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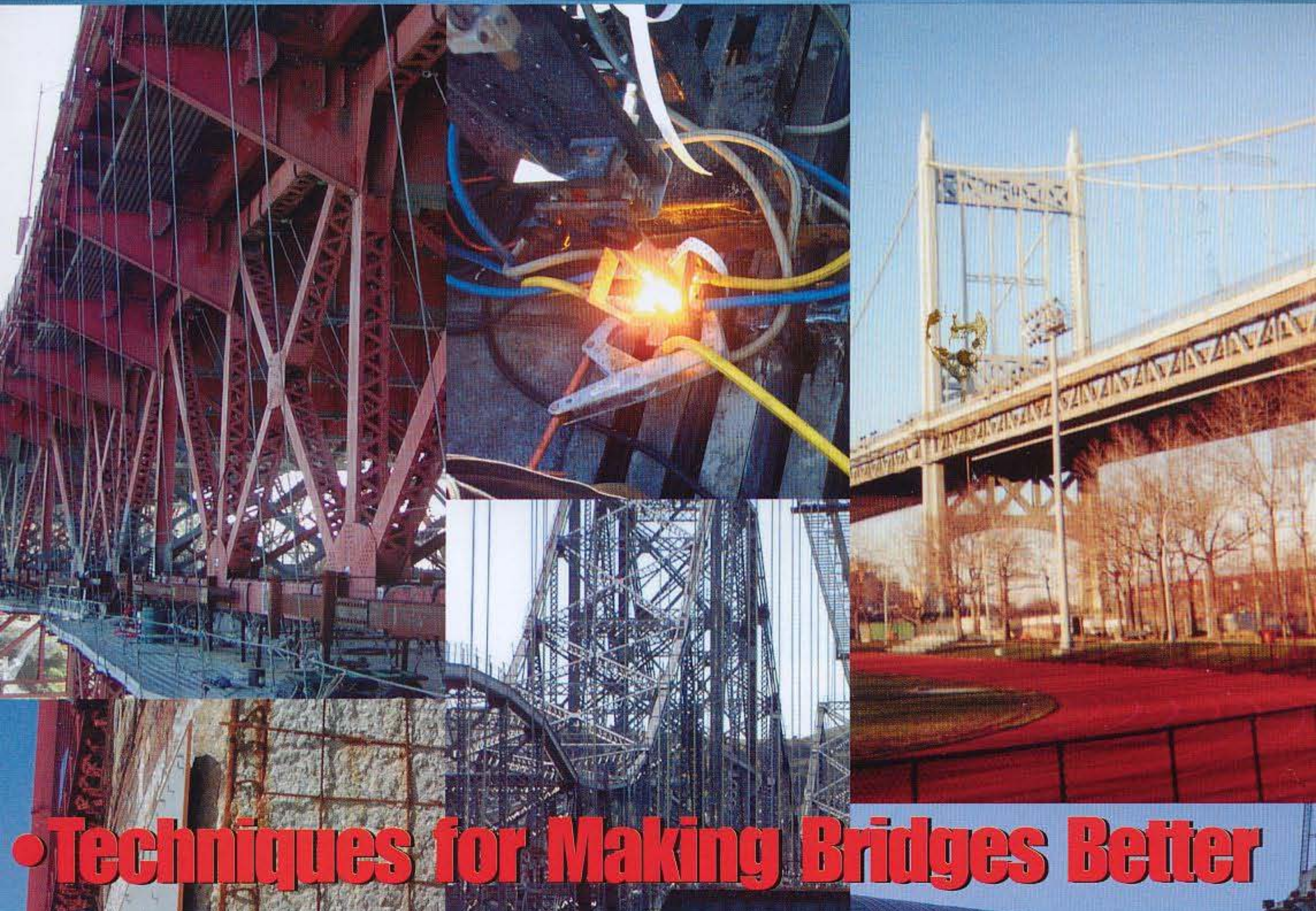

•Techniques for Making Bridges Better

•Joining Aluminum with Ultrasonic Spot Welding

•Improved Sheet Metal Welding

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Electroslag Welding Makes Comeback for Fabricating Bridges

One-pass welding of 4-in.-thick structural members without preheat makes electroslag welding cost effective and productive

BY WILLIAM BONG

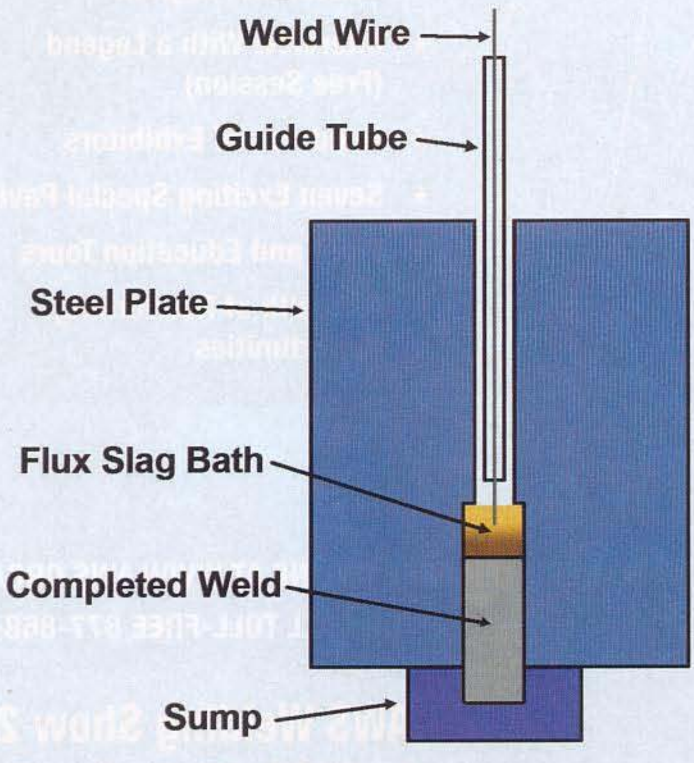

Fig. 1 — Narrow groove improved electroslag welding for joining thick steel plates.

An improved electroslag welding process for joining steel plates up to four-inches thick shows promise for greatly increasing productivity in fabricating steel bridge girders. Unlike all other welding processes specified by the bridge welding code, electroslag welding of bridge steels takes place in one pass and does not require preheating regardless of thickness. These attributes, plus the need for little edge preparation, makes narrow groove improved electroslag welding (NGI-ESW) highly cost effective and productive. The process is ideal for welding plate girders end to end. It can cut the time for creating complete joint penetration welds by more than 90%.

This process is now permitted on main bridge members that are in tension and/or subject to reversal stress loads. Typical applications include butt joint welding thick steel plates for subsequent cutting into plate girder flanges and for the bottom flange of tub girders. The American Welding Society (AWS) Bridge Welding Code Committee is working toward adding this process to the bridge welding code. Presently, fracture-critical applications are not included in the code change, nor are AASHTO temperature zone 3 applica-

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tions. But many fabricators expect these restrictions to be lifted with further research.

Research Improves Process

The electroslag process has been used in the past for steel bridge main members, but in 1977, the Federal Highway Administration (FHWA) placed a moratorium on its use because of problems with some of the welds. In the 1980s, the FHWA commissioned research to investigate ways to improve the electroslag welding process. The research aimed at developing better-quality welds with higher impact values.

The fruit of this research was an improved electroslag process for narrow groove welding. Improvements to the process greatly enhance toughness of the weld metal and the heat-affected zone, eliminating previous objections to weld quality. As a result, the FHWA lifted the moratorium on this electroslag welding process in March 2000.

Using Electroslag Welding

Figure 1 shows the basic process. The two thick steel plates to be joined are positioned vertically about 1 in. apart, creating the "narrow groove." Since the electroslag flux bath and weld metal pool are fluid, the process requires that the steel plates to be joined be vertical. It also requires devices to contain the fluids on the bottom and sides of the weld. To this end, water-cooled shoes span both sides of the groove between the plates, forming a deep cavity. The molten slag first forms in a sump tack-welded to the bottom of the cavity.

The process requires a welding arc only at the beginning of the weld cycle. The arc melts a small amount of granular flux and forms a molten slag bath in the sump, which extinguishes the arc. Weld wire is fed through a guide tube and into the slag bath that forms above the molten weld metal. The weld builds from the bottom in one-pass and continues without interruption.

The electrically charged slag bath resists the welding current passing through it and reaches a temperature of about 3500°F to maintain a molten state. At this temperature, the slag is hot enough to sustain continuous melting of the welding wire without an arc. The welding wire melts as it passes through the floating slag bath, forming a pool of molten weld metal under the slag. The weld metal solidifies as the weld progresses upward, becoming the weld bead that joins the two plates together.

The welding wire passes down holes inside the steel guide tube. The guide tube serves to conduct the weld wire current

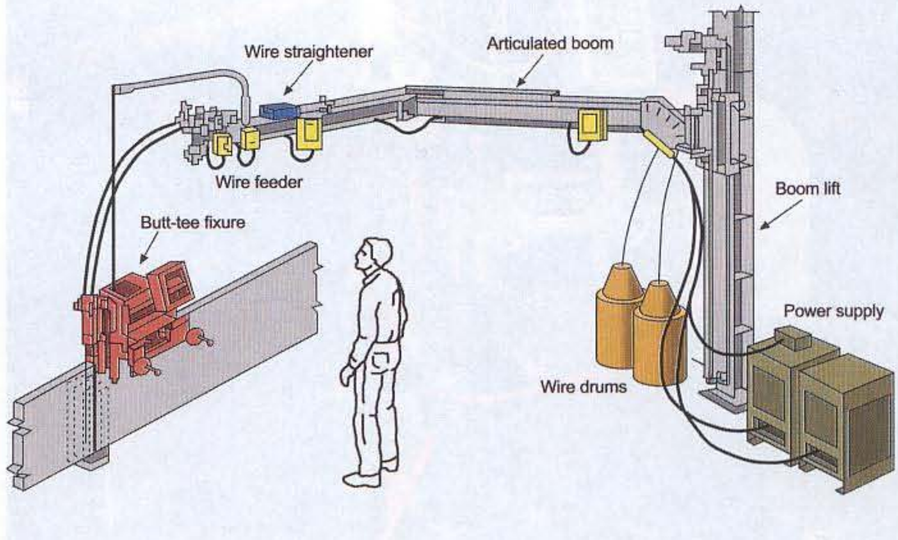

Fig. 2 — Basic components of the welding system.

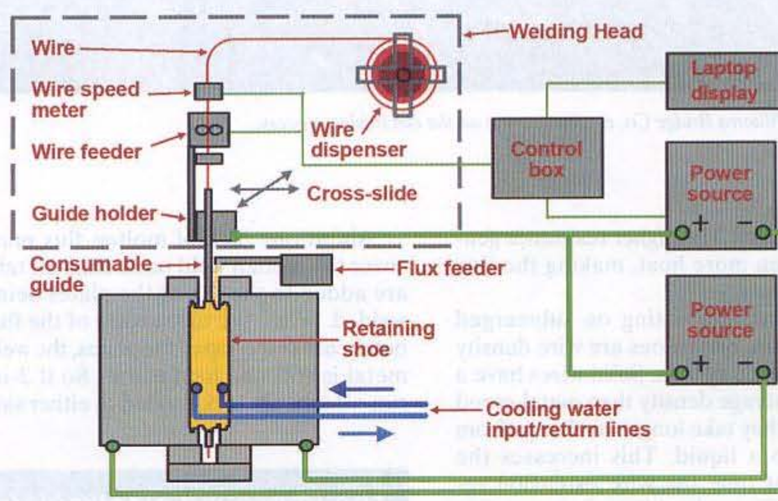

Fig. 3 — Schematic of the computer-controlled electroslag welding system.

between the two plates so that neither the wire nor the tube touches the plates being joined. Insulators protect the tube from touching the steel plates, avoiding an electrical short that would stop the welding operation.

As welding wire continues to feed and melt as it passes through the molten flux bath, the weld progresses upward. The 3500°F temperature of the molten flux bath continually melts the bottom of the steel guide tube. In this way, the entire steel guide tube is consumed and becomes part of the resultant weld that joins the two plates together.

A certain amount of welding wire, the "unsubmerged wire extension," extends below the end of the guide tube before entering the top of the molten flux bath. Below this extension, an additional length of the wire plunges into the molten slag bath. This length of wire is the "submerged wire extension" This submerged portion of the wire is significant to the welding operation.

The electrical resistance of the welding wire generates heat as electrical current passes through the submerged wire extension. The longer this length of wire remains submerged in the molten flux, the thinner it becomes. As it becomes thinner, its electrical resistance to current

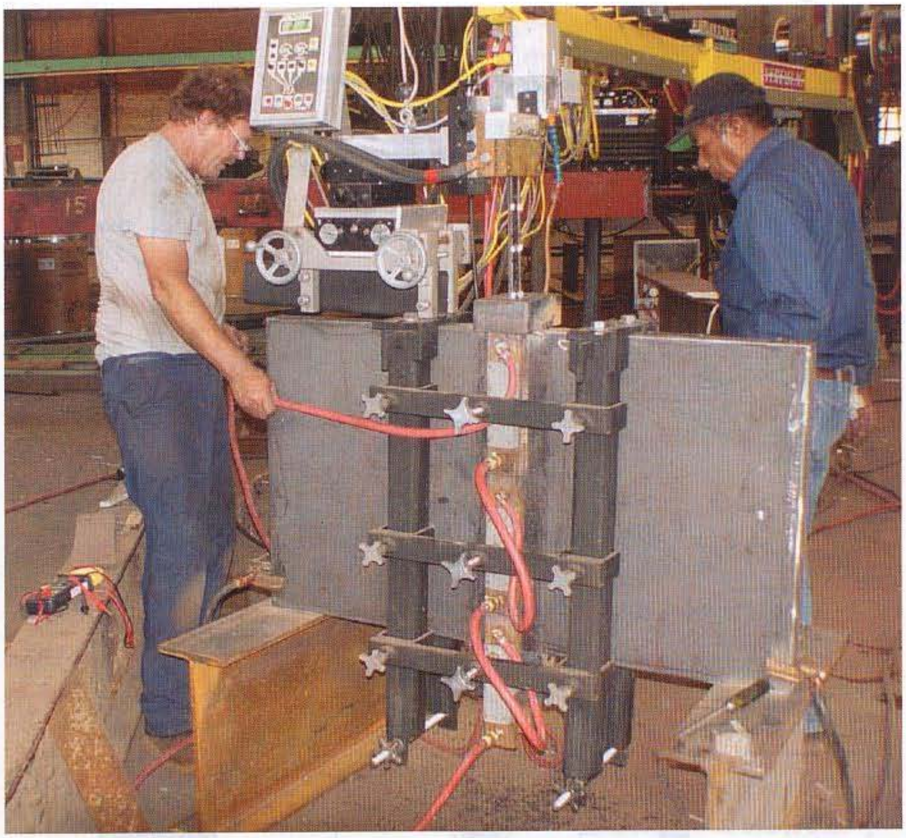

Fig. 4 — Williams Bridge Co. conducts a test on the electroslag process.

flow increases. The higher resistance generates even more heat, making the flux bath hotter.

Two variables acting on submerged welding wire extensions are wire density and wire-feed speeds. Solid wires have a greater average density than metal-cored wires, so they take longer to change from a solid to a liquid. This increases the amount of time the wire extension remains submerged, adding more resistant heating to the flux bath. The increased heating of the flux bath creates a hotter and deeper weld metal pool. Higher wire speeds have the opposite effect by chilling the molten flux pool. The depth of the weld metal pool directly affects the grain formation "form factor," which determines the physical characteristics of an electroslag weld.

Creating the Weld Cavity

The sump at the bottom of the plates being welded helps to ensure that complete fusion occurs at the start of each weld. The depth of the sump allows time for the flux to melt and the molten weld pool to liquefy enough to tie into all sides of the steel plates. The sump usually has a "U" shape and is tack welded to either side of the weld groove on the bottom of the two plates being welded.

About one inch of molten flux must cover the molten weld pool. Run-off tabs are added to the top of the plates being welded. When the top surface of the flux bath reaches the top of the plates, the weld metal is still one inch below. So if 2-in. run-off tabs are tack-welded to either side

The improved electroslag process offers weld reliability, toughness, fatigue resistance, and improved impact toughness, and minimizes internal flaws.

of the joint clearance, the flux pool can rise 2 in. above the top of the steel plates. When welding stops, and the flux is cleaned off, the weld metal should be 1 in. above the steel plates.

Water-cooled copper shoes contain the molten weld pool on either side of the joint clearance between the two steel plates to be joined. The cavity formed between the two steel plates to be joined and the two copper shoes spanning the clearance between them contains the molten slag bath and weld pool. The shape of the contoured face of each copper shoe also determines the finished surface appearance of the weld bead.

Maintaining Flux Levels

As the weld builds, the slag bath comes in contact with the copper shoe and cools, which causes a thin layer of flux to deposit on the exposed portion of the shoe. It is important to have good contact between the copper shoes and the base metal being welded. If the contact point of the copper shoe does not fit firmly against the steel plates, an air gap forms between the plate and the copper shoe. As the weld progresses, hot flux flows between the shoe and the steel plates, causing an undercut. A certain amount of flux plates against the copper shoes and is lost. If the height of the flux bath falls to a level less than one inch, the weld becomes unstable.

To maintain a proper flux height, operators must continually add and withhold flux to the pool during the welding operation. If the pool depth shrinks to less than ½ in., arcing may occur between the guide tube and the sidewalls of the steel plates. If the welding operator adds too much flux, the pool becomes too deep. A deep pool chills the weld and causes incomplete fusion or cold-roll on the wet lines.

The weld pool makes a louder sound as it becomes more agitated. As operators become experienced, they can use this sound as a guide for adding or withholding flux. Operators should add flux only as needed.

Power Source and Control System

During electroslag welding, the electrical current (amperage) can vary over a wide range. Conventional constant-voltage power sources allow easier control of this weld than constant-current sources. With the voltage level (E) held constant, the electrical load or resistance (R) controls the electrical current (I) according to Ohm's law: $I = E/R$. The resistive load varies, depending on the speed of the welding wire feed, the diameter of the wire, and presence of the guide tube in the bath.

As the slag pool rises, it eventually reaches the bottom of the guide tube, and submerses the guide tube in the molten pool. The power supply sees this large cross-sectional load, and increases current to supply the load. As the slag pool melts the bottom of the guide tube, a momentary gap forms between the bottom of the guide tube and the top of the slag pool. The gap decreases the load, and the power supply draws less amperage.

In like manner, the power supply amperage varies directly with the wire feed speed, increasing with faster speeds and vice versa. The self-regulating characteristic of the constant-voltage power source adjusts the welding current to maintain a fixed voltage level.

Equipment Setup

In 1993, Arcmatic Corp. developed a line of electroslag welding equipment based on the NGI-ESW process for heavy plate fabrication and bridge building. The system was named VertaSlag®. It is computerized, which minimizes operator skill necessary to create quality welds in a short amount of time.

As indicated in Fig. 2, basic components of this welding system consist of the following:

• Butt-tee fixture, which includes a welding gun, clamping mechanism, motorized flux dispenser, water-cooled copper shoes, copper shoe clamping device, and the means for adjusting the consumable guide tube about the center point of a weld.

• Articulated boom for positioning the welding fixture in a horizontal plane with respect to the workpiece. The welding fixture hangs from a cable suspended from the balanced lift, located at the end of the boom. The boom also supports the wire guides, motorized dual-wire straightener, wire feeder, and operator's control panel.

• The boom lift for adjusting the height of the articulated boom for welding various plate heights. A motorized carriage supporting the boom rides on the vertical track. The operator pushes a toggle switch to raise or lower the boom.

• Welding wire from drums placed on the floor. The wire travels to the boom and along the top, through a wire straightener and into a wire feeder mounted on the end of the boom. The feeder pushes the wire down a flexible conduit to the welding torch and through the consumable guide tube to the weld pool.

Additionally, water circulates from a reservoir to the copper shoes that contain the weld pool. Flexible water hoses run inside a fiberglass insulated tube under the boom, to the welding fixture, through the copper shoes, and back to the reservoir.

This system includes a control system and operator interface (Fig. 3) for regulating subsystems such as the, welding power supply, the motorized dual-wire straightener, motorized flux dispenser, and wire feed motor. Once setup is complete, the welding operation runs automatically, requiring little operator intervention.

The National Steel Bridge Alliance is encouraging its fabricator members to qualify for the improved process. To do so, they must butt-joint weld two thick steel plates using the new equipment. The finished welds are submitted to independent labs and to state DOTs for testing. Fabricators such as Williams Bridge Co. (Fig. 4) in Virginia and Trinity Industries in Texas have recently qualified their procedures for using the improved process. Jesse Engineering in the state of Washington and Stupp Bridge in Kentucky are in the process of qualifying with the VertaSlag welding system.

To summarize, NGI-ESW offers weld reliability, toughness, and minimizes internal flaws. This in turn should minimize major bridge repairs. The process also demonstrates fatigue resistance and improved impact toughness. The FHWA has lifted the moratorium on the process and is encouraging state DOTs to permit its implementation by commercial fabricators who qualify their procedures.◆

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