Combat old foes with new technology in LNG tank construction

Semi-automatic FCAW with alternating current reduces arc blow issues

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Introduction.

Magnetic arc blow is a phenomenon that has haunted the welding industry ever since the moment direct current (DC) welding processes were introduced. Magnetic arc blow can be caused by either the welding process or can be inherent to the base material which is welded. But in both cases, when excessive, magnetic arc blow can result in unacceptable defects and slow down production. 9%Nickel steel, the base material used to construct cryogenic storage tanks for Liquid Natural Gas (LNG), is one of the steel grades that is relatively easily magnetized and magnetic arc blow is frequently encountered. There are a number of methods that can be considered to overcome the negative effects of magnetic arc blow. The phenomenon of magnetic arc blow including fundamentals, root causes and solutions will be described in this article. Attention will be given to equipment required to achieve AC output for semi-automatic welding processes as well as nickel base flux cored wire which is one of the consumable options for 9%Ni-steel. The applied Waveform Control Technology™ will be explained as well.

Principle of magnetic arc blow.

Magnetic arc blow (arc blow) is best described as an unbalanced magnetic field surrounding the welding arc making it difficult to control the welding arc. Arc blow can be caused by either the magnetic fields created by the electrical current used by the welding process or related to residual magnetism in steel products.

Figure 1 Forward and backwards directed arc blow

Arc blow can be caused by the welding current and is affected by the distance between the arc and the ground clamp. The magnetic field is especially distorted when changing from one medium to another that is less conductive; for instance from steel to air. A high concentration of magnetic force is observed in the interface between steel and air, and is especially concentrated in narrow V- grooves or where plates change thickness. In practice the welding arc is drawn and deflected between the two sides of the joint and this is observed as arc blow (figure 1). A secondary arc blow effect is caused by the ground current which passes through the work piece. The ground current generates a magnetic field in the work piece as shown in figure2.

The magnetic field generated by the ground current can both increase and decrease the arc blow effect generated by the welding current. The magnetic field generated by the ground current is less strong than the one generated by the welding current. Ground clamp positioning is therefore only moderately effective in combatting
arc blow. In highly susceptible metals, it is critical that other measures than just ground clamp position are considered.

Figure 2 Arc blow due to ground current

Arc blow can also be related to (residual) magnetism in the steel. Ferromagnetic steels can become magnetized, as is seen by the attraction of a magnet. On a micro scale individual magnetic sections are formed within the grains of a ferromagnetic material. These magnetic sections are frequently referred to as "Weiss domains". In a demagnetized state the Weiss domains are more of less randomly aligned. A material becomes magnetized when the Weiss domains are reoriented / aligned to point in the same direction. The level of magnetism is depending on the level of alignment in the Weiss domains. Reorientation / alignment of Weiss domain can be caused by several external factors such as:

- Mechanical factors (bending, grinding, machining, shocks/vibration during transport)
- Storage conditions (close proximity of steels of which one could be magnetized)
- External magnetic fields (magnetic lifting equipment, overhead lines of railways)

It is possible to demagnetize steel but in many cases there will be some residual magnetism. The level of residual magnetism is a significant factor determining if there is a negative influence on the welding process.

### How to reduce arc blow

As mentioned before, existing magnetism in the steel can be “removed” by demagnetizing the steel by various methods. Suffice it to say that welding even on a fully demagnetized steel can exhibit arc blow, which is why it is important to apply other remediation techniques. Arc blow originating from the welding process can be reduced by various methods which include amongst others:

- Reduce the welding current
- Use a shorter arc length
- Make a heavy tack on both ends on the seam and several tack welds throughout the seam.
- Weld towards a tack or a weld that is already made
- Weld away from the ground to reduce backwards directed arc blow
- Weld towards the ground to reduce forward directed arc blow
- Apply a welding process using alternating (AC) current

More practical details and recommendations to combat arc blow are found in the Procedure Handbook of Arc Welding published by The James F. Lincoln Arc Welding Foundation.

### Application of Alternating Current (AC) welding processes

Alternating current (AC) welding equipment for stick electrode welding (SMAW), submerged arc welding (SAW) and gas tungsten arc welding (GTAW) have been available to the industry for decades. The introduction of inverter technology has provided the industry safe and low energy consuming welding equipment solutions for
these processes. Specifically for SAW, digital inverter technology offers the possibility to optimize the balance between penetration and deposition rate while eliminating magnetic arc blow.

Until recently, semi-automatic welding processes such as gas shielded flux cored arc welding (G-FCAW) were almost exclusively applied using DC welding current. The sensitivity to magnetic arc blow is thus substantial. The development of new high speed digital inverter technology allows AC welding current to be applied to GMAW and G-FCAW. The construction of LNG tanks was identified as a potential field of application for AC G-FCAW. As previously mentioned, LNG storage tanks are constructed using 9%Ni-steel which is, due to its martensitic structure, inherently sensitive to become magnetic. The sluggish nature of molten liquid metal makes the likelihood of defects due to arc blow especially significant. This is why it has been common practice to employ AC current with AWS A5.11 ENiCrMo-6 electrodes for manual welding on these steels. Special care is taken during manufacturing and transportation of the 9%Ni-steel plates to avoid that magnetism exceeds 50 Gauss.

This is a maximum level of magnetism for 9%Ni-steel frequently specified by contractors, but it can still be an issue when flux cored welding is applied resulting in an increased risk of weld defects. The demand for nickel base flux cored wire such as Supercore 625P (AWS A5.34 ENiCrMo3T1-4) continues to grow with increasing demand to improve productivity in the field of LNG tank construction. But awareness to the issues of magnetic arc blow must remain diligent in this field.

**Constant Voltage G-FCAW using AC**

Lincoln Electric’s Power Wave® S350 with optional Advanced Module (figure 3) allows for a Constant Voltage welding process in AC (CV-AC), which can be used in combination with nickel base flux cored wire such as Supercore 625P. A dedicated weld mode was developed with a set polarity switch based on frequency (Figure 4).

Unlike other processes that use AC, this waveform is not a balanced (sine wave) waveform. Rather, it is optimized for the operating characteristics of the Supercore 625P FCAW electrode.
This mode contains an adjustable wave control of the negative polarity duration and amplitude. As this control is increased, the ratio of positive polarity to negative polarity approaches 50/50.

Once the weld mode was developed, a test method was developed to determine if the AC mode has an effect on arc blow. Several joint configurations and methods of introducing magnetism into steel were tested. An especially effective technique was to weld a plate (bead on plate) and place a large earth magnet on the side of the plate that "draws" the arc close to the magnet as the welding torch passes by (Figure 5). The welding procedure was developed to allow arc blow to occur.

![Figure 5 Test set-up with magnet on side of the plate](image)

A longer arc length than typical was applied which results in a higher voltage. Using a longer arc length does result in more spatter during the test, but increases the sensitivity to arc blow. This worst case scenario provided appropriate circumstances to test the effectiveness of CV-AC to arc blow. To produce consistent welds and data the welding torch is mounted on a travel carriage to provide steady travel speed and arc length. The testing and welding parameters for this experiment are shown in Table 1.

<table>
<thead>
<tr>
<th>IPM / M/min</th>
<th>Voltage</th>
<th>CTWD</th>
<th>Travel Speed</th>
<th>Gas / Flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 / 11.5</td>
<td>33</td>
<td>0.75 / 15 mm</td>
<td>15 IPM</td>
<td>80/20 / 40 CFH</td>
</tr>
</tbody>
</table>

Table 1 Welding parameters

A series of welds were completed comparing the CV-AC mode to conventional CV-DC using the same weld parameters to determine if there is a reduction or elimination of arc blow. Each test was repeated to ensure accurate and reliable test results. Welding with the magnet on the side of the plate causes the arc to "wander" and does not produce straight line bead but rather a "dip" in the bead progression (Figure 5 & 6). Each weld bead was inspected for this "dip" and helped to determine the level of susceptibility to arc blow.

![Figure 6 Weld showing "dip" using CV-DC](image)

![Figure 7 Weld showing no "dip" using CV-AC with wave control 5](image)

Test Results

The CV-DC welds consistently showed signs of arc blow as expected. Arc blow was consistently reduced when welding using increased levels of Wave Control. Arc blow was eliminated with the wave control increased to a setting of 5. As the wave control of the AC mode is increased, spatter generation is also increased. The magnetic field generated by the test is intentionally stronger than the residual magnetism found in steel which could equate to a lower wave control required to be used in practice and thus reduction of spatter. In addition to the arc blow test a series of hot cracking tests were performed in the both CV-DC and CV-AC weld mode. Hot cracking is a general concern when using nickel base alloys. And for the application in LNG tanks construction it is relevant to determine the effect of the CV-AC weld mode to the hot crack sensitivity. The hot...
crack tests were performed according to JIS Z3153 on ASTM A553 (9% nickel). The tests showed that there is no change in the hot crack sensitivity between CV-AC and CV-DC; both modes show robust resistance to hot cracking.

**Conclusions**

• In the test method AC FCAW has shown to significantly reduce if not eliminate arc blow.

• Further testing in a real application with residual magnetism is warranted to determine the full benefit of AC wave from.

• Changing from CV-DC to CV-AC did not influence the hot crack behavior of ENiCrMo3T1-4 all position flux cored wire (Supercore 625P)

**References:**

• The procedure handbook of arc welding 14th edition The James F. Lincoln Arc Welding Foundations

• Residual magnetism of steel products White Paper Edition 05.2011 Maurer Magnetic AG Grüningen Switzerland

• Test Report for T-Joint Hot Cracking Test per JIS Z3153 Lincoln Electric Internal Test Report

• Test Report AC FCAW-G and its effectiveness to reduce Arc Blow Lincoln Electric internal Test Report