpretation of the testwork results
- Ore preparation prior to stacking
- Agglomeration and curing requirements

Other issues:
- Compliance with the 'smaller' requirements of environmental authorities
- Adequate and timely drainage of solution from the base of a leaching lift
- The degree of saturation in the pads
- Heap porosity – coarser or finer ore, which is better?
- Higher or lower irrigation rates – which would produce a better result?
- Laying out irrigation pipework for ease of operation and maintenance
- The addition of water, raffinate during agglomeration where needed

The heap leaching of sulfide ores, including chalcopyrite, via enhanced bacterial leaching is discussed.

INTRODUCTION

Over the last twenty years production of extremely pure copper from solvent extraction and electrowinning (SX/EW) has become more common in a market of real declining prices for copper metal. This paper touches on a number of heap leach operations and experiences. These projects were subjected to extensive engineering design and resulted in low capital cost, efficient operations with a number of lessons learned. The key to these operations was the performance of the heaps and associated fluid collection systems rather than the plants themselves.

HEAP LEACH PRINCIPLES

Heap leaching is a simple processing technique involving mining and crushing (optional) of the ore, which gets stacked into a heap pile on a prepared surface and is irrigated by a lixiviant. The solution percolates through the heap, dissolving the target metals of value, which are recovered in later processing stages. The barren solution left over is treated and chemically adjusted before it is recirculated again in the leaching circuit.

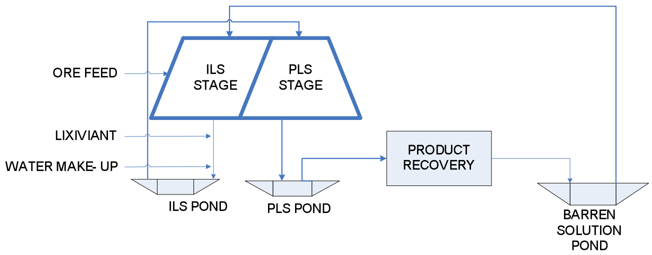


Figure 1: Schematic for a standard heap leach operation.

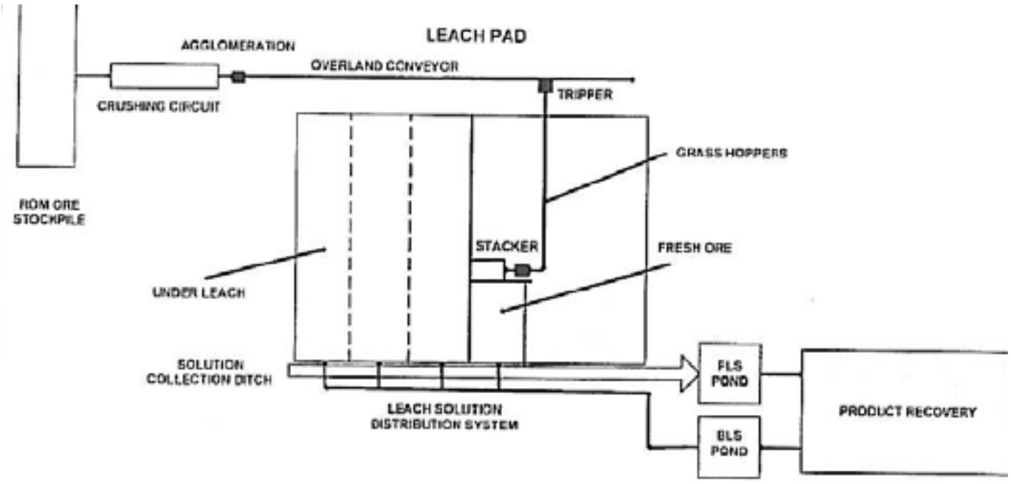


Figure 2: Schematic diagram of a ROM leach facility.

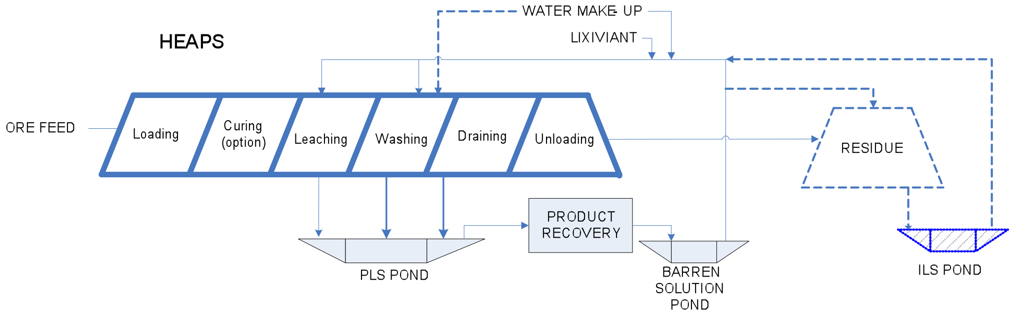


Figure 3: Schematic diagram of an on/off heap leach operation.

- **Permanent Pads** – ore crushed/agglomerated and placed on designed pads in lifts of 5 to 8 m and total heights of up to 200 m. A solution irrigation system and collection system utilising pumps is used. The ore is left *in situ* at the end of the project.
- **On/Off Heap Leach Pads –** ore crushed/agglomerated and placed on designed pads in lifts of 7 to 8 m and total heights of up to 200 m. A solution irrigation system and collection system utilising pumps is used. After several leaching and washing cycles the ore is removed from the pads and fresh ore put on the pads.

Heap leaching is favourable for the following reasons:

- Low capital expenditure and operating costs (relatively when compared to milling options).
- Rather quick installation to set up operations – it is advantageous for smaller companies to set up.
- Simple process with low levels of training required for routine operations.

However, there are some disadvantages that should be mentioned, including:

- Reduced metal recovery compared to milling.
- Cash flow delays at start up.
- High inventory of valuable metals.
- Leach kinetics – slow to change and difficult to analyse potential problems that can develop.
- High risk – especially for low grade ores with little 'margin for error'.
- Management of exhausted heaps and closure

Heap leaching often offers a viable alternative to milling. The use of heap leaching as a secondary operation to existing milling sites dealing with higher grade ores is sometimes disregarded or overlooked.

TYPES OF HEAP LEACHING

- **Dump Leach Facility** – low grade mineralised waste with suitable permeability characteristics. Material placed in 10 m lifts. A solution irrigation system and collection system utilising pumps is used.
- **ROM Leach Facility** – ore crushed and placed on designed pads in lifts of 7 to 8 m and total heights of up to 200 m. A solution irrigation system and collection system utilising pumps is used.

ORE MINERALOGY

Heap leaching with sulfuric acid is only able to efficiently recover Cu from certain species of minerals.

Table 1 which is based on conventional heap leaching could now be considered out-dated, particularly for copper sulfides. The introduction of new bacteria, higher temperatures and forced aeration can enhance sulfide leach kinetics to acceptable rates.

BACTERIAL HEAP LEACH COPPER SULFIDES

Microorganisms oxidize ferrous iron and reduced sulfur compounds to obtain energy. Biogenic ferric iron and sulfuric acid attack sulfide minerals resulting in metal dissolution. The process requires air, water and some nutrients (N, P) for the microorganisms. Bioleaching has been commercially used for the extraction of Cu, Ni, Co, Zn and U. There are

Table 1: Economically extracted copper minerals and their heap leaching performance

TableMinera	Composition	Leaching rate	Copper extraction
Azurite	$2CuCo_3.Cu(OH)_2$	Fast	High
Malachite	$CuCo_3.Cu(OH)_2$	Fast	High
Cuprite	Cu_2O	Fast	Moderate
Tenorite	CuO	Fast	High
Native Cu	Cu	Moderate	Moderate
Chalcocite	Cu_2S	Fast	High
Covelite	CuS	Moderate	High
Bornite	Cu_3FeS_4	Fast	Moderate
Enargite	Cu_3AsS_4	Slow	Low
Tetrahedrite	$Cu_{12}Sb_4S_{13}$	Moderate	Moderate
Chrysocolla	$CuSiO_3.2H_2O$	Fast	High
Chacopyrite	$CuFeS_2$	Slow	Low

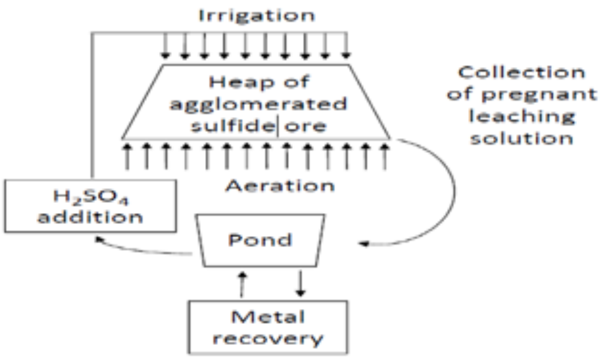


Figure 4: Schematic diagram of a bacterial heap leach operation.

two conventional biological reactions occurring in bio-heap leaching, shown in equations 1 and 2.

Biological iron oxidation:

Equation 1

$$4\ Fe^{2}+ + O_2 + 4\ H^+ \rightarrow 4\ Fe^{3}+ + 2\ H_2O$$

Biological sulfur oxidation:

Equation 2

$$4\ S^0 + 6\ O_2 + 4\ H_2O \rightarrow 4\ SO_4^{2-} + 8\ H^+$$

Biological sulfur oxidation is the most commonly used process in the heap leaching of copper sulfides. Ore is agglomerated (fine particles attached to larger ones with concentrated H_2SO_4 solution) before stacking. Aeration is supplied from the bottom of the heap to provide O_2 and CO_2 for microbes. The heap is then irrigated with sulfuric acid (pH ~2) solution and allowed to propagate through the heap. The microbes are inoculated throughout the heap, typically through the irrigation solution. The microbial oxidation results in temperature variation throughout the heap, which can have impacts on leach kinetics. Heap leach kinetics are characteristically slow, with common leach times of months before desired recoveries are met.

THE CHALLENGES

Heap leaching is not without its challenges. An accumulation of iron and sulfate ions in the leach liquors over time can impose limitations on leach kinetics and requires rigorous management procedures. The presence of these ions leads to the formation of precipitates and potentially passivation of mineral surfaces, ultimately preventing further metal extraction. Iron and sulfate ions can also cause complications in downstream processing. The formation of jarosite is also an issue and requires management not to mention neutralisation costs imposed on the opex.. The bleed stream effluent treatment needs to be managed.Over the last twenty years operating at +55 centigrade has been established as a necessary condition and new bacteria that can operate at these temperatures. The use of chloride media as per the BHP patent (now expired) has resulted in improved copper recoveries with chalcopyrite.

TESTWORK STRATEGY

The objectives of any copper heap bacterial leaching should encompass the following main points:

1) Characterise ore for particle size, elemental composition, mineralogy, acid consumption and bioleaching potential.
2) Evaluate copper bioleaching in columns with crushed ore.
3) Characterise heat generation during sulfide oxidation using pseudo-adiabatic columns.
4) Explore excess iron and sulfate removal from leach liquors.

HEAP LEACH TESTWORK

When designing a testwork programme, a number of factors need to be considered.

- Design considerations:
  - Size of ore reserve
  - Grade of ore
  - Crush size sensitivity
  - Percolation
  - Leach kinetics
  - Geological location of ore
  - Local weather conditions
  - Economics
- Factors affecting testwork:
  - Ore mineralogy
  - Ore grade
  - Acid consumption
  - Size of deposit
  - Commitment of company
- Ore characteristics – UCS, CWI, SG, bulk density, moisture, Ai.
- Bottle roll tests
- Crush size sensitivity
- Initial column testing
- Water analysis
- Agglomeration
- Percolation
- Leach kinetics
- Soak test, slumping
- Large scale columns

PILOT HEAP LEACH PROGRAMME

The heaps are the core of the operation, and generally, the area that receives less engineering and attention than it deserves. The heaps are the area that gives most of the

Figure 5: Conventional copper heap leach project.

Figure 6: Heap leach facility layout.

operational grief based on our experience. The best SX/EW plant will not help if the copper is leaching slowly or percolation within the heaps is problematic. The heaps cannot be fixed after construction whereas the processing plant can be modified in most cases. Mistakes made with the heaps are locked in forever. Some operators have re-mined the heaps because of fatal errors made up front. This is an unwanted added cost for any heap leach operation. There is a risk/reward ratio if you are looking to spend money wisely to minimise risk. It is paramount that the organisation is certain that they have the best information that money can buy to give the best shot at a 'one chance only' unit operation. Moreover, a continuous and rigorous testing regime should be a part of the operational management strategy.

THE DESIGN STAGE

With so many tonnes of ore to be stacked over a finite period, a final-shape heap becomes a reality. At least sometimes, the final shape ends up as a trapezoid of leached ore, which after final rinsing is top dressed and revegetated. This is not correct and can lead to errors in pad size, under funding, environmental issues, lack of suitable leach pad area and so on. In general, the correct final shape should approximate a stepped trapezoid (similar to the shape of a Mayan Temple), a series of progressively perched smaller trapezoids. The height of each level is the heap height determined by various methods.

The reasons for this are that when progressing to the next level:

- The outer edge is bunded.
- The start of the next lift is a nominal distance (commonly 5 metres) from the outer edge to contain any slump. This is quite commonly a requirement of the relevant environmental authorities.
- Solution collection is needed at the toe of the lift.
- Heap maintenance access.

Where this is not done, slumped material can fill up the collection drains, solution can be diverted to the wrong area, recoveries are lower. Poor maintenance leads to poor performance. Another important point is that such a structure requires a larger footprint than a traditional trapezoid because for the same tonnage of material, the final height is generally determined by regulation and geotechnical considerations. This must be foreseen at the design stage.

PROJECT EXAMPLES

Haib Copper Heap Leach Project

The Haib Copper Project is a large copper-molybdenum porphyry located in the Karas region of southern Namibia. The main mineralised hosts at the Haib depsoit are a quartz feldspar porphyry and a feldspar porphyry rock. The principle ore material at Haib deposit is chalcopyrite with minor constituents being bornite, chalcocite and various green copper oxides. The Haib deposit features an indicated resource of 456.9 MT at 0.31% copper grade. The plant design proposed for the Haib Copper Project will use 3 crushers and an ore sorting system. The process is designed for a 90% availability, processing over 23,000 tonnes of ore per day (at a 8.5 Mtpa scenario) at a strip ratio of waste:ore of 2:1.

For the recovery of copper from the Haib copper deposit, ore heap leaching was considered for all options in recovering copper. The primary reason for the selection of heap leaching is due to the vast scale of the orebody and the low grade nature of the ore. Previous work that was conducted on the Haib Copper Project suggested that a conventional method featuring a crush-grind-float and sale of copper concentrate method is not economically feasible due to the hardness and low grade of the ore, which would require a significant amount of energy for grinding. The costs associated with heap leaching compared to a whole ore floatation circuit are considerably lower which is believed to improve the viability of the project.

Heap leaching is traditionally performed on oxide materials; however more recently there has been an increase in development in its application for acid insoluble sulfides. Previous sighter amenability testwork suggests that high amounts of copper can be extracted from the Haib ore material, with up to 95.2% via bacterial leaching. Bacterial heap leaching has advantages due to the claim of being able to selectively attack chalcopyrite which avoids the build-up elemental sulfur that is a common problem with chemical-based leaching, as it brings passivation of the mineral surface. More recently, column leach bacterial testwork showed that copper recoveries of up to 82.2% could be achieved with acid being generated during leach reducing net acid consumption. Although to further optimise operating parameters additional testwork is required. Given these results there is no reason why to suggest the chalcopyrite in the Haib ore deposit will not be amenable to bacterial assisted heap leaching.

CONCLUSIONS

Significant advances have been made with leaching sulfide copper ores over the last twenty years. Commercial leaching is achievable but current operators are guarding their intellectual property. The leaching of chalcopyrite in heaps requires elevated temperatures to obtain copper recovery. The forced aeration is also necessary for enhancing bacterial oxidation of chalcopyrite is also necessary. Predicted copper recoveries of up to 80% over 120 days are achievable. Jacketed laboratory column testing can predict the likely copper recovery and together with an energy balance and observed kinetics. The heaps are the core of the operation and generally, the area that receives less engineering and attention than it deserves. The heaps are the area that gives most of the operational grief. The best SX/EW plant will not help if the copper is leaching slowly or percolation within the heaps is problematic. The heaps cannot be fixed after construction while the plant can in most cases. Mistakes made with the heaps are locked in forever. Some operators have re mined the heaps because of fatal errors made up front.. An operation cannot spend enough cash on testwork and knowledge based on a risk/reward scenario. It is paramount that the organisation is certain that they have the best information that money can buy to give the best shot at a 'one chance only' unit operation. Moreover, a continuous rigid testing of the ores should be a part of the operational management strategy.

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