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Development and Challenges in the Canadian Mining Industry

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ABSTRACT: Canada is one of the leaders in the world for developing and employing highly efficient and advanced mining technologies to supply the world with various minerals, oil sand and coal The Canadian mining industry's goal for future is to continue to remain one of the world leaders by increasing the value of mining products for customers. The industry will employ processes and produce products at lower costs, reduce energy consumption. At the same time will continue to minimize the adverse environmental, health and safety effects associated with mining and mining products. Achieving this goal will provide enormous benefits to the Canadian prospering population, their quality of life and the environment. This paper is to give a brief overview of the Canadian Mining industry and then discusses some of the development of the Canadian mining industry in the past decade. Attempt is made to highlight related challenges, which will be the basis for the necessary future research and development program.

1 INTRODUCTION

1.1 *The value of mining to Canada*

Mining products are the building blocks of our society. They are still the primary materials in our buildings, roads, and machines. Mining products are the basis of many products that have become increasingly critical to everyday life in the twenty-first century-advanced materials. Canadian mining products are metallic minerals, industrial minerals, precious stones, as well as, energy resources such as oil sand and coal.

The economic benefits of mining are far reaching; it is not an exaggeration to say that mining helped build this country. It opened Canadian frontiers. Glace Bay, Rouyn-Noranda, Val d'Or, Chibougamau, Sept-Iles and Labrador City, Sudbury, Timmins, Kirkland Lake, Cobalt, Flin-Flon, Thompson, Fort McMurray, Trail, Kimberley, and Dawson City all started as mining towns. At present mining takes place in almost every Canadian province. However it is more important in Ontario, Quebec, Alberta, British Columbia and Saskatchewan. Hundreds of mines operate in Canada today, providing materials for the manufacturing, construction, automotive and chemical industries, as well as the energy resources upon which we are so dependent. Hence, this industry affects the Canadians socially and economically. The mining industry continues to helped Canada's rural and developed regions by creating many jobs and providing the opportunity of growth in the areas. It is estimated for every job created within the mining industry, another job is created to an indirect source of this industry.

Mining provided direct employment for over 368,000 people in 1998. Mining operations are often the leading employers in the communities where they operate. Mining employees eam some of the highest wages of all Canadian industries. Contrary to popular perception, the mining industry has a low rate of occupational injury, lower than retailers, hospitals, and hotel. The mining and mineral processing industries contributed approximately $28.0 billion to the Canadian economy. If, energy resources contribution to the economy is added to the above, the total will be approximately 50 billion Dollars. It exports 80 percent of mining production, which comprises 15% of the Canadian total export. However, the mining industry's contribution to the GDP does not, by definition, take into account the total contribution of the mining industry.

A recent study demonstrated that for every $1 billion in output created by the mining, smelting and refining sectors direct demand of goods and services increase by $615 million. Hence, a strong Canadian mining industry is an engine of growth of Canada's small and medium companies in the areas of services, consulting engineering and equipment industry. At present, one in seven of all Canadian export dollars comes from mining. Mining has helped make Canada a major world trader. Toronto is considered capital of the world and is home not only to the Toronto stock exchange, but also to more than 400 mining and exploration company offices. On the other hand, Vancouver is the world's exploration centre with more than 850 mining and exploration company offices. Furthermore, Montreal is home to a number of mining companies and is an important location for mining research and development and education. McGill University and Ecole Polytechnique jointly offer the only bilingual mining engineering CO-OP program in Canada. Globalization of the mining industry has brought other developments. Canadian financial institutions have become world leaders in equity financing for global exploration and mine development. More than '/i of the world's mining companies are listed in Canada. At the beginning of January 2000, approximately 1500 companies were listed on Canadian exchanges, compared to 38 on the London metal exchange, 35 on the New York stock exchange, 66 on the Johannesburg stock exchange and 342 on the Australian stock exchange. This is why it is not a very big surprise to find more than half of the mining analysts of the world in Toronto.

Today, Canada is perceived as being the world largest and most sophisticated mining finance in the world and it is a major contributor to the Canadian finances. Canada's mining success has been based on good geology, continued support for research and development, applied new technologies, and progressive mining and environmental regulations. This combination has made Canada one of the most preferred targets for exploration capital in the world as a destination for international mineral exploration capital. In 1996 Canada ranked second, after Australia. Canada also ranks among the top five producers of 17 major minerals and metals It headquarters some of the world's largest and most successful multinational mining companies such as Inco, Barrick Gold, Alcan, Cominco, Falconbridge, Placer Dome and Noranda.

2 DEVELOPMENTS

The Canadian mining industry in the past two decade has overcome many of its operational difficulties as well as increasing the efficiency of its operations to compete with outside competitors by investing heavily in research and development Canada is a world leader in application of mining technology. Mining companies spend over $100 million annually in Canada on research and development. Over 85% of the work force use advanced technology, including electronics, advance materials, expert systems, and telecommunications.

New bulk mining methods has dominated the raining operations in Canada in the last decade. The applied rock mechanics research and development at depth especially in the rockburst-prone ground, together with innovation in support system, and mine backfill., rock characterization techniques as well as the deployment of the semi automated/ automated excavating , drilling and bolting machinery has contributed to the present success. Brief overviews of some of these developments are highlighted herein.

2 1 Applied geophysics

The mining industry has developed and employs sophisticated techniques to explore and characterize mineral resources. Minimizing the need for extensive capital and advanced work. This reduces the costs of, and the environmental disruption that can be associated with, finding economic resources. Ground disturbance associated with exploration and development is minimized and the accuracy of the measurement of resource volumes and quality has been improved. Reserve maps are more accurate and mine plans are designed make mining more productive. Improved efficiency in mineral extraction reduces dilution and therefore reduces mineral processing costs and minimizes wastes.

These achievements have been possible with application of advance geophysical techniques, such as Ground Penetrating Radar, Radio tomography, and *3D* seismic as well as laser stope profiling systems and MSR (Miniature Seismic Reflection.). Further development^nd challenges in this area, will be in better interpretation of the signals as well as combining and fusing data from different techniques to produce a more detailed and accurate images of geo-structures.

2.2 Mine backfill

From the tremendous activity in backfill technology in the past 20 years, it is clear that mine backfilling continues to be highly significant to our industry from both support and environmental point of views The large number of research projects awarded by the Federal Government and Provincial Government together with the mining industries addressing different issues concerning backfill operation has contributed greatly İn improving mine backfill operation as well as keeping Canada in the forefront of mine backfill technology in the world.

In recent years, through the increasing awareness of backfill's benefits to mining operations, as well as the technological developments in the application of an energy and economically-efficient system, backfill has gained a place as an integral part of the whole mine design and operation. Processes such as mixing, dewatering, transportation and placement as well as geotechnical considerations have improved substantially and have been the subject of much discussion. Due to the complexity of backfill systems, applications of backfilling to different mining environments require extensive experience. Such experiences, documented as case studies, are very useful especially when the time comes to apply new technology, such as expert systems, artificial intelligence and an object-oriented program to backfill design.

The computerization of backfill design and implementation has already begun but there are still significant areas of the backfill operation that require technological and theoretical advancement. Hydraulic transportation, although relatively well understood in practical terms, continues to vex scientists and engineers alike, although advances in plug flow understanding have contributed to an increasing interest in total tailings backfill.

The placement of backfill has often caused problems in practice but has rarely received the attention it deserves in terms of research. Tight filling of all types of fill and reduction in coning and segregation for rockfill all require research if the advances required are to be made. Total tailings placement is always cited as a 'grey' area although very little research seems to have been done and cost effective solutions found. As stricter environmental standards are adopted then we will be forced to look more closely at these issues and the benefits will certainly outweigh the investments required to solve these problems.

Mining with backfill requires reliable and energy efficient pipeline systems for transporting waste material underground. Such systems offer advantages in terms of convenience, low operation and maintenance cost, in addition to being environmentally "correct".

The technical constraints imposed on such systems may be summarized as follows:

- If possible, the system should operate with full utilization of its potential energy.
- The material transported should be carefully engineered through appropriate mix design to ensure a stable and flowable fill mixture with maximum solids capacity.
- Flow velocity should be carefully selected and maintained to avoid unsteady flow and excessive wear of the pipeline.

Although the conveying of solid-liquid mixtures in pipelines has been a subject of extensive research and development for various commodities over the last forty years (e.g. coal and phosphate over long distances), its application to backfilling with the above-mentioned constraints is relatively recent.

This type of backfill practice has been developed simultaneously in different parts of the world. A brief summary of the use of backfill in Canada is given below:

1933 Use of furnace slag and pyrrhotite tailings at the Home Mine, Noranda, Quebec.
1935 Use of standard gravel at Falconbridge Mine in Ontario.
1948 Use of sand/tailings at Frood Mine, INCO, Sudbury, Ontario.
1959 Use of cemented tailings at Falconbridge.
1960 Use of cement to stabilize sandfill at [NCO.
1960 Use of cement to stabilise rockfill at Noranda, Geco Mine.
1962 Use of cemented tailings at Frood Mine, INCO.
1962 Hydraulic cemented mine backfill became standard.
1970 Development and optimisation of hydraulic fill and rock fill throughout the industry, worldwide
1976 Original developments of paste fill in Germany at Preiessage, Bad Grund Mine with the use of putzmeister pumps.
1978 Paste backfill development in South Africa by Chamber of Mine and CAMERO.
1981 Development of pastefill in Helca, Luck Friday Mine in U.S.A.
1983 First pastefill operation in Canada. Development of paste fill with tail spinner, Dome Mine of Placer Dome in Timmins, Ontario.
1983 Placer Dome and McGill University. Research and development of paste fill at McGill University.
1984 Research and development of paste fill at INCO.
1994 Paste fill production at Garson Mine of INCO.
1995 System development for standard paste fill by various groups in Canada
1998 In situ behaviour of past fill in stopes, Cambior lnc and McGill University.

In bulk mining with backfill, inter-chamber pillar recovery operations are closely related to stability of surrounding fill, which is governed by slope size and mechanical properties of die host rock. Results of practical studies show that cement or binder content in a fill and its slurry density are essential factors affecting fill stability and the economy of backfilling. The uncertainty in fill design, based solely on theoretical or numerical modelling techniques, without understanding of the behaviour of fill insitu or practical input, may result in fill block failure or excessive consumption of cementing material. In cyclic backfilling, the filled stope is utilised mainly as a work platform. As such, the cement content required of this platform is generally higher than that necessary in delayed backfill because of the short curing times available and the need for rapid deployment of heavy mining equipment in the stopes

In order to quantify the factors fill stability and to optimize economic effects, it is essential to consider a rational and practical design approach upon which operators can effectively manage backfill technology. Basically, backfill design should consist of determining fill composition and the water requirements needed for fill preparation to produce an acceptable mix having certain physical and mechanical properties i.e. strength and backfill cost estimation.

Binding agents, such as Portland cement or flyash, are applied in backfill technology to improve the mechanical properties of the fill, i.e. strength. Chemical additives such as flocculants, accelerators, and retarders are employed to improve the fill permeability, flowability of the slurry and the consolidation properties of the fill

These fill materials can be used either as 'full plant tailings' or deslimed by using hydro cyclones to meet desired percolation requirements. Their size compositions largely depend on ore processing and deshming technology. The fraction of 10 urn particles in classified tailings is usually less than 20% of total mass by Weight. Sand from surface alluvial basins is widely used in mine backfill and its particle size is generally less than 2 mm. Waste rock from mine development or quarries must be crushed to meet transport requirements. The maximum size for pipeline transportation is less than 1/4 the diameter of the pipe; in the case of hydraulic transportation, this means aggregate sizes less than about 60 mm whilst aggregates up to 30 cm can be transported by truck or conveyor.

The most recent development in mine backfilling is the introduction of the paste fill.

Paste fill has a higher pulp density, between 75 and 85% by weight, depending on the grain size distribution. They utilise total tailings and may often incorporate sand or waste rock. The material can be transported from surface and does not require İn-situ dewatering. Cement may be added at sites of preparation or immediately prior to placement.

Paste fill represents state-of-the-art fill technology and holds tremendous long-term potential in mining. The application of paste fill could significantly reduce the cyclical nature of mining, improve ground conditions, speed up production and greatly reduce environmental costs.

Although a great deal of experimental data has been gathered, there remains the challenging task of making the best use of it. One way of achieving this is to encourage more basic research and development in the mechanics of flow of highly concentrated suspensions. The outcome of such research could be in the form of semi-theoretical or mechamstic models, the validity of which may be checked by comparison with experimental data. Such models would then serve for scaling up to different pipe diameters and flow conditions and for prediction of the effect of a particular variable on the overall performance of the system.

In recent years in Canada, the behaviour and support capacity of mine backfill at narrow vein as well as bulk mining operations has been studied by the author at McGill University with collaboration with mines of Cambior Inc. Some of the data are presented at this conference.

The mine backfill (1998) book by F. Hassani and J. Archibald covers İn detail all aspects of mine backfill design and use.

2.3 Support system

Canada experiencing the effects of declining grades as the shallower to medium depth richer deposits are exploited. Canadian mines are heading literally downwards to greater depths. This in itself means higher mining costs and greater operational problems related to support loads, stability of the openings, ventilation and other stress-related problems. Crucial to the mining process, whether at depth or on the surface, is the in place support system. If the opening we are concerned with is important for short term or long-term mining activity, it needs to be supported for the projected life of the opening, at the least.

It's impossible to cover *all* aspects of this topic in a few pages, so this keynote address will briefly address the panorama of support systems presently used İn Canadian mines and the many contributions made to its development by mining practitioners and Canadian research establishments. An attempt is made to concentrate on the major elements of support systems used in Canadian mines without unduly neglecting any related issues.

The design of a mine support system, first involves the identification of the potential failure mode of the rockmass, followed by the design of the support system that will prevent the identified failure mode for the projected life of the rockmass and the constraints of the project economics. As long as raining activity in Canada did not face long term problems of depleting reserves, environmental concerns and difficult economic choices, the rockbolt was the ubiquitous element of support used in underground mines. Initially, they were mass produced in specific lengths, which had nothing to do with the depth of the rockmass to be supported, nor its nature. The rockbolt today has its important use in rockmass support and will no doubt continue to serve its purpose. As is often the case with development and progress, necessity being the mother of invention has caused modifications in rockbolt design and even newer support systems to be developed for mining at depth in Canadian mines. The support systems which are used in Canadian mines such as Polyurethane (Spray-on) Support, Shotcrete, Rock bolting, Cable Bolting will be addressed:

In the deep hard rock mines of Canada, high in-situ as well as mining induced stresses due to total ore extraction can lead to seismic events and rockburst. These unpredictable phenomena usually result in rock fells and the weakening of otherwise solid rock masses to the point of requiring major support, if mining is to continue. As mining in Canada gets deeper there has been an increase in the occurrence of seismicity and rock bursts. The support of rockmass in burst-prone ground is therefore a major concern for the mines experiencing this phenomenon and for research establishments in Canada. The Geomechanics Research Centre of Laurentian University in Sudbury was involved in the design of support appropriate for use in burst-prone ground. Tannant et al. (1996), İn their overview have identified three main functions of a support system as follows:

- To reinforce the rockmass, thus enabling it to support itself (Hoek and Brown, 1980);
- To retain or prevent broken rock from spalling and falling, thus possibly resulting in progressive failure and unravelling of the rockmass
- To securely hold or tie back the retaining elements, thus preventing gravity-driven rock falls.

In their research, they characterized support elements into six categories and gave examples of their support roles. They further grouped the load-displacement behaviour of support elements into six general characteristics as stiff versus soft, strong versus weak, and brittle versus ductile and produced a guidelines n form a table showing load-displacement parameters of various support elements from their research.

23.1 Polyurethane lining

Polyurethane lining is a spray-on lining, which has application properties that make it suitable for automated support installation. It also has potential where fast development and short ground support cycle times are desired. It is used in various underground support applications including prevention of small rock falls and rock unravelling, control of rock fracturing and bulking in rock that is failing progressively, and, prevention of small-scale strain bursts near the face of tunnels (Archibald et al., 1997). Polyurethane lining has been used successfully by Inco Ltd. to support ground in narrow-vein mining stopes and to protect mesh and bolts on the backs of top sill drifts exposed to blast damage (Espley, 1998). In the latter application, polyurethane effectively replaces shotcrete

Tannant (1998) describes a testing system designed to evaluate the performance of membrane liners in situations where the membrane is employed to support jointed or fractured rock. The test also measured the capacity of the membrane to resist loads from small-scale wedge failures and provide comparative assessments with mesh. Spraying polyurethane over an arrangement of inter-locked concrete blocks constituted the test panels. They were then loaded with a 300-mm pull plate and the loads and displacements were measured. The testing is claimed to demonstrate the importance of creating a near-continuous membrane in order to provide effective support for the blocks. When the limng failed to bridge the gaps between blocks, the resulting support capacity was severely compromised.

Archibald et al. (1997) presented a report on the field and laboratory support response of spray-on Mineguard Polyurethane liners. They described the brand name "Mineguard" as an innovative spray-on rock lining material developed, manufactured and tested primarily for use in underground hard rock mine and other geotechnical sites in order to provide rapidly-depioyable area support coverage. They state that it is intended to replace or work in conjunction with either shotcrete or the screen component of bolt-and-screen support systems in a variety of support roles. Mineguard can easily and rapidly be deployed on rock surfaces, and has the ability to achieve over 90% cure within seconds of being applied, thus offering considerable benefits for mining or excavation operations in which rapid rates of advance and a high degree of automation are essential. Mineguard support is claimed to be similar in cost to bolt-and-screen support methods and cheaper than non-reinforced shotcrete support. Additionally, the material handling requirements are low.

The authors carried out six-year, laboratory and in-situ mine assessment trials to determine support and other physical response capabilities of Mineguard for various mining and geotechnical applications. In their paper under reference, they review practical considerations, usage and results of several field case histories, which illustrate various mining applications of Mineguard. Other conclusions from their study are the following:

Its bright colouring improves lighting conditions in underground environments. This property obviously improves worker safety.

Mineguard polyurethane liner material has been shown to be one of the most effective sprayable barriers to radon gas diffusion yet measured. Its potential application in uranium mines and other mines where such gases may be present are obvious.

2.3.2 Cable bolting

Cable bolting was introduced into die Canadian mining industry over 20 years ago and it has since become, with relatively good success, one of the most important support systems in large underground openings. A conventional cable bolt is a flexible tendon comprised of a number of steel wires wound into a strand, which is grouted into a borehole. Cable bolt boreholes are usually drilled İn a grid pattern, to provide reinforcement and support for the walls, back and floor of underground or surface opening.

The cable can usually bend around fairly tight radii, thus making cable bolting a versatile form of support, especially in cases of long boles and tight working environments. The capacity of the cable bolt is transferred to the rockmass through the grout, which is usually made of Portland cement and water. Thus, they are used in underground hard rock mines to provide a safe working environment, increase rockmass stability, and control dilution of ore from slope boundaries. Cable bolts find greatest use in large spans of underground mines such as major intersections, large underground chambers or in active mining stopes, since larger spans in general result İn greater potential for large free blocks or broken rock falls. Cable bolts can be installed deep into the rockmass thus providing reinforcement and preventing separation along planes of weakness such as joints. By maintaining a continuum nature in the rockmass, cable bolts help to mobilize the inherent strength of the rockmass, thereby improving overall stability.

By far, cable bolting has received the greatest attention in research over the past several years. Research work in Canada in both the laboratory and İn the field by McGill, Queens and Laurentian University, together with mining companies such as Inco and Noranda has identified three principal factors that contribute to the poor performance of plain 7-wire strand cable bolts :

- Poor quality grout,
- Poor quality rockmass providing low radial stiffness at die borehole walls, and
- Mine-induced stress changes which further reduce the rockmass quality.

These three problems have been the subject of detailed research and progress can be reported in solving them. As an example, the introduction of the Garford bulb and the bulge cable offered a practical solution to the three problems while the use of modified geometry cable bolts has been shown to improve bond strength (Hyett et al., 1995).

Most research, however, has dealt mainly with short embedment length pull tests whereas design issue usually involve long cable bolts. Research in this area has led'to the development of computer software nanied CABLE (Computer Aided Bolt Load Estimation), which attempts to extrapolate between thi?- too» \using a numerical simulation (Bawden et al^"l995). Bawden, Möosavi and Hyett (1996) furthejc address the theoretical research of load distribution problem alo$g fully grouted bolts, together with some parametric studies on the effect of grout water: cement ratio, rockmass modulus and face plates on cable bolt performance.

Advances in the theory, application and numerical simulations of cable bolts have been made in several institutions and research centres İn Canada. In the field of laboratory and theoretical studies relating to cable bolts, Hassani et al. (1992, 1995) performed experimental and numerical studies of grouted cable bolt support systems. Khan and Hassani (1993) also examined the application of rigid composite tendons in ground support in mines. Major factors affecting the use of cable bolting have been studied both in the laboratory and in the field. Hassani and Rajaie (1991.) discussed their investigation of the optimization of a particular shotcrete cablebolt support system. They demonstrated the unique yielding behaviour of the particular type of cable bolt, together with its high peak and residual load bearing capacity over conventional cable support systems. Advances in validating the theory and numerical simulations of cable bolts were also made with the development of an instrument called SMART (Stretch measurement to Assess Reinforcement Tension, Hyett et al. 1998). In tests carried out thus far, it has been shown that SMART does not interfere with the bonding process.

Although the primary purpose of cable bolting is in ground support, its use directly affects other important aspects of mining such as dilution control can have a very direct and large influence on the cost of mining. The cost of dilution is high: waste rock is mucked, trimmed, crushed, skipped, milled and impounded in a tailings disposal area at great and unnecessary cost. Anderson and Grebenc (1995) provide a useful illustrative case history of dilution control through the understanding of the causes of failure in one stope and the effective design of support for the adjacent stope by use of cable bolting and backfill.

They discussed the factors to be considered in assessing the cost of dilution. The required information - % dilution, % recovery and % overbreak - is collected from a laser survey of each stope after mining is complete.

There are now in Canada, several grouting systems which are able to mix and pump thick (<0.40 water: cement (w: c) ratio) and even super thick (<0.30 w: c ratio) grouts. The importance of the Portland cement grout in determining the cable bolt capacity has been demonstrated both in the laboratory and in the field, (Reichart et al., 1992, Hyett et al. 1992, Hassani et al., 19).

Cablebolts can be used to support, reinforce or contain rockmass around most types of excavation found in underground mines, including drifts and intersections, open *stope* backs and walls, cut-and-fill stopes, draw points and permanent openings. The following examples are typical of cable bolt application and layout.

It is rare and expensive for a mine to provide access and drifts solely for installing cable bolts. Cable bolting patterns are therefore usually designed depending on the stope and access configurations. The particular borehole pattern selected depends on the intended function of the cable bolts and the available access to the site.

Proper installation İs very crucial to the successful attainment of the objective of using cable bolts. After installation, follow-up and careful observation of the effects of installation are important so that changes, if found necessary, can be effected in the next round of installation. Hutchinson and Diederich, 1996, showed a Cable bolting Cycle, which provides a comprehensive overview of the steps involved in cable bolting operation. It is a cyclical, iterative process, which should be worked through a number of times as mining progresses to ensure that the cable bolting operation is well tuned.

Previous research in the use of cable bolts established that failure most commonly occurred by slip at the cable-grout interface and that the peak strength is related to frictional rather than adhesional resistance. Poor quality grout is one identifiable factor that has contributed to the low performance of the plain 7-wire strand cable bolt. Hyett et al. (1992), carried out a comprehensive investigation to determine the physical and mechanical properties for cement grouts with water/cement ratio varying between 0.70 and 0.25. They pointed out that the factors which affect the physical and mechanical properties of grout (which is essentially Portland cement and water) - namely, the type of cement, its treatment before use, the water/cement ratio and the pumping system - may contribute to the ultimate capacity of die cable bolt.

They examined in detail the factors relating to the major components of cement grouts, namely, the Anhydrous Portland PortlandjCement (APC), Fresh Cement Paste (FCP), and the Hydrated Cement Paste (HCP). For each factor, they made recommendations ranging from storage of the Portland cement both on the surface and in underground environment, to mixing and pumping of the grout by using MINPRO or MAI pumps. These are some of their important findings:

On Anhydrous Portland Portland_Cement (APC), they found that two different cement specifications are used for cable bolting in Canada: normal (type 10) and high-early (type 30). They found that the finer grained type 30 required careful and proper storage in preserving its shelf life, it was more expensive than type 10, and its strength was less than that of type 10 after 2 weeks. Among their recommendations were that operators should use type 10 Portland cement unless the cement paste was for short-term support use of less than 10 days, and that the cement bags arriving at the mine site should be checked for "hardness". Any hard bag detected should cause the whole batch to be sent back to the supplier for a fresh supply.

On Fresh Cement Paste (FCP), they noted that some water is necessary in the paste to make it easy to mix and pump and that for practical cable bolting, ensuring that the specified grout is actually pumped up the cable bolt holes is the most single important quality control issue. They found that for water, cement ratio between 0.70 and 0.35, the bulk density of the paste increases from 1.6 to 2.10 g/cm^3. This property can therefore be used to estimate the water/cement ratio for pastes with values lying within this range.

On thick FPC, they recommend the use of MINEPRO or MAI pump although their pumping efficiency decreases with water/cement ratios < 0.35. They also recommended batch mixing rather than continuous mixing of the grout. On Hydrated Cement Paste (HCP), they carried out laboratory tests to determine the physical and mechanical properties of cement paste with water/cement ratio varying between 0.70 and 0.25. Samples were mixed using an MAI pumping system and left for 28 days to cure at a relative humidity of 95%. They obtained the following results:

The UCS, tensile strength and Young's Modulus increase for 0.70 < water/cement ratio < 0.35, with the Poisson's ratio remaining nearly constant at 0.18. Only the Young's modulus continues to rise for water/cement ratios < 0.35. The 28-day dry density can be used to estimate the water/cement ratio.

Hyett et al. (1992) earned out a laboratory and field research programme in their investigation of the major factors that influence the bond capacity of grouted cable bolts. All tests were conducted on standard 5/8" (15.9 mm) 7-strand cable grouted using type 10 Portland cement pastes. The results indicate that cable bolt capacity most critically depends on the following factors:

- The cement properties, which are primarily controlled by water/cement ratio.
- The embedded length, and,
- The radial confinement acting on the outer surface of the cement anmîus.

They found that the properties of the cement paste varied with the water/cement ratio of the mix, and that a low ratio (< 0.40 by weight) can increase the peak cable bolt capacities by 50 - 75%. According to the authors, this is attributable to then-high uniaxial compressive strengths and their high Young's moduli. They also report that the effect is maximized under conditions of high radial confinement. On the other hand, the use of super-thick pastes (0.30 and less) may be both impractical and undesirable, first because of their limited pumpability and second because of their inconsistency in strength.

Bawden et al. (1995) present a numerical formulation for determining the axial load along a cable bolt for a prescribed distribution of rockmass displacement- Their formulation is based on research findings (Fuller and Cox, 1975; Goris, 1990; Hyett et al., 1992) that the bond strength of a fully grouted cable bolt is frictional rather than adhesional in nature, and that during the process of debonding, a progressive increase in the mismatch between the cable and the grout first splits the surrounding grout annulus, and thereafter pushes the grout wedges aside. Depending on the stiffness of the borehole wall, a reaction pressure develops that controls the normal stress acting at the cable grout interface where slip is occurring and hence the bond strength of the bolt.

In another paper by the three authors, Bawden et al. (1996), they present an explanation for the observation that fully grouted reinforcement is more effective in hard rock that behaves as a discontinum than in soft rock. They present analytical solutions for displacement and load distribution along an untensioned fully grouted elastic bolt of specific bond stiffness, which is activated during excavation either by a continuous or discontinuous distribution of rock displacement. They report that results indicate that significantly higher axial loads are developed for the discontinuous case. They also carried out parametric studies, using a finite difference formulation combined with a non-linear model for the bond behaviour of a cement grout of a seven-wire strand cable bolt, to show that lower loads are developed in soft rock.

An excellent book, on all aspects of cable bolting, has been written by Hutchinson and Diederich (1996) with the sponsoring of the Canadian Mining Industry.

2.3.3 Shotcrete

The use of shotcrete İn Canadian hardrock mines has experienced rapid growth over the past 10 years. Field and laboratory evaluation of its performance as a ground support system has been investigated by several researchers. The work of the Geomechanics Research Centre of Laurentian University, Ontario is typical of the kind of research done in this area. They confirm that in some cases, the introduction of shotcrete has helped to extend the mine life or has reduced rehabilitation costs and production delays. While shotcrete is now accepted as a viable support option, there is increasing evidence that better guidelines are needed to ensure appropriate (cost-effective) selection and application of different types of shotcrete in widely differing underground environments.

The Geomechanics Research Centre has been involved in numerous field and laboratory investigations of shotcrete performance and is working towards establishing guidelines to assist the mining industry in selecting the most appropriate type of shotcrete or support system for a given application.

A zone of failed rock usually develops around excavations at depth or in highly stressed ground. This failing rock dilates and bulks in volume as it fails. Support systems designed to control the failure process and to maintain stability and safety in the excavation must be able to accommodate these deformations. Hence, much of GRC's testing has focused on the performance of shotcrete under large imposed displacements.

Loading of the shotcrete may occur very rapidly m rockburst situations or gradually over time when progressive failure processes dominate the rockmass response near the excavation. From numerous tests on shotcrete with various loading rates (pull tests, impact tests, and explosive loading) much needed data about the capacities of shotcrete under field and large-scale testing conditions has been generated. Some of the findings include:

Contrary to results from tests on small-scale shotcrete beams, GRC has found that mesh-reinforced shotcrete offers more toughness and higher load carrying capacity than steel-fiber reinforced shotcrete at very large imposed displacements. Preventing excessive tangential stresses in the shotcrete is necessary for optimal shotcrete performance m excavations that will experience large convergence or closure after me shotcrete is applied.

Shotcrete can retain its functionality near large production blasts. Shotcrete (plain, steel fiber, or mesh reinforced) can survive peak particle velocities in the order of 1 to 2 m/s as long as the underlying rock is not forcibly ejected into the excavation and the shotcrete İs applied as panels that are not highly stressed.

The addition of shotcrete to mesh greatly improves the mesh's load carrying capacity and results in a retaining component that has superior energy absorption properties.

GRC plans further testing to evaluate shotcrete performance (Tannant, 1998). Other areas of interest include the abrasion and impact resistance of shotcrete for use in ore passes and storage bins, comparative evaluation of shotcrete, Mineguard and new types of fiber reinforced shotcrete, and the development of procedures for designing shotcrete-based support systems for different applications. Our research will also focus on developing better tools for predicting the demand (load, displacement, and energy) that may be placed on shotcrete for specific excavation geometries, stress levels, and rockmass conditions.

One of the major problems in the use and application of shotcrete is quality control as well as ensuring the thickness of the shotcrete lining. This issue is currently being addressed by the author at McGill University and within the next six months special non-destructive testing equipment will be available directly give the above information on site (Hassani et al., 2001).

3 AUTOMATION

As the mining industry moves towards the twenty-first century, the opportunity to apply emerging technologies to enhance production and resource performance and provide new products are critical to the industry's ability to serve the nation and achieve profitability. Once these technologies are developed and in place, they will allow the industry to use its energy, land, capital and labour resources even more efficiently during all stages of the mining cycle. This will in tum, create a safer, less environmentally disruptive industry with higher quality output at lower cost. Satellite communications systems and information processing technologies are already reducing costs and minimizing environmental disruption associated with reserve characterization and production. Automated machines reduce worker exposure to hazards while in situ processes contain the disruption associated with extraction and processing.

Canada is considered to be amongst the leaders in technology in the mining industry. There are many companies considering Automation because of new discoveries of complex deposits. Canadian companies have invested greatly İn Robotic mining technology and techniques that offer a number of positive benefits and some unique engineering challenges. These Canadian companies believe that on-line information about geology, (geophysical, geomechanical and geochemical), production rates and quality will provide a significant advance in mine engineering planning and logistics.

The automation research in mining was initiated by (Canadian Centre for Automation and Robotics in Mining (CCARM) at McGill University in Montreal with support of mining companies such as Inco, Noranda and Falconbridge. In recent years, a five years project with partners Sandvick, Tamrock, Mining Equipment Inc, DynoNoble and Inco was initiated to create a teleoperated mine. This Mine Automation project Or MAP started in 1996,and has had tremendous achievements.

Remote mining in combination with some simple automation offers some solutions to some technical issues. Robotic mining or automation of equipment requires communication systems, positioning and navigation and process engineering, momtonng and control systems. These processes are easier to develop for surface mines in Canada however the challenge relies İn underground environments. Currently most mining operations are searching for voice communication and some limited computer control and video surveillance. Inco was able to develop a commercial communication system, which is now marketed by Automated Mining Systems.

Communication advances are the main reasons for the use of robotic mining. Inco contracted with IBM in 1988 to develop an advanced communication system for underground mining based on CATV and radio transmission technology. This system has been installed, tested and deployed in mining operations such a Stobie Mine.

Since robotic mining is gaining support, Canadian companies are now considering an enhancement of the communication system components.

Canadian automation is now to a point where engineering systems provide online information directly to machines for set-up of drills and the provision of map co-ordinates. It is also possible to use Drift drilling using jumbos by teleoperation from surface. These machines will, in turn, provide feedback to blasting systems and rock classification systems. Furthermore, explosives loading equipment can feed emulsion-based variable energy explosives into each hole placing a detonator that can be fired over the network electronically from surface. Finally, Robotic mucking will picked-up the fragmented rock (ore or waste) and move it to the appropriate dumping point.

This new technology allows minimal ground support, as the opening will be smaller since there will be no people in the workings. If ground support is required it will be done only where needed to ensure equipment survival. Similarly, ventilation will be reduced, as no personnel will be needed in the operation. Road conditioning can be accomplished by equipment such as the Road Router TM to ensure that the high-speed reliable machines can work effectively in this robotic environment. Furthermore, Constant feedback of production, engineering and maintenance information will be transmitted to ensure each mining mission is accomplished.

4 ENVIRONMENT

Increasingly stringent environmental policies in Canada will put upward pressures on production, processing and product costs at the same time that international competition and alternatives to mining products will require that costs remain competitive. Environmental costs can be significant. For example, the cost of environmental compliance in Canada for metal mining, processing and fabrication was about 10 percent of total costs.

It is very important briefly address mine waste in the context of the new environmental era. The disposal of tailings is a major environmental problem. It becomes more serious with the increasing exploration for metals and working of lower-grade deposits. It is estimated that the Canadian mining industry produces in excess of 500 million metric tonnes of solid waste each year - a 1988 estimate that includes metal, uranium, coal and industrial minerals. Wastewater associated with the mining and milling operations constitutes an equal amount of liquid waste (Intergovernmental, 1988). Quebec alone İs estimated to have produced 102.1 million metric tonnes of tailings in 1990 (Rallon, 1989). This waste has to be disposed of in the most environmentally and economically acceptable manner.

Traditionally, three techniques are available to the mining industry to dispose of its waste: (1) underwater (lake) disposal; (2) underground disposal (backfilling) and (3) surface disposal. Underwater disposal lacks public acceptance and has limited application, this method requires a deep body of water. Tailings must be chemically harmless, and piped to deep water to avoid the most biologically productive areas near shore zones (Vick, 1981). Some believe that underground disposal represents the future of waste disposal in the mining industry. New backfill methods like total tailings fill can utilise all size fraction tailings and recent advances suggest that İt may significantly reduce surface disposal, which has traditionally been the most common method of waste disposal. The high percentage of fines within current tailings as well as the presence of sulphide ores pose some difficulties with tailings pond management.

The increasingly strong environmental lobby, in its search for scapegoats, are now turning to the law in their pursuit of the directors of mining companies. They can be held personally responsible for pollution attributed by their company

It becomes clear that as the mining industry moves in to new millennium will have to clean up its act. Otherwise the North American mining industry will go the way of the spotted owl and the desert tortoise and become the latest addition to the endangered list. Over die years the regulatory conditions have "snowballed" and before they strangle the industry it must change and keep ahead by utilising new technology. Such technology exists and as we start the 21st century the importance of an appropriate total mine solid waste disposal can only increase.

5 CHALLENGES AND VISION FOR THE FUTURE

As the Canadian mining industry moves into the twenty-first century, it is required to continue produce products with lower costs and superior qualities, while minimizing environmental disruptions and maximizing safety of the labour in order to stay competitive. The mining industry must continue to practice responsible stewardship of national resources by developing and applying advanced mining and environmental management technologies in Canada.

Advanced mining techniques and technologies are the key to increase productivity and permit exploration, extraction and processing to occur with maximum efficiency and minimum environmental impact. The development of new technologies and the transfer of appropriate technologies developed for other applications. Transfer of these technologies and development of new technologies will enable the industry to reach its goals and provide Canada with materials critical to economic, environmental and energy sustainability. Paradoxically, successful development and application of new technologies that incorporate advanced technologies such as computers, communications and robotics together with new mining techniques will be the key to the mining industry's improved profitability.

The future success of the mining industry will also depend on its relationship with the public. Public opinion is one factor that will determine whether young men and women become mining engineers rather man engage in opportunities in other industries such as high technology sector. Another factor is the lack of academics available to teach mining related" subjects. The public needs to be further informed of the value of mining. So to insure that they recognize the value of the goods derived from mining and their integral role in our everyday life.

The lack of highly trained mining engineers for the industry is going to be one of the major challenges facing the industry. The decline in number of students choosing mining discipline in the Canadian universities is the indicative of the future shortage.

It is vital that in the schools, teachers and students to have accurate information about mining and the importance of minerals to their lives. The mining industry and the education community needs to provide accurate, interesting, and informative teaching materials and delivery systems that reach the majority of administrators, teachers, and students.

A strong massage should be sent out stating that the mining industry provides professional opportunities that attract the best and the brightest. University mining programs should employ interdisciplinary faculty and should offer programs that enable students to learn all of the skills applicable to an advanced mining industry, including environmental sciences, chemical engineering, computers and robotics, advanced communications, mineral economics and international relations as well as language training.

The industry needs to work together with the public to ensure that environmentally sound minerals resources that are required to sustain a high quality of life in Canada and throughout the world.

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REFERENCES AND BIBLIOGRAPHY

Adams, D.J., Gurtunca, R.G., Jager, A.J., and Gay, N.C., ((989). Assessment of a new mine layout incorporating concrete pillars as regional support. In Innovations in mining backfill technology, Proc. of the 4th International symposium on mining backfill, Montreal, 2-5 October, 1989, Hassani, Scoble and Yu Editors, Rotterdam : A.A. Balkema, 1989, pp. 199-208.

Anderson, B., and Grebenc, B., (199S). Controlling dilution at the Golden Giant Mine. CIM Mine Operators Conference, Timmins, Canada, paper no. 4, 14p.

Archibald, J.F., Espley, S.J., & Lausch, P. (1997). Field and laboratory Support Response of Spray-on Mineguard Polyurethane Liners. Proc. Int. Symp. On Rock Support: Applied Solutions for Underground Structures. Lillehammer, Norway, pp. 475 - 490, June 1997.

Aref, K. and Hassani, F.P. (1988), Strength Characterization of Paste Backfill. Proceedings of the International Conference of Applied Rock Engineering. Newcastle upon Tyne, pp. 4-8.

Bawden, W.F., Moosavi, M. & Hyett, A.J., (1995). Computer Aided Bolt Load Estimation (CABLE). 97* A.G.M. of d.M. Rock Mechanics and Strata Control Session, Halifax, Nova Scotia, may 14-18, 1995.

Clarke, I.H. (1988), Evaluation of Cemented Tailings Backfill in South African Mines. SAIMM Special Publication No. SP2, pp. 77-89.

Clarke, LH. (1988), The Properties of Hydraulically Placed Backfill. Proceedings of Backfill in South African Mines, Johannesburg SAIMM, pp. 15-33.

Corson, D.R. (1971), Field Evaluation of Hydraulic Backfill Compaction at the Lucky Friday Mine, Mullan, Idaho, U.S. Bureau of Mines, RI7546.

Corson, D.R. and Wayment, W.R. (1967), Land Displacement Measurement in a Backfill Stope of a Deep Vein, U.S. Bureau of Mines, RI 7038.

Epsley, S. (1998). Implementation of Minguard spray on liners in the hard rock mining industry. M.Sc. Thesis, Laurentian University.

Gurtunca R.G., Adams D.J., (1991). Determination of the in situ modulus of the rockmass by the use of backfill measurements. J. S. Afr. Inst. Min. Metall., vol.91, no.3. March 1991, p.81-88.

Gurtunca R.G., Jager A.J., Adams D.J., Gonlag M., (1989). The in situ behaviour of backfill materials and the In: Innovations in mining backfill technology. Proceedings of the 4th international surrounding rock mass in South African gold mines.

Hassani, F.P., and Rajaie, H., (1990). Investigation into the optimization of shotcrete cable bolt support system. Proc. of 14lh Congress of the Council of Mining and Metallurgical Institution, Edinburgh, Scotland, pp. 119-130.

Hassani, F.P., Mitri, H.S., Khan, U.H., & Rajaie, H. (1992). Experimental and numerical studies of the cable bolt support systems. Rock Support in Mining and Underground Construction, Kaiser an McCreath (eds), 1992 Balkema, Rotterdam

Hassani, F.P., Khan U.H. & Mortazavi, A. (1995). Laboratory testing of fully resin grouted weldgrip fiberglass rockbolts. Rock Mechanics Daemon & Schultz (eds), 1995 Balkema, Rotterdam.

Hassani F. P. and Archibald, J.F.(1998) Mine backfill , published by Canadian Institute of Mining and Metallurgical Engineering Montreal Canada, CD Format.

Hassani, F.P., Fotoohi, K., and Doucet, C, (1998). Paste backfill performance in a narrow vein gold mine. 3rd North American Rock Mechanics Symposium, Cancun, Mexico.

Hassani, F.P., Momayez, M., and Guevremonl, P., *Odanold D.* (2001). Insitu non-destructive thickness measurement of shotcrete lining. Presented at annual general meeting of CIM , Quebec city, 12pp.

Hassani, F.P., Momayez, M., and Guevremont, P., (1998). Shotcrete measurement tests : Preliminary investigation at INCO's Stobie Mine using MSR Impact-echo and GPR. SubSurface Sensing Laboratory, McGill University, Montreal, Canada, report no. SSSL-98-003,34 p.

Henderson, A., Newman, P., Landriault, D. and Antoniazzi, P., (1997). The Cost Advantage of Using Paste as a Backfill. 99lh CIM Annual General Meeting, Vancouver, British Columbia, April 27-May 1,1997. CD-ROM.

Hoek, E., and Brown, E.T., (1980). Underground Excavation in Rock. Inst, of Mining and Metallurgy, London, England, 527 p.

Hutchinson, D.J., and Diedericks, M.S., (1996). Cablebolting in underground mines. BiTech Publishers Inc., Vancouver, Canada, 406 p.

Hyett, A.J., Bawden, W.F. & Coulson, A.I., (1992). Physical and mechanical properties of normal Portland cement pertaining to fully grouted cable bolts. Rock Support in

Mining and Underground Construction, Kaiser an McCreath (eds), 1992 Balkema, Rotterdam

Hyett, A.J., Bawden, W.F. *Sc* Reichert, R.D., (1992). The Effect of Rock Mass Confinement on the Bond Strength of Fully Grouted Cable Bolts. Int. J. Rock Mech. Min. Sei. & Geomech. Abstr- Vol. 29, No. 5. pp. 503 - 524,1992

Hyett, A.J., Bawden, W.F., Maccsporran, G.R. & Moosavi. M.. (1995). A constitutive law for bond failure of fully grouted cable bolts using a modified Hoek Cell. Int. J. Rock Mech. Min. Sei. & Geomech. Abstr. Vol. 32, No. 1, pp. 11-36,

Hyett, A.J., Bawden, W.F., Hendrick, N. and Blackall, J-, (1995). A laboratory evaluation of the 25 mm Garford bulb anchor for cable bolt reinforcement. CIM Bulletin, Vol. 88, No. 992,

Hyett, A.J., Moosavi, M. and Bawden, W.F.. (1996). Load Distribution Along Fully Grouted Bote, With Emphasis on Cable Bolt Reinforcement. International Journal for Numerical and Analytical Methods in Geomechanics, Vol. 20,517-544,

Khan, U.H., and Hassani, F.P. (1993). Analysis of new flexible and rigid composite tendons for mining. *Innovative Mine Design for th 21" Century,* Proceedings of the International Congress on Mine Design, Kingston, Ontario, Canada, 23-26 August 1993.

Landriault, D., Welch, D. and Morrison, D., (1996). Mine Tailings Disposai as a Paste Backfill for Underground Mine Backfill and Surface Waste Deposition. Prepared for the Society.for Mining, Metallurgy, and Exploration, Inc. Short Course, March 9 and 10.

Tannant, D.D., (1998). Personal communication. Geotechnical Research Center (GRC), Laurentian University, Sudbury, Canada.

Tannant, D.D., McCreath, D.R., and Kaiser, P., (1996). Impact test on shotcrete and implications for design for dynamic loads. 2nd North American Rock Mechanics Symposium Montreal, Vol. 1, pp. 367-373.

Thibodeau, D. (1989), Insİtu Determination of High Density Alleviate Sandfill. 4th International Symposium İn Mine Backfill. Innovation in Mining Backfill Technology, 267 pp.. Editor F.P. Hassani et al., Balkema Publishers.

Intergovernmental Working Group on the Mineral Industry. 1988. "Report on the economic and policy aspects of acid discharge". By the Federal/Provincial/Sub-Committee on Mine Water. August 29,1988,64p.

Rallon, H., 1989. "L'industrie Minérale du Quebec". Le Service de la Statistique et de L'économie minérale de la Direction de L'analyse Economique et du Développement Minier. Ministère de L'Energie et des Ressources, 1989, 89 P-

Scoble ,M. (1994) Competitive at depth: Re-engineering and hard rock mining process. Rock Mechanics.Nelso&Laubach(eds),BaIkema .Rotterdam ,p3646,

Vagenas, N. Scoble, (1998) Issues İn underground hard rock mining automation, Mine planning and equipment selection Edited Singal ,Balkema,Rotterdam,p469-474,

Vick, S.G., 1981. "Sitting and design of tailings impoundments". Mininp Engineering. Vol. 33. No. 6. June 1981. pp. 653-657.

Udd, j. (1989) Backfill Research in Canadian Mines. Innovation in mining backfill technology .3rd Int. mine backfill Symposium, Montreal .Edi. F Hassani et al. Balkema pubL pp3- İ 3