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ALUMINUM REDUCTION TECHNOLOGY

Potline Operation II – Equipment

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Solutions to Address Arc Welding Problems in an Operating Potline

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Abstract

Arc welding in an operating potline has always been problematic, especially repairs to aluminium busbar systems. The modern trend for higher potline amperages both in new and existing plants has led to an increase in these problems. To address this issue an electromagnetic shield has been developed. The shield is described along with modelling and magnetic measurements demonstrating its effectiveness. Further, the shield has been tested by welding cover plates on positive riser bolted joints at full line current. The results are encouraging and demonstrate that voltage drop gains can be made by on line repairs.

Introduction

Aluminium and steel arc welding in a potroom is a common maintenance task. Arc welding is the most economical and practical welding technique but it is also sensitive to magnetic fields. External magnetic fields make arc welding very difficult over 100 Gauss. In a 300 kA and above potline technology, magnetic fields are above 600 Gauss, which makes both weld quality, and even the ability to weld at all, an issue. Much of the welding work in an operating potline is carried out on busbar. Thus weld quality is critical not only for mechanical strength but also for energy consumption. Tactics and technologies have been developed to address these issues. Welding is mainly carried out in four situations:

Routine maintenance
- pot restart after relining
- positive risers maintenance

Special intervention
- busbar or superstructure repair
- busbar modifications to allow/debottleneck creeping.

1. A review of the technical issues associated with using arc welding in magnetic fields.

External magnetic fields impact the quality of the weld seam. Low magnetic fields will deflect the arc in the welding zone, reducing penetration and thickness of the weld seam (Refs 1 & 2). This is illustrated in the following figures which show cross sections of 10 mm thick steel plate welded without the influence of a magnetic field (Figure 1) and with a continuous magnetic field (Figure 2). Figure 2 shows a lack of 3 mm weld seam penetration.

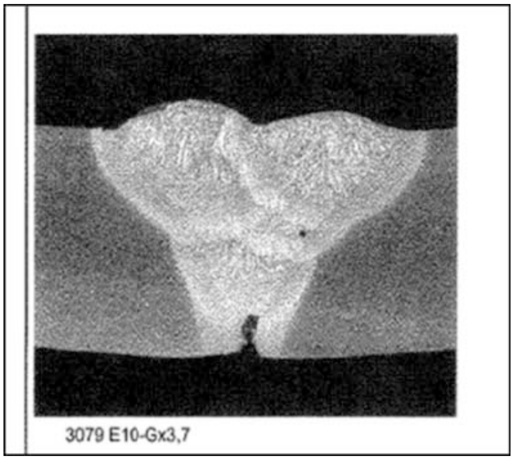

Figure 1 Weld seam with arc-welding without external magnetic fields

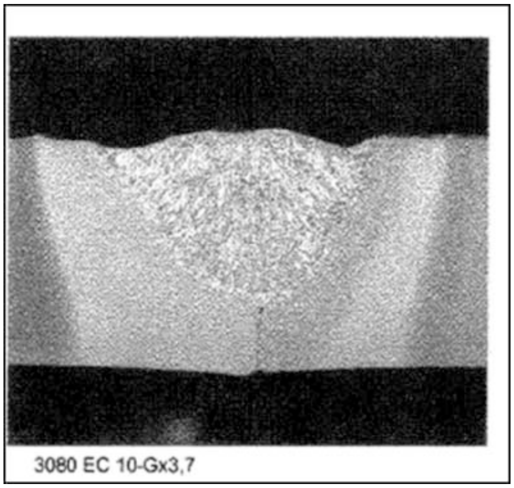

Figure 2 Weld seam with arc-welding with external magnetic fields

Figure 3 shows a steel sheet weld seam welded in differing external magnetic fields. The weld seam thickness is reduced by half when external magnetic fields reach 500 Gauss.

As the external field increases, a situation will be reached where the arc is blown away from the weld area, making welding impossible. This deviation of the arc due to the magnetic field is commonly called "arc blow".

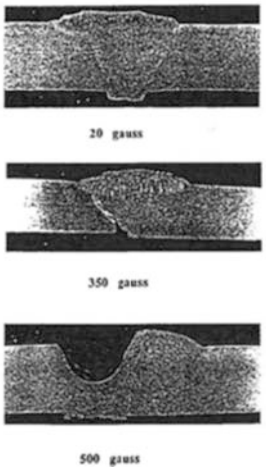

Figure 3 Weld seam quality according to different external magnetic fields

2. Differences between welding steel and aluminium

Ferritic steels are magnetic and an external field will concentrate in the weldment. The magnetic field will be intensified in the gaps in the weld set up, e.g. a butt weld preparation. One solution is to use the weldment as the iron core of a solenoid by winding a heavy current carrying cable around the structure. This allows the field in the weldments to be nullified and is a technique used in commercially available solutions.

Aluminium on the other hand is non-magnetic and the solutions used for steel are not effective. Also the direction of the field can be variable, depending on the conditions of the external field. This makes finding a welding solution a lot more difficult.

3. Value at stake

Being able to achieve and maintain good quality welds in a potroom environment is important from an energy consumption point of view. Based on measurements taken in different smelters, there is a potential saving of several mV per pot if we compare good and poor quality positive riser welding. As an example, for a modern smelter, 1 mV saving can represent 1.5 GWh savings of energy consumption per potroom, per year.

4. Review of techniques for welding in magnetic fields

Techniques to address welding issues in magnetic fields can work on the following principals:

- Global nulling of the external magnetic field
- Local nulling of the external magnetic field
- Using a welding process insensitive to magnetic fields
- Turning the power off or stopping the pot

It is possible to shut down a potline for short period (about 1 hour) to achieve some welding. Of course shutting a potline is never desirable from an operational viewpoint because it will have a subsequent impact on pot performance (hazardous working conditions with unstable pots, anode effects, production loss, current efficiency, specific energy consumption) As a consequence, this approach is not applicable for routine maintenance. It should be used as a last resort to achieve welding.

Welding can sometimes be carried out when the pot is shut down and the current by-passed around the weld area. In this situation the magnetic fields are reduced. However, due to the proximity of nearby operating pots, magnetic fields are still present and can be problematic for welding in some areas; external positive risers being one example.

- Using passive shielding rings

A common technique is to use a shield to locally reduce the magnetic field. Welding is carried out in the narrow gap shown in the shield, Figure 4. The shield is made of high magnetic field permeability material, typically mild steel. In order to lower magnetic fields to an acceptable level, shields are often bulky and heavy with the result that they are difficult to position as they are themselves sensitive to magnetic fields. Moreover, the shield ideally needs to be positioned in the plane of the field with the slot at right angles to the field, Figure 4 (Ref 3).

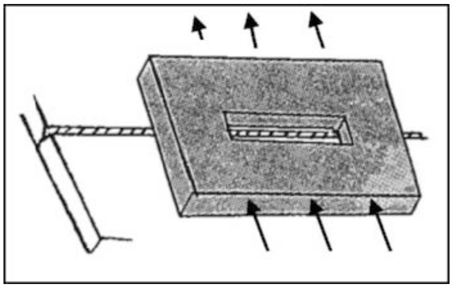

Figure 4 A typical passive shield

- Alternating Current (AC) or pulse welding equipment

AC welding reduces the bending of the arc. Induced eddy currents generate magnetic fields in the opposite direction of the arc magnetic field (Ref 4).

With pulse welding, arc pressure is increased by high frequency current pulses and this improves arc stiffness.

Both techniques are less sensitive than traditional DC arc welding to external magnetic fields but they show their limits in high magnetic fields of the potline.

- Active shielding

Active shielding is generating a magnetic field locally to null the external magnetic field. It can be achieved using a magnet or an electromagnet. Section 5 reviews this technique and is illustrated through the latest evolution: the ZeroB active magnetic shield from Diverse Technologies and Systems.

- Alternative non-arc welding processes

Exothermic and electroslag welding (ESW) are alternative solutions which are non sensitive to external magnetic fields. However, these techniques require special molds clamped around the components to be joined. This raises issues such as space for fit up and time to manufacture the molds. Consequently these techniques do not have the flexibility for many repair tasks.

5. Active magnetic shield technology: the ZeroB

The Diverse ZeroB shield combines both passive and active shielding with use of an electromagnet. The passive shield reduces the magnitude of the field; the balance is then compensated by the active part of the shield.

- Design and modelling

Many design scenarios have been investigated using magnetic finite element analysis (FEMA). This approach allows for a detailed performance assessment with high confidence that the results obtained with the actual shield will be accurately predicted.

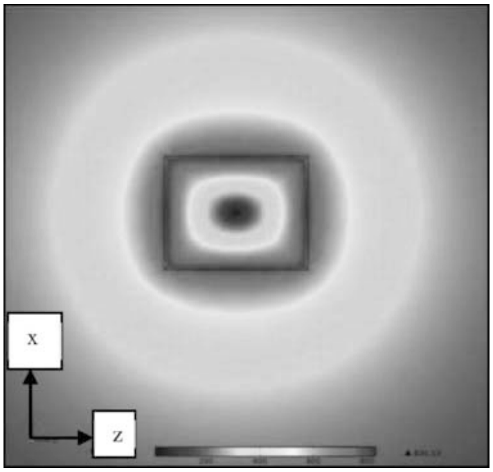

Figure 5 Magnetic field (G) modelling around an Al busbar

The basis for the analysis is a long aluminium busbar of 0.30x0.38m cross-section having a current of 80 kA, hence a current density of ~70A/cm^2. The modelling results for this busbar are shown in figure 5. This shows the magnitude of the magnetic field in the plane (xz), the busbar runs into the page in the y-direction. The magnetic field is a maximum at the surface of the busbar and gently falls away further from the busbar. Within the busbar the field also falls from the surface to zero at the centre. The fields on the busbar surface have a magnitude of ~700G and are typically aligned across the face (i.e. either in the x or z direction). Close to the corners there is significant field in both the x and z directions.

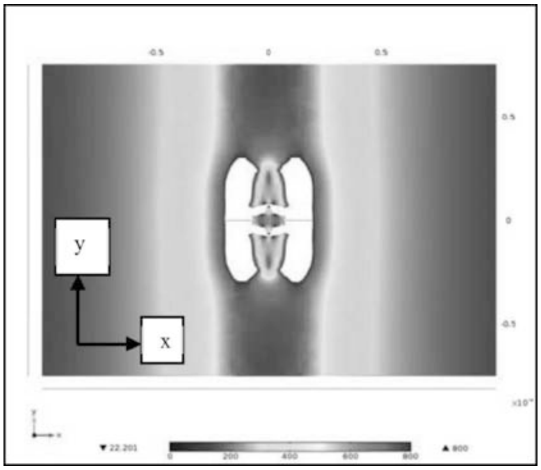

Figure 6 Magnetic field (G) modelling with ZeroB active shield

When ZeroB is deployed on the xy face of the busbar the magnetic field is distorted by the magnetic materials in the ZeroB screen, Figure 6. In the central region (area for welding) the field is passively shielded and reduced from ~800G to ~250G.

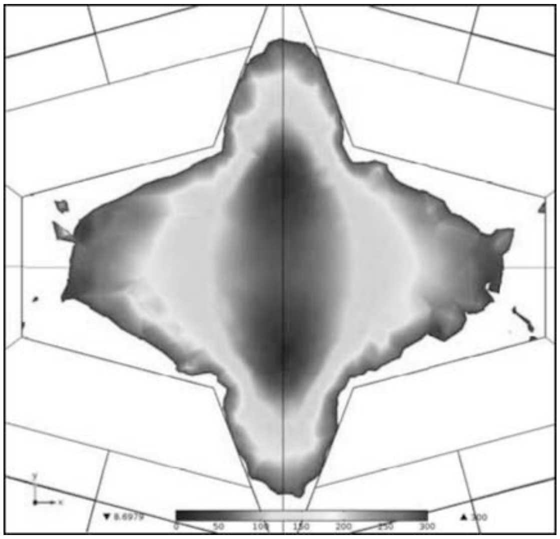

Figure 7 Magnetic field (G) modelling with ZeroB active shield

The final FEMA results with ZeroB actively shielding are shown in figure 7. Here the field in the centre of the welding region is reduced to ~50G. Quality welding can be carried out in such fields

- Performance and practical results

Practical tests were carried out at an aluminium smelter. Work was conducted at a number of different positions on a number of different busbar positive risers. The results reported below were on a riser where the magnitude of the magnetic field was ~800G, ZeroB performance was assessed both at the centre of the busbar and around its edge.

The nomenclature used throughout was an xyz space orientated so that y is the direction is along the busbar in the direction of the current, x is left to right across the busbar and the z axis is orthogonal to the front surface (the same as that used for the earlier modelling). The position nomenclature is that x=0 at the centre of the front face and z=0 at the centre of the side face.

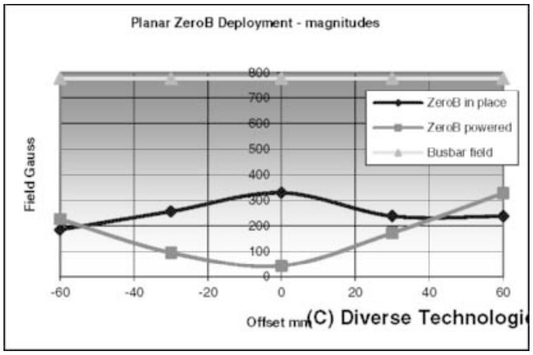

Figure 8 Magnetic field measurements, ZeroB planar deployment

Figure 8 shows the normalised magnetic field measurements taken across the front face of the busbar. The busbar field trace shows the field to be reasonably constant at ~800 Gauss without ZeroB in position. When ZeroB is deployed, its passive shielding reduces the field to ~300 Gauss. With the active shielding operating, then at the centre the field is reduced to ~50 Gauss. There are several points to note: welding at the centre of the shield is easy, and arc blow does not occur until approximately+/-40mm. The active shield was optimised to minimise the field at the centre, but it could be optimised for a different x position, or indeed changed dynamically as the weld progresses.

In practice excellent welding performance was achieved with this deployment and welding difficulty only occurred towards the edges of the busbar.

ZeroB can be physically reconfigured for use around the edge of the busbar. Figure 9 shows the xyz magnetic field measurements taken along the weld line, where the 0 point on the graph x axis is the edge of the busbar and to the left are distances away from the edge in x and to the right are distances away in z.

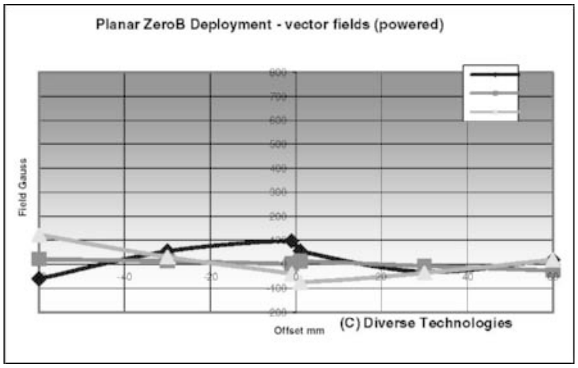

Figure 9 Magnetic fields measurement, ZeroB edge deployment

Measuring the 3 axes of the resulting magnetic field shows field values less than 100 Gauss along the top and side of the busbar (again this is a reduction from the ~800 Gauss before deployment). Welding performance here was also very good. These results will in the future be supplemented with other potline area welding applications (e.g. positive riser welding Figure 10).

Figure 10 ZeroB in use on a live busbar positive riser

Conclusion

In a global context of energy cost constraint, being able to ensure good quality welding in a potline whilst minimizing stoppages becomes more and more of a challenge. There are several techniques available with both advantages and drawbacks, but no clear winner. However, the latest active shield development shows promising results. Once the full potential has been demonstrated for potline applications, it will provide a simple solution for smelters to improve their welding quality, using the current flexible arc welding technique.

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