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WELD CLADDING FOR MINING AND MINERAL PROCESSING: A CANADIAN PERSPECTIVE

1. INTRODUCTION

A snapshot of weld cladding in Canadian mining and mineral processing sectors has been acquired through a technological market research, including analyses of publicly available information (such as various technical and trade articles) and the results of an industry survey. The findings are discussed in this article, with the results of the survey presented in Appendix A.

2. BACKGROUND

In addition to original equipment capital costs, the maintenance, repair and operations (MRO) costs to operators in mining and mineral processing industries can be high; this is, in part, due to significant materials wear and corrosion of operating components and systems in the harsh operational conditions.

Weld cladding, also known as weld overlay or hardfacing depending on application purposes, is a technology evolving from welding processes; however, in its own right, it becomes

Photos: Coal excavation (left), Weld cladding, courtesy of ESAB (Top)

one of the important manufacturing technologies for achieving cost/performance benefits in industrial sectors, such as mining and mineral processing. During weld cladding, a layer or multiple layers of materials are deposited on the surface of a base material [1], to improve the surface performance, such as wear and corrosion resistance, or to repair the worn components.

Weld cladding can be used to achieve direct economic benefits by improving performance or restoring performance; for instance:

- Components of cheap bulk materials are protected by weld cladding to achieve enhanced performance;
- Critical components are consolidated by weld cladding for achieving prolonged service life and thus reduced MRO costs; and
- Worn or undersized parts (which are either expensive themselves or costly to replace) are repaired and restored by weld cladding/surfacing.

Weld cladding can also be used to meet component performance requirements that are otherwise impossible:

Photos: Longwall Mining: Shearer, with two rotating cutting drums and movable hydraulic powered roof supports called shields.

A bulk material can be selected to achieve the desired mechanical properties (such as strength, impact resistance, and toughness), and a weld-clad surface layer is deposited to provide high wear and corrosion resistance.

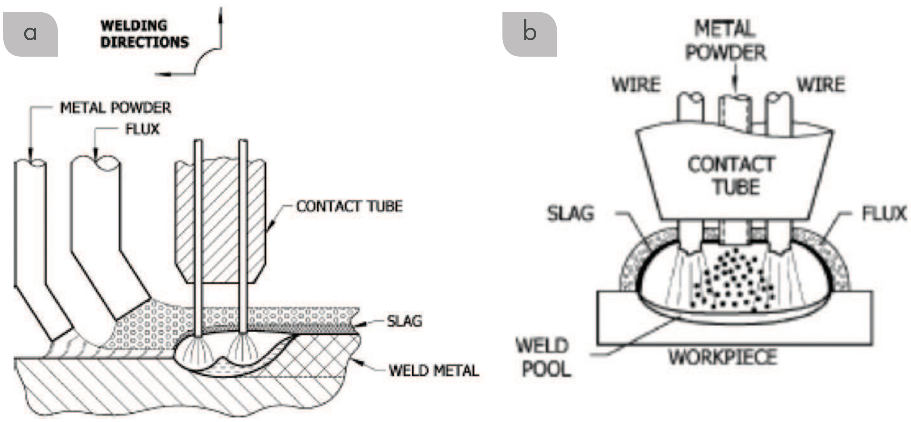
As compared with its parent technologies, weld cladding has some unique characteristics:

- The sole purpose of weld cladding is to deposit a surface layer on the base material, rather than for the purpose of joining.
- The composition and microstructures of the clad material are of critical importance; as such, dilution from the base material to the cladding is of special interest. Dilution is an important parameter [2, 3], which defines the degree to which the clad material has mixed with the substrate material and may significantly affect the performance of the cladding.
- The heat-input may therefore be even more critical as compared with welding/joining itself.

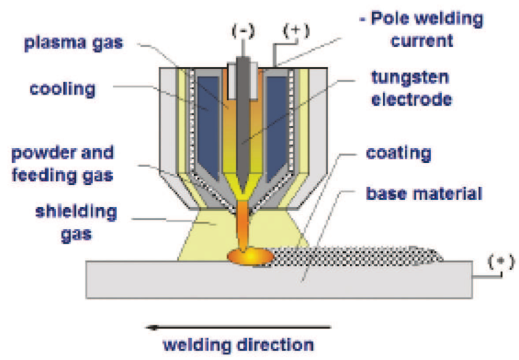
It is well known that Canada has significant presence in mining and mineral processing operations where weld cladding plays significant roles. Nevertheless, detailed information on the market position of the technology in the industrial sectors is not easily obtainable from the public domain. This study is intended to sort out some pertinent information to fill the gap.

3. THE TECHNOLOGICAL STATE OF THE ART

For the majority of mining components working under very harsh operational conditions, significant



01 Schematic of SAW cladding with double-wire (a) and with metal powder additions (b) [5]



02 Schematic of the PTA weld cladding process [6]

material losses (associated with wear and corrosion) occur before their replacement/repair; therefore, thick protective layers, typically in the order of a few millimeters, are often necessary. In addition, those components are repeatedly subjected to significant mechanical loading and impacts. Under such conditions, weld cladding becomes necessary in many operations, due to its capability of producing thick surfacing layers as well as metallurgical bonding to base metals.

There are several technologies that could be used for deposition of wear resistant overlays [4]. In general, arc welding technologies are widely used to produce wear plates and overlays on wear components as well as for repair and restoration of worn or undersized parts.

3.1: Some popular arc weld cladding technologies

Popular arc welding technologies, such as shielded metal arc welding (SMAW), gas metal arc welding (GMAW or MIG/MAG), gas tungsten arc welding (GTAW or TIG), are widely used, due to the fact that they are relatively inexpensive, flexible, easy for field applications, broadly available, etc.

The GMAW enjoys high filler metal utilization due to continuous wire feeding process. As a variant of GMAW, metal cored arc welding (MCAW) employs composite electrodes comprising a metal sheath with a powder-metal core, and provides also possibilities of depositing specialized overlay compositions not easily available or producible in solid wire form.

Flux-cored arc welding (FCAW) is also used widely. The uniqueness of FCAW is that the electrode comprises a metal sheath surrounding a core of fluxing and alloying compounds. Flux-cored, self-shielded electrodes (FCAW-S) are suitable for outdoors, in-situ, and out-of-position welding/cladding, as no protective gases are needed.

Overall, however, arc weld cladding tends to have the following inherent drawbacks:

- High heat input: This may cause distortion of base component, high residual stress and cracking of both clad materials and the substrate.
- High dilution level: It will significantly reduce the maximum alloying levels and changes the desired material compositions in the overlay/cladding, leading to poor performance.
- Limited types of cladding materials: Wear resistant materials are typically hard and difficult to be made into the wire or rod form. Despite of the fact that cored wires significantly extend the possibilities by putting powders into metal sheath, the maximum possible alloying levels are often limited.

Photo: old mining tunnel near salmon glacier, bc.

3.2: Submerged arc welding cladding

Submerged arc welding (SAW) is a common arc welding process, a process where the molten weld and the arc zone are covered under a blanket of granular fusible flux. Its high deposition rate is advantageous for cladding/overlaying. The significant drawbacks are high heat input and less flexibility in field applications as compared to SMAW, GMAW and FCAW.

SAW has been used to produce wear plates for mining applications. Recently, novel concepts are being explored by incorporating multiple wires as well as by integrating powder feeding (*Figure 1*), which may significantly increase the productivity and possibility of controlling/altering cladding compositions; the use of metal powders will also increase the weld arc efficiency and reduce the shielding flux consumption.

The recent introduction of AC/DC power sources has significantly contributed to the increase in productivity and fine dilution control with base metals.

3.3: Plasma transferred arc weld cladding

Plasma transferred arc (PTA) weld cladding, or PTA surfacing utilizes a confined, columnar welding arc generated by a specifically designed welding torch (*Figure 2*), and the heat input is highly localized, generating lower overall heat input and enabling a lower dilution level as compared to other arc welding processes. As shown in *Figure 2*, plasma gas passes through an inner annulus between the cathode and the anode, being ionized and forming a constricted plasma arc column. The ionised gas provides a current path for a transferred arc between a separate pair of electrodes of tungsten cathode and work-piece anode.

3.4: Laser Cladding

In contrast to arc weld cladding, laser cladding is a process where a laser beam is used to melt and deposit feed materials onto a metal substrate. To cover a surface area, a laser is scanned to form overlapping clad tracks and, thereby, a cladding layer. A thicker cladding is achieved by depositing multiple cladding layers. Some of the major advantages of laser cladding include relatively very low heat input, low dilution, flexible feed materials (powder or wire), precise

control of cladding dimensions, being able to clad on complicated surfaces/geometries, and easy to manipulate/control material compositions.

Drawbacks of laser cladding include high costs, low deposition rates, the lack of qualified personnel in the industry, less flexible in practical/field applications, etc

4. A SNAPSHOT OF THE CANADIAN INDUSTRIAL SECTORS

4.1: An overview of relevant industries

Welding and related technologies play important roles in Canada's resource industry (Appendix A). It seems that mining and mineral processing, oil and gas extraction, and construction are three top industrial sections where welding and weld cladding have an important role to play.
A majority of the companies involved in welding and cladding are small to medium-sized enterprises, with annual revenue not exceeding C$ 100M (Appendix A). These companies have mostly operations only in Canada or in North America, and are involved in a variety of business including welding/cladding processing, production and services of welding consumables (including feed metals) and machines, and automation system integration.

Overall there are more companies involved in oil-sands mining and services than in hard-rock mining and services (Appendix A), which may be in alignment with the findings that, according to statistics from the year of 2013, relatively a large portion of welding-related industrial personnel were identified as welders (who may have connection with oil sands operation) in the province of Alberta [7].

It is apparent that three main relevant applications are welding/joining, weld cladding of new components for performance improvement, and weld surfacing for repair (Appendix A), aiming mainly at MRO cost reduction and for equipment performance improvement.

4.2: Technological adoption by the industry

Due to its harsh operational environment, heavy-duty equipment and systems have to be employed in oil-sands and hard-rock mining, while severe wear and corrosion damage is common. Weld cladding of protective overlays for performance enhancement and for repair of damaged components are common practice in the industry [8-21]. Arc weld cladding, such as the processes engaging SMAW, GMAW, FCAW, SAW, and PTAW, are intensively used in Canadian oil-sands mining and transportation as well as in hard-rock mining and mineral processing.

Weld cladding of various hardfacing alloys were proven to be cost effective in dealing with a variety of maintenance problem for mining operations [10], despite the fact that reliable test and validation methodologies are needed to guide the material selection.

Weld cladding of WC-reinforced metal matrix composite (MMC) overlays and chromium carbide overlays [11, 12], for example, have been shown to be extremely valuable, sometimes maybe critical for mining operations. However, successful applications are strongly dependent on operational systems and conditions; tests under simulated operational conditions should be performed carefully, before the employment of a specific type of overlay materials.

If employed properly, PTA cladding of WC-MMC overlays are shown to be very valuable for reduction of operating costs in oil-sands mining [15-18]. PTA cladding is generally limited to in-shop production, and is impractical for most field welding applications. GMAW cladding of WC-MMC overlays could be used for in-situ maintenance, albeit achieving only inferior overlay performance [19, 20].

It should be mentioned that many companies related to mining and mineral processing operate in remote locations. Especially for those operations in Canadian Northern areas, due to the inconvenience for equipment transportation and the extremely short mining season, equipment reliability and effective MRO are critical [22]. Fast turnaround in equipment maintenance and repair is critical; SMAW and FCAW are mostly employed for on-site maintenance and repair.

Laser cladding is an emerging technology for the said industrial sectors, and has found only very limited, niche applications in Canada. Few shops in Alberta are using laser cladding for in-shop repair of critical components that require high performance. Further developments are needed for laser cladding to find more niche applications in the mining industry.

4.3: The industrial sustainability

For Canadian companies involved in welding and weld cladding, the perceived competition comes mainly from the USA (Appendix A). It is believed that welding machines, electrodes and other consumables represent the largest segment in welding and related market in Canada, where US-based companies command a strong presence. While the US-based companies are establishing manufacturing, distribution and supply services in Canada, local manufacturers and suppliers may be focusing on niche end-use sectors. Most of these players are small and few others are subsidiaries of US-based companies.

To remain competitive, the companies usually employ strategies, such as cost-saving processes, technology innovations, strengthening bottom-line performance, high value-added processes, etc.

While evaluating new production, it appears that both price and quality are important factors, with quality (rather than cost) being emphasized.

Some niche application areas, such as niche consumable market for oils-sands mining and transportation, may experience less competition. In addition to above-mentioned overall strategies, companies with sole operations in Canada remain competitive also by providing superior customer services, engaging technological innovations, and exploring niche market opportunities (Appendix A)

5. AN OUTLOOK INTO THE FUTURE

5.1: Technological innovation

Welding-related innovations may be related to advances in welding power sources and processing control, novel feed materials, processing automation, novel welding/cladding processes, process mechanization, etc.

IMPROVEMENTS IN RESPONSE TO INDUSTRY FEEDBACK

Positive changes to CSA W47.1- 2009 Update 7

The Canadian Standards Association (CSA) recently advised the CWB Group that an amended version of CSA Standard W47.1-2009 is now available. Like all CSA Standards, W47.1-2009 has been amended by CSA to ensure that the certification program continually improves in response to industry feedback and changes in technology. This amended version of CSA W47.1-2009 is known as Update 7.

FOR MORE INFORMATION
Contact us at: 1800.844.6790 or visit www.cwbgroup.org

Please watch this video outlining the changes to W47.1-2009
* Video is also available online www.cwbgroup.org

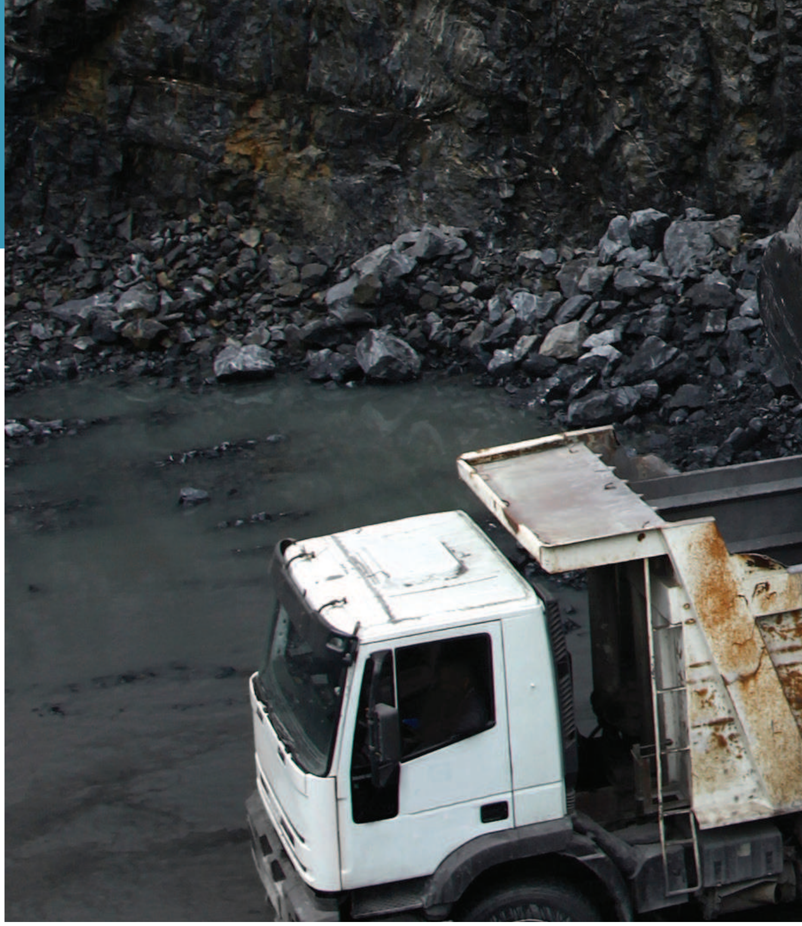


Photo: An excavator mines minerals from a quarry

It seems that end users (mining and processing operators) play the most important role in promoting technological innovation (Appendix A); this may be due to the fact that they could set up their own standards or requirements that the OEMs, suppliers, and services providers should follow. In general, there seems to be a desire to advance GMAW, FCAW, and SMAW as top choices for potential technological innovations (Appendix A). More convenient and advanced SMAW may be needed for field, in situ maintenance and repair.

For GMAW, one of the most characteristic phenomena is the mechanism for transfer of molten droplets across the arc from the wire electrode to liquid weld pool on the work-piece. The droplet transfer modes (such as globular, spray, and dip transfer) define heat input, weld quality, productivity, penetration, and dilution level. Dip transfer mode could realize the lowest heat input.

To reduce spattering for dip transfer, different equipment manufacturers have come up with a number of solutions, most of which rely on sophisticated control of the current profile and a rapid reduction of the welding current immediately prior to arc re-ignition [23], which is realized by significant advances in power sources using advanced electronic devices and modern logic control [24, 25].

Another type of approach is to employ "reciprocating wire feed" where, during the dip transfer of the droplet, synchronized (and reciprocating) filler wire retraction is employed in addition to rapid reduction of welding current [26].

It should be mentioned that the acceptance of a technology depends not only on technological demonstration but also on cost-benefit validation.

5.2: Welding and weld cladding automation

Welding/cladding automation could offer various benefits, such as enhancing productivity, achieving improved quality and reliability, reducing labor cost, and reducing the scrap and rework rate. It should gain increased acceptance when the industry faces more severe shortage of skilled welders.

It seems to be a popular view that welding/cladding automation is especially suitable for mass production. That may be true in most cases; nevertheless, using welding robots for small-batch production has proven to lead to cost saving and efficiency improvement in industrial practice [27, 28], especially where quality and performance consistency are critical factors.

Generally speaking, there seems to be some resistance in adoption of welding automation; this view may be changed when both technological benefits and cost reduction prospective can be demonstrated.

5.3: R&D at research organizations

The National Research Council Canada is developing advanced weld cladding processes and robotic arc weld cladding technologies at its Vancouver site, with a view to attracting industrial collaborators for advancing weld cladding and repair processes, aiming at providing industrial partners with practical solutions, directly scalable processes, and transferable know-how for effectively combatting mining wear and corrosion and thus reducing MRO costs of its industrial clients.

Other research organizations, such as the University of Alberta, are providing welding programs where intensive research on welding and weld cladding are ongoing. These R&D efforts are to advance the related technologies

and/or to clearly demonstrate technological benefits and cost-reduction potential, so that the industrial counterparts can make informed decisions in adopting certain advanced technologies for their specific applications.

6. CONCLUSIONS

Analyses of publically available information and the results of an industry survey on weld cladding in mining (including oil-sands mining) and mineral processing can lead to the following conclusions:

- Weld cladding is a valuable means in mining and mineral processing industries, to deposit wear- and corrosion-resistant overlays for performance improvement and for MRO (maintenance, repair and operations) cost reduction.
- Arc weld cladding technologies related to SMAW, GMAW, FCAW, SAW, and PTAW are intensively employed in Canada's oil-sands and hard-rock mining. Laser cladding is used only for limited, niche applications.
- A majority of the companies involved in welding and weld cladding in mining are small to medium-sized enterprises, and overall they have more involvement in oil-sands mining than in hard-rock mining.
- Perceived competition for those companies comes mainly from the USA. To remain competitive, the companies usually employ strategies, such as cost-saving processes, technology innovations, strengthening bottom-line performance, high value-added processes, etc.; additionally, companies with sole operations in Canada also rely on providing superior customer services, engaging technological innovations, and exploring niche market opportunities.
- While considering new productions and/or services, both price and quality are important factors, with quality (rather than cost) being emphasized.
- There seems to be considerable resistances in employing novel technologies, such as welding/cladding automation, unless both technological benefits and cost reduction prospective are clearly demonstrated.
- The National Research Council Canada is developing weld cladding and repair technologies for mining applications at its Vancouver operation. Objectives of these R&D efforts are to advance the related technologies and/or to clearly demonstrate technological benefits and cost-reduction potential, so that industrial adoption of novel technologies can be promoted. CJ

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APPENDIX A:
Industry Survey on Welding and Weld Cladding in Canadian Mining and Mineral Processing Sectors

The National Research Council Canada (NRC) and the Canadian Welding Association (CWA) collaborated early this year in a survey among CWA's corporate and premium members regarding welding/weld cladding technologies, with focus on their application in Canada's mining and mineral processing sectors. The outcomes are summarized as follows.

A-1: On participants' organizations

One hundred and eleven valid responses were received. Their main organizational involvements are in a wide spectrum of industrial sectors, among which the largest three are oil and gas extraction including mining and processing of oil sands, mining and mineral processing, and construction, as demonstrated in *Figure A1*. Other industrial sectors mainly involved are industrial and commercial machinery, chemicals and petroleum products, energy generation and utilities, agriculture, consulting and/or engineering, aircraft and/or aerospace, automotive and transportation, defense, shipbuilding, and others such as education and verification entities.

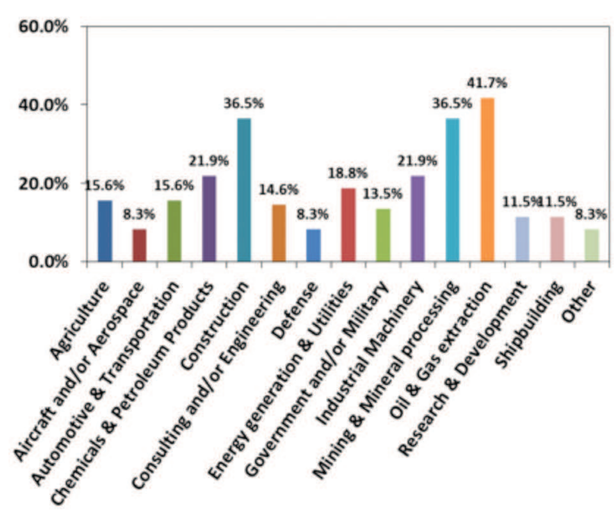

Figure A1: Organizational main involvement in industrial sectors

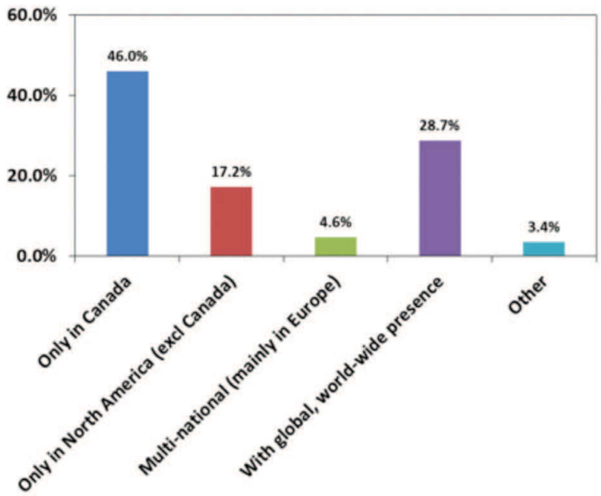

Figure 2A: Geography of organizational operation

As indicated in *Figure 2A*, many of the organizations (close to half of them) have operations in Canada only. The majority (roughly 63%) of them have operation in North America (including Canada) only. Close to 29% of them are international companies with global, world wide presence. Some (close to 5%) of them have multi-national operation with a focus in Europe, and others (a little bit more than 3%) have operations focusing on markets other than North America and Europe (respectively identified as in Australia, Brazil and China).

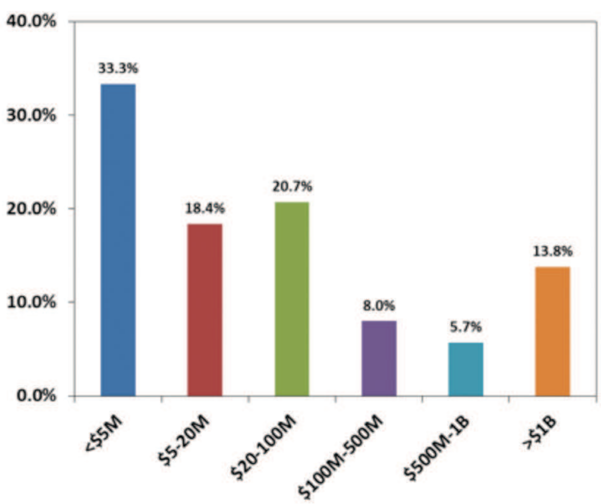

Figure A3: Annual revenue of participants' companies ($CDN)

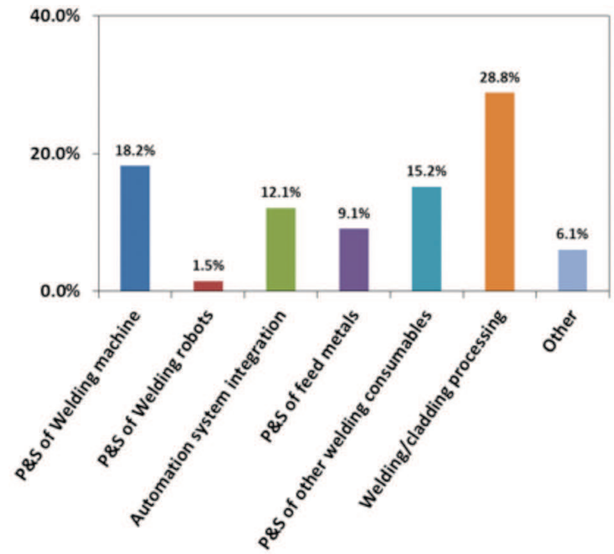

Figure A4: Business categories with involvement in welding/cladding

Most of the companies are small to median in size. As showed in *Figure 3A*, about one third of them have annual revenue less than C$5 million. More than half of them achieve annual revenue under C$20 million, and over 70% under C$100M. Only about 14% of the participants' companies achieve annual revenue more than C$1 billion.

As shown in *Figure A4*, the major businesses of most of the participants' organizations are involved in welding and/or weld cladding, including welding/cladding processing (29%), welding consumable production and supply (P&S) (24%), and welding machine production and supply (18%). Some are involved in welding automation and system integration (12%), and others (total 6%) in consulting, inspection, and test services.

A-2: Employment of the technologies in mining & mineral processing

It is estimated that over half of the participants' organizations are mainly involved in mining and mineral processing sectors, if taking into account mining of oil sands (Figure 1A). As indicated in *Figure 5A*, the detailed nature of the involvement of these organizations in mining are linked to hard-rock mining operations; oil-sands mining operations; mining and mineral processing equipment manufacturing and services; pipe line installation and services; maintenance, repair, and operation (MRO) services related to hard-rock mining and mineral processing; MRO services related to oil-sands mining, etc.

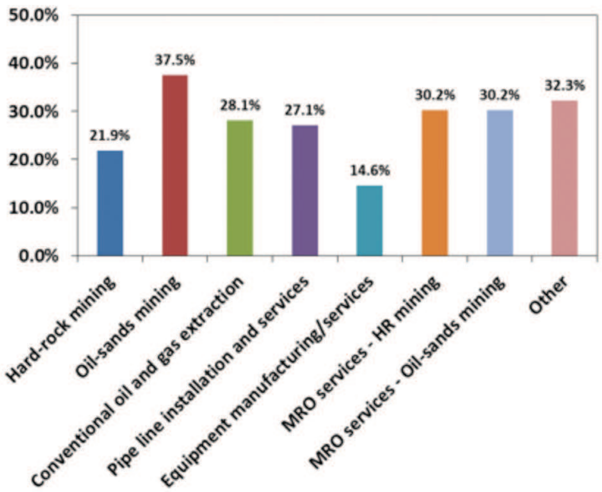

Figure 5A: Areas of organizational participation in mining and mineral processing

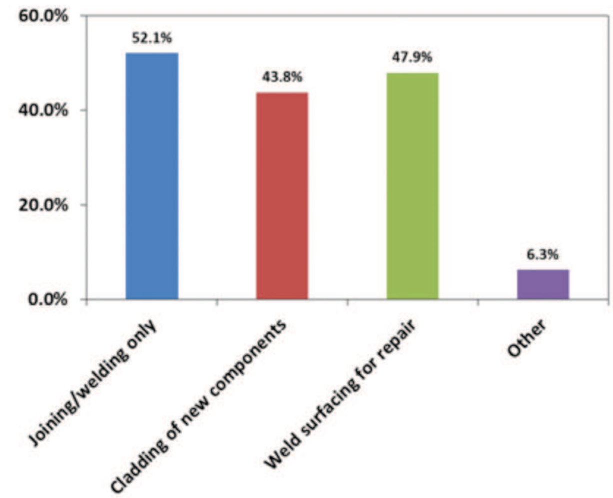

Figure 7A: Technical drives of employing welding/cladding technologies in mining

As demonstrated in *Figure 6A*, by operational functionality the participants' organizations represent mainly service provider (e.g., consultant, EPCM, etc.), shops/centers primarily related to metal fabricating and/or welding, respectively, as shown in Figure 6A. Nevertheless, participants come from many industrial segments, covering end users (i.e., mining and mineral processing operators), original equipment manufacturers (OEM), components and/or materials suppliers (to OEMs), welding equipment /consumable manufacturers, welding-related dealers and/or distributors, and others identified as certification organization, utilities, etc.

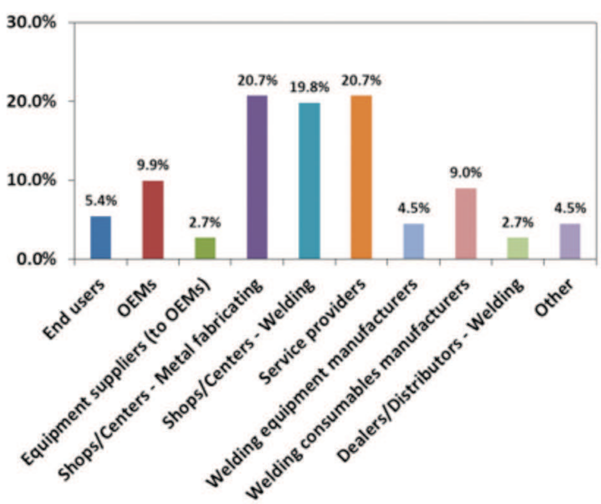

Figure 6A: Organizational categorization by functionality

It appears that, for those companies or their clients that employ welding and related technologies in mining, about 48% of them are involved in weld surfacing for repair, about 44% in weld cladding of new components, and about half of them for joining only, as indicated in *Figure 7A*. It is a clear indication that weld cladding and surfacing for performance improvement or repair are very important aspects for utilizing welding-related technologies.

As to the economic benefits to be achieved, as shown in *Figure 8A*, MRO cost reduction was identified by the majority (59%) of the participants, followed by maintenance cost reduction (33%), reduction of repair costs (30%), equipment cost reduction (22%), and operation cost reduction (16%).

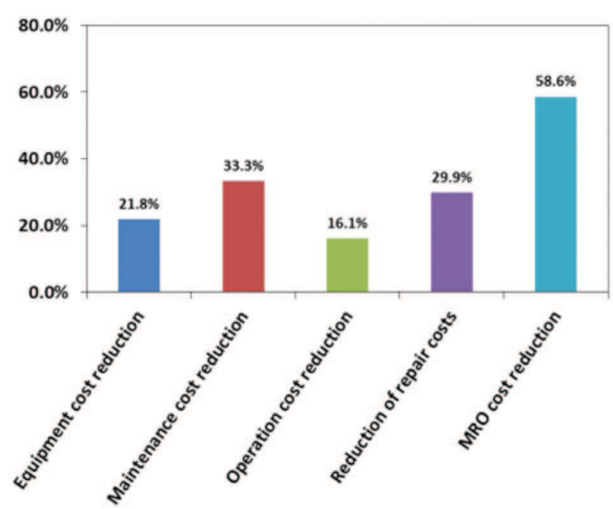

Figure 8A: Economic drives of employing welding/cladding technologies in mining:

A-3: Remaining competitive

As shown in *Figure 9A*, the main competitors, as far as the business of the participants' companies is concerned, come from the USA (45%), followed by China (24%), Canada (18%), and Europe (18%) as well as from some other countries such as India, Southeastern Asian countries, Brazil, and countries from Mideast and North Africa (MENA).

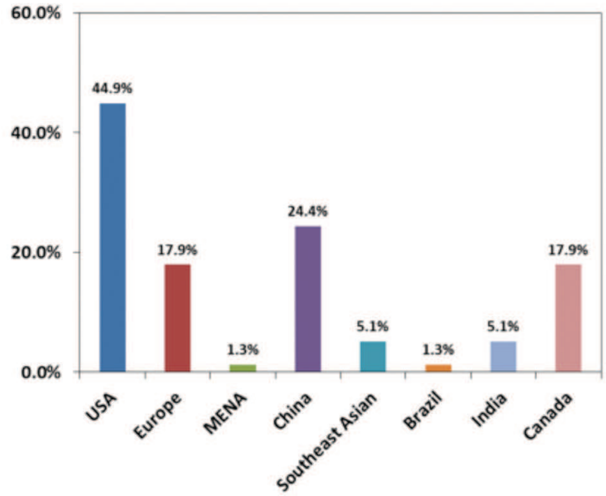

Figure 9A: The major sources of competitions to the weld/cladding business

Generally speaking, as revealed in Figure 10A, strategies for remaining competitive are identified as cost-saving processes by 29% of the participants, followed by technology innovations (27%), strengthening production economies and achieving bottom-line performance (24%), high value-added processes (23%), developing/engaging novel products (14%), engaging advanced welding and cladding technologies (11%), and promoting welding/cladding automation 10%. Other factors (21%) include quality control and customer satisfaction.

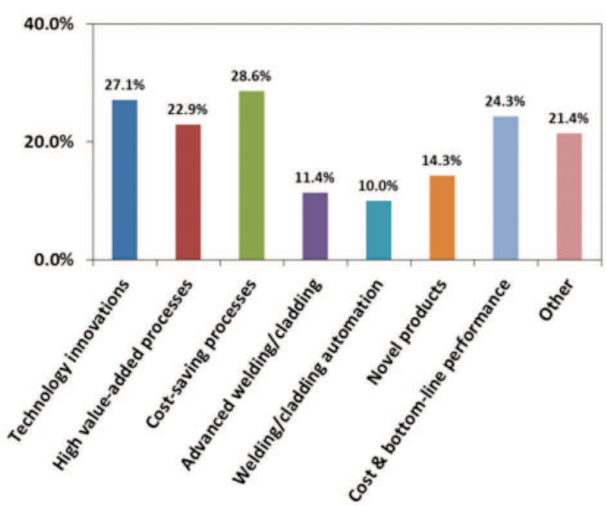

Figure 10A: Strategies to remain competitive

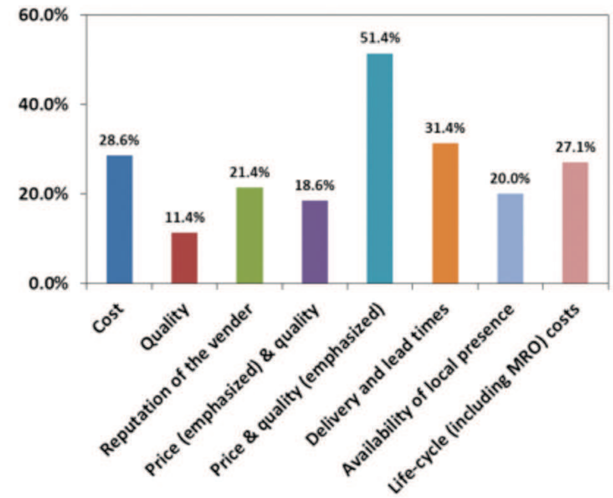

Figure 11A: Criteria for considering new products or services

As illustrated in *Figure 11A,* while deciding whether or which new products or services should be considered, the criteria are identified as price and quality with emphasis on quality (scored 51%), delivery and lead times (31%), and cost competiveness (29%), followed by life-cycle costs including MRO expenses (27%), reputation of the vender (21%), availability of local presence (20%), price and quality with emphasis on price (19%), and quality (11%).

As shown in *Figure 12A*, specifically for the companies that have sole Canadian operations, in addition to the above strategies, some additional tactics for keeping competitive edge could be superior customer service (42%), technological innovations (40%), bargaining power in terms of quality (33%), bargaining power in terms of price (28%), preferential accessibility to Canadian customers (21%), and specializing in niche applications (21%).

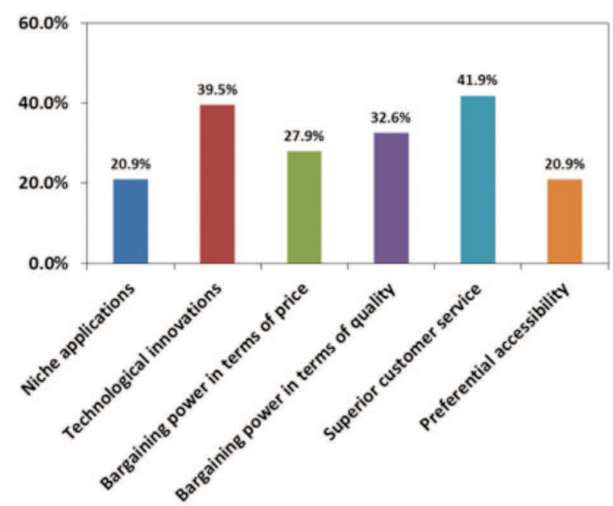

Figure 12A: Additional strategies to remain competitive for companies with operation in Canada only

A-4: On technological renovations

The majority (71%) of the participants consider that the technological advancements are mainly driven by the end users (mining and processing operators), as revealed in *Figure 13A*. The lesser important players are OEMs (23%), service providers (21%), and suppliers to the OEMs (11%). Health and safety consideration (14%) and government requirements and regulations (5%) could also be contributing factors.

As shown in *Figure 14A*, as to specific technologies in consideration for advancement, it appears that the GMAW is the top one that is desired to be advanced (59%), followed by FCAW (50%), SMAW (46%), SAW (34%), GTAW (32%), and PTAW (18%). The desire for advancing laser welding (scored for 16%) or laser-arc hybrid welding (9%) is lower than that for arc welding. There seems to be certain desire for welding and/or weld-cladding automation (scored for about 30%).

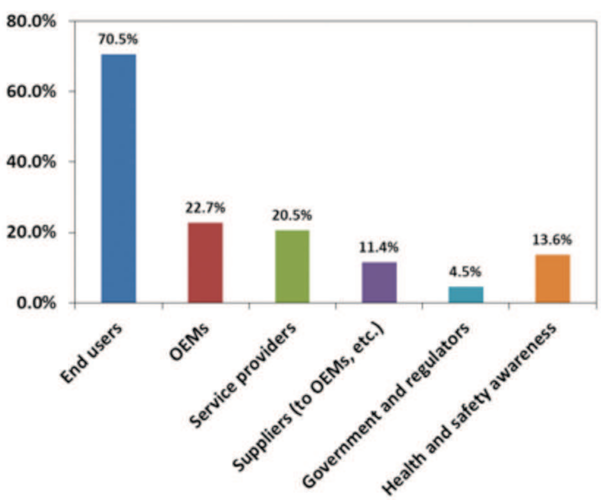

Figure 13A: Perceived drivers for technology innovation

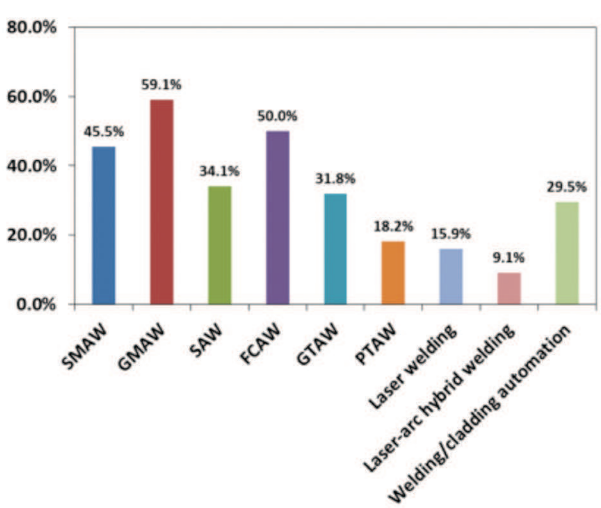

Figure 14A: Technologies in consideration for advancement

Specifically regarding welding and/or weld cladding automation, for example, it seems that many companies (34%) do not have any desire to the mechanistic technologies (*Figure 15A*), while 18% of the companies have very strong desire. Close to 36% of the companies indicate that their desires are somewhat low/high (or perhaps somewhere in-between).

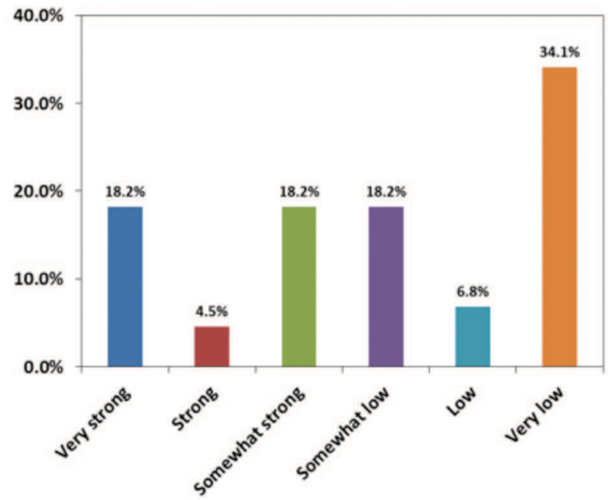

Figure 15A: Level of desire for welding/cladding automation

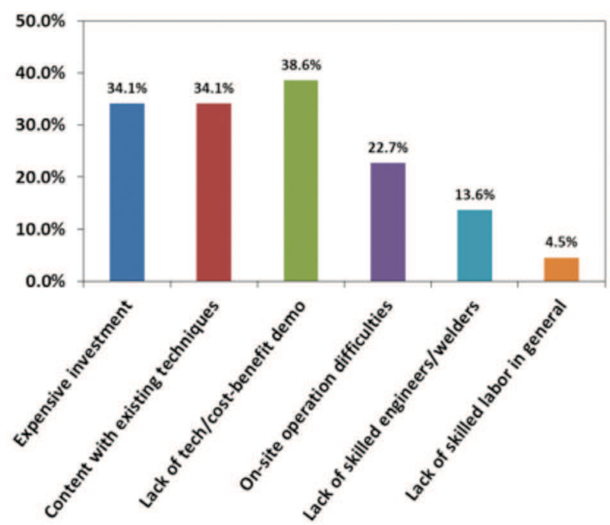

Figure 16A: Main reasons for not adopting advanced technologies

The major motives for not adopting advanced technologies (*Figure 16A*), such as novel welding techniques and/or welding/cladding automation, are the lack of technical and cost benefit demonstration (scored 39%), lack of capital for initial investment (34%), and being content with existing /available technologies that can still meet the clients' needs and requirements (34%), followed by technical difficulties and feasibility for on-site operation and repair (23%), the lack of skilled engineers and/or welders (14%), and the lack of skilled labor in general (5%).