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ELECTROSLAG WELDING (ESW): A New Option for Smelters to Weld Aluminum Bus Bars

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Abstract

In recent years, a new process to weld aluminum bus bars has been developed, tested and used industrially, permitting significant productivity gains both in terms of time and manpower savings. ESW (new aluminum bus bars welding process) offers among others advantages the possibility to modify or repair bus bars in magnetic field of an operating smelter with minimum power shutdown time (about 20 minutes per full bus bar section weld).

The present paper will cover the historic development of ESW, describe this new welding process, discuss the weld quality and present 2 industrial applications: first the factory construction of the bus bar network of a new smelter per sub assembly, second the alteration of the bus bar network of a smelter in operation in order to add a new rectifier to the network (additional capacity).

Introduction

When it comes to join two very thick metal plates, Electroslag welding (ESW) is the most productive, single pass welding process available.

This process is initiated by an electric arc that is struck between a wire fed into the location to weld and two slightly spaced vertical plates. A powdered flux is then added and melts to form the slag that will shield the weld pool. As the slag reaches the tip of the electrode, the arc is extinguished. Through a consumable guide that extends down the length of the joint, the wire is continually fed into the surfaces of the metal workpieces. With this method, the welding head remains at the top of the joint, while both the electrode and the guide tube are progressively melted by the slag. A retaining shoe, put into place before starting the process, is used to keep the coalesced metal between the plates. The result is a single pass welding joint obtained much more rapidly than with the conventional method.

History of the process development

As highlighted by some authors [1, p. 1], although the ESW process was conceived as early as the 40's, its acceptance was very slow in the USA and the Western European countries who were already committed to more conventional alternative secondary melting processes. The origins of the process are mixed, since it was developed simultaneously in the United States and in Russia.

R. H. Hopkins, of M. W. Kellog Co., is usually credited with inventing the ESW in the USA around 1940 [2] although there is an early patent by Armstrong in 1930 for a melting process using a flux to prepare ferrous alloy shapes. The Kellog company was interested initially in joining thick steel plates for the manufacture of pressure vessels.

In parallel to the work done in the USA, the Russians became interested in this technology and refined it through the 40's. The Paton Institute in Kiev, through the works of B. I. Mendovar, developed a method that was released at the 1958 Bruxelles World's Fair [3].

As a result of all these efforts, the ESW was used extensively in the 60's for railroad tracks, bridge beams, ship hulls, traction motor frames, etc. Two of the tallest buildings in California were welded, using the Electroslag welding process - The Bank of America building in San Francisco [4] (Fig. 1), and the twin tower Security Pacific buildings in Los Angeles. The ESW performed especially well when it came to resist crack formation during an earthquake. The only failure was observed for a bridge flange in tension - subjected to reversal stress loading. This problem was solved by the invention of the Narrow Gap Improved Electroslag Welding (NGI-ESW) around 1985 [5].

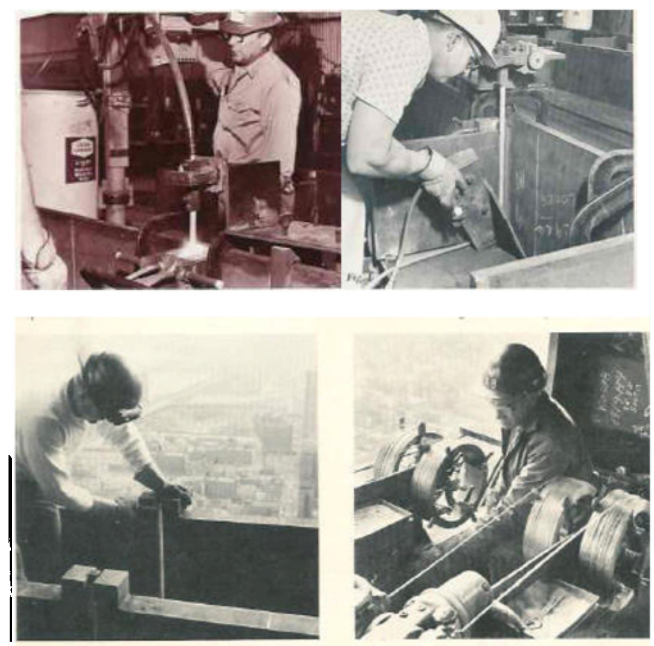

Figure 1: Electroslag welding was used extensively in California high rise in the 60's.

But all this development concerned the steel works. In the 70's, there was still no application of the ESW to weld aluminum parts. The Union Carbide Company (UCC), through its subsidiary Linde, has done extensive research at that time on the welding of massive aluminum bus bars used in aluminum production but found out that the development of this process was more complicated than anticipated. At the time, the majority of the work was limited to a maximum of 50 mm (2 in) material thickness. As the aluminum market deteriorated, the project was terminated [6].

The traditional method used by the aluminum industry was then to weld heavy aluminum bus bars using a « staggered plate » method (Fig. 2).

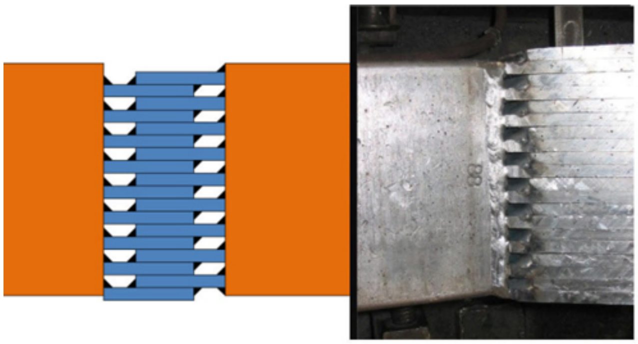

Fig. 2: Staggered plate method for bus bar welding

With this approach, plates about 12 mm (0.5 in) thick are piled in a staggered pattern one by one. GMA welds are then placed on each edges. The process is then repeated until the joint between the two bus bars is entirely filled.

This traditional method has been used extensively through the years and presents two major irritants: the resulting weldment is only about 80% conductivity efficient due to gaps that are left and weld quality issues; it is also very time-consuming and, in the case of a greenfield plant, requires a great deal of competent workforce at the same time. Some deformation should also be expected as the plates are welded.

In 2003, Alcoa asked Bechtel to build the Fjardaal project, a 346 000 ton/year aluminum smelter in Iceland on a site located at an eight-hour drive from Reykjavik. Due to the remote location and winds that exceeded 140 km/hr, the project included a high degree of preassembled modules [7]. When it came to the bus bar welding, Bechtel faced an unexpected problem: qualified welders were a scarce resource in this area. Looking for a cheaper and more performing way to weld those aluminum bars, they began to search for a process that would weld the bars in one pass and on the full depth to decrease electrical losses since the current resistance would be diminished.

Selected to provide a technical solution, the CANMEC company, located in Saguenay, province of Québec, Canada, bought the research portfolio of Linde on the Electroslag technology applied to aluminum welding in October 2005.

Working with a consultant that was a former Union Carbide researcher, as well as with regional institutions like the Centre québécois de recherche et de développement de l'aluminium or CQRDA (Quebec R&D center on aluminum) and the National Research Council of Canada (NRC), CANMEC encountered the same numerous technical problems than the American engineers before them. The thickness of the metal to weld was 275 mm (11 in), a major research challenge considering what had been achieved previously for aluminum.

After many analysis and feasibility studies, the equipment was chosen and the first tests conducted in May 2006 (Fig. 3). After beginning with a one head prototype, they quickly developed a three head welding unit and then a five head unit that proved to provide the ideal combination of electrode spacing.

Fig. 3: First test of the Electroslag welding at CANMEC

Then, the implantation of the ESW technology in the Iceland project went fast: the bus bars were welded in two weeks only compared to two months if the traditional method could have been used. In summary, the bus bar conductivity was improved by at least 20% in the welded area and the ESW provided better quality welded joints while reducing the welding time in total manhours per joint by half.

This was the first time that the ESW was proven to be a good opportunity of the aluminum industry in terms of achieving proper welding joint while reducing the necessary workforce and the construction time.

Process description

The bus bars to weld are typically made from the 1000 alloy series, and more specifically from 1350 alloy. The main steps for the process are: the preparation of the joint, the bars assembly, the welding and the finishing.

Preparation of the joint

To ensure that the spacing between the bus bars will be maintained to 4 cm along all the length of the weld joint, it is important that the edges of the bars are cut at a right angle and that the surface is relatively smooth. This can be achieved through saw cutting, but it doesn't have to be made just before the welding. Small asperities on each side (front, back and bottom) of the bars can also be polished by hand with a buffing machine in order to avoid leakage during welding.

Bar assembly

Bus bars are positioned side by side, leaving the specified 4 cm gap.

This gap is required to insure a slag bath that is large enough and has a good circulation as well as to avoid any contact between the guide tube and the bus bar wall. An excessively large gap would require a quantity of metal non economically justifiable and the fusion would be compromised. When ready, surfaces are cleaned with acetone to be free of oil, carbon deposits or humidity.

Fig. 4 shows a typical arrangement of the materials to be Electroslag welded. A bottom extension or sump provides a place to start the weld so the flux is fully molten and fuses the weld start. Procedures were developed with satisfactory results to allow a very short sump (more likely to be used integrated in a bottom shoe because of the lack of space) of approximately 25 mm (1 in) high.

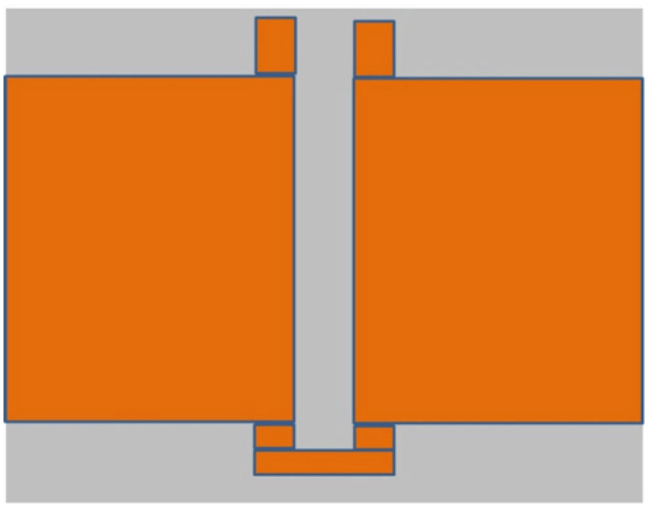

Fig. 4: Bars assembly before using ESW

As with the bottom of the weld, an area above the weldment is needed to carry the molten flux out of the joint. This is referred to as a top sump or run out.

Retaining shoes are then installed on both side (front and back) of the gap to retain the molten slag and metal. For Consumable Guide Electroslag welding of steel, copper is generally employed. However, for joining aluminum, the high heat conductivity of copper does not produce adequate fusion at the weld edges. Another material being inert to the slag and having a lower thermal conductivity than copper is used instead, like graphite.

Finally, the consumable guides are installed. Their number will vary with the width of the weld joint to do, but adequate spacing is important. Their primary function is to guide the aluminum wire down to the bottom of the joint and the electric current at the same time. The guide has to be isolated to prevent short circuit. As its name indicates, the guide will be consumed as the slag bath rises in the joint. The exterior diameter of the guide is generally half the gap left to the next guide and is chosen according to the diameter of the wire that will be used (up to 3.2 mm or 0.125 in). The heat of the slag melts the guide but its chemical composition has little impact on the fused metal composition.

The maximum angle to the vertical position is ± 10° in order to avoid defect like inclusion of slag or lack of fusion. It can also be a nuisance to the proper alignment of the consumable guides.

The electrode wire is adjusted to be 5-8 cm (2-3 in) longer than the guide in order to easily start the weld and it will always stay that way for the full welding time to avoid a situation that would cause operation instability (Fig. 5).

Fig. 5: The consumable guides and the electrode wires

Welding

In preparation for the welding, the welding head unit is put in place. This contains a powerful wire feeding motor (over 300 mm/sec) for each welding head. Since aluminum conducts heat rapidly, it is essential to weld at a speed such that the heat generated in the molten Electroslag flux is contained in the welding area long enough to melt the base metal and is not conducted away too rapidly in its mass.

The head unit also contains all electrical connections to the power source and the instrumentation necessary to provide the desired electric current in the wire.

It is important that there is no interruption during the welding by lack of wire or flux since it will create imperfections in the welding joint. A good provision of flux is then added on the feeding plate. The flux used must be conductive to allow the process to enter the Electroslag mode. It must have the correct resistivity to generate the temperatures required to melt the welding electrode and the base material. However, it must also be lighter than aluminum so it floats on top of the molten puddle. This eliminates many of the typical oxides used in most fluxes. Optimizing the flux chemistry was part of the process development efforts.

There is no need for preheating since the process does it by itself. First an electric arc is established between the electrode and the bottom sump. Flux is added regularly. As the joint progress and the slag and fusion bath gets higher, heat dissipates by the bottom, the sides and the metal walls. The molten metal in the weldment then gets colder and solidifies slowly in such a way that no cooling devices are required (see Fig. 6, 7 and 8).

At the top of the welding, the speed of the wire feeding is slowed gradually until the slag could pour over the run out.

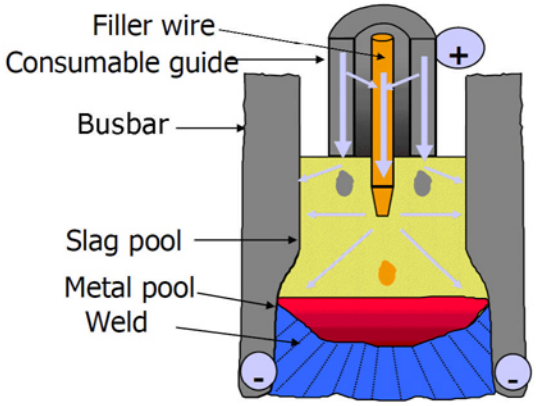

Figure 6: The Electroslag welding process

Figure 7: The ESW electrode system

The welding time for the joint is usually about 20 minutes for 280 mm X 1000 mm (11 in X 39 in) bars. The rest of the steps can be conducted during operation, meaning that the shutdown time is kept to a minimum when the assembly is done online.

Finishing

When the joint has cooled, all the assembly is stripped (equipment, retaining shoes) as can be seen in Figure 9.

To clean the welded bars, the run out is then cut when needed with a saw to insure a joint that covers the full length of the gap between the bus bars. If required, the external surfaces can also be polished by hand.

Figure 8: ESW welding system – view from the top showing the slag in fusion

Figure 9: The ESW joint after removing the retaining shoes but before cutting and polishing showing the solidified slag

Weld quality

The welding joint obtained with ESW is a full joint, presenting no gap like the staggered plates method where the plates are piled and welded one by one (as seen in Fig. 2). The process with the retaining shoes mentioned previously ensures that the joint goes well beyond each extremity, leaving no void: this translates in a very good conductivity with no voltage drop.

Figure 10 shows the weld surface at the end of the process.

The quality of the welding joint can be verified by non destructive methods (NDT) like ultrasound testing (UT). Taking into account the two welded surfaces, the worst cross section surface with a defect should be no more than 20% of the total section of the busbar. For example, the welded surface obtained in Fig. 10 would be 100% cross section surface without defect.

The alloy used typically for the bus bar is almost pure aluminum (99.5%). The filler wire, for its part, has to be from a slightly different alloy, offering enough rigidity to guaranty easy feeding to the welding head. The 4043 alloy is usually chosen and presents a composition of 94.7% Al and 5.2% Si.

Figure 10: Electroslag welded surface

The mechanical properties of the alloy in the filler mean that the weld joint is stronger (18 400 psi in mechanical tests on ultimate resistance) than the bus bar metal (12 150 psi). If submitted to a major stress, the bus bar would crack before the joint. This is important, since it allows the transportation of preassembled modules without risking cracks or breakages has demonstrated in the next section.

Applications of ESW

Two applications of the ESW will be discussed in this section: the first is the opportunity to use preassembled modules for bus bar assembly and the second is the possibility to modify the bus bar circuit while in operation.

Preassembled modules

The traditional welding method using staggered plates is not mechanically designed for transportation. Cracks could appear in those joints. Quality checks cannot be performed by NDT. Destructive tests have to be conducted during fabrication.

The excellent mechanical properties of the ESW joints on the other hand allow them to withstand all stresses implied by transportation, with no required bracing. This opens two options for the preassembly of modules, a method that saves a lot of time on site.

Depending on the transportation logistics implied, one can either chose to make minimal preassembly (Fjardaal project) and will then have to perform the maximum number of welding joints in the field; or chose to preassemble modules. Two options are then possible: assembly near the site in bigger modules which involve fewer ESW weld joints in the field (AP-60 plant in Saguenay) or further from the site in smaller modules as was done for the Kitimat project (Fig. 11).

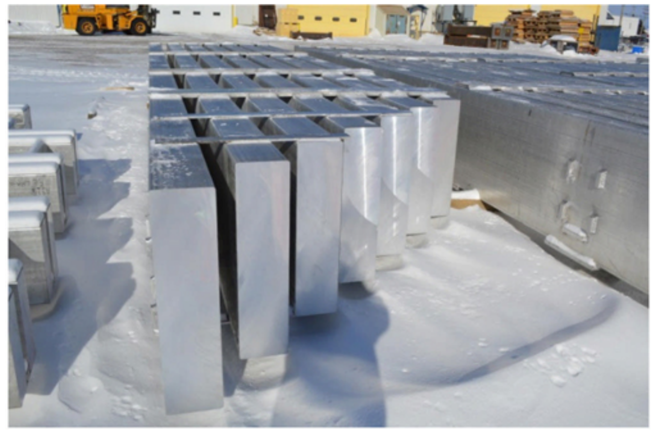

Figure 11: Preassembled modules ready to be shipped to Kitimat from Saguenay

The module preassembly allowed by ESW technology is then characterized by shorter deadlines for the plant construction and the presence of far less qualified welders on site than with the staggered plate method. The only limits for module dimensions with ESW are those set by the transportation specifications or the plant lifting capacity.

Modifying the bus bar circuit in operation

The other situation where the ESW offers a clear advantage on the staggered plate method is the modification of a bus bar configuration while the smelter is in operation.

Since every ESW weld joint takes only 20 minutes to complete approximately, the number of plant shutdowns necessary to perform the modification is minimal. Even more, many weld joints can be performed during each shutdown.

For example, in the Fjardaal case, only two shutdowns were necessary (one for positive polarity and the other for the negative one). If the staggered plate method had been used, 40 shutdowns would have been required to perform the same task. This would not have been feasible.

Figure 12: Example of a change in the bus bar configuration of a smelter in operation

Conclusions

The Electroslag welding is an innovative method to join aluminum bus bars that allows significant gains both in manpower and time. It also makes possible the modification of the bus bar circuit while in production, a task that was impossible using the staggered plates welding method.

In summary, ESW shortens bus bar installation, improve conductivity by 20% through the weldment, lowers voltage drops, provides welding joint of very high quality and represent a significant gain of time (20 min for a standard joint).

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