

Twin-wire GMAW for High-productivity Precision Fillet Welds

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State-of-the-art waveform-controlled gas metal arc welding (GMAW) technologies are being evaluated for a range of large-scale welding and directed energy deposition (DED) additive manufacturing (AM) applications that need high productivity and integrity. The deposition rate of conventional single-wire GMAW process variants are limited by plasma-jet induced defects at high current levels. Here, excessive penetration, poor bead shape, and/or plasma-jet induced porosity may become a problem. Modern two-wire GMAW process variants offer a 200-300% improvement in speed and deposition rate compared to conventional single-wire GMAW for these large-scale applications.

EWI, with support and guidance from several U.S. shipyards and the Naval Surface Warfare Center Carderock Division (NSWCCD), recently completed a National Shipbuilding Research Program (NSRP) project that evaluated twin wire (TW), tandem (T), and hot wire tandem (HW-T) GMAW process variants that use two wires in a common torch for DED AM.¹ While all the variants show significant improvements in productivity, the TW-GMAW process showed more tolerance to contact tip-to-work distance (CTWD) variations and was omni-directional, making it easier to program using robotic offline programming and DED software packages. Because the results of this project showed that TW-GMAW should be evaluated for high productivity welding applications, EWI conducted

internal research investigated the TW-GMAW process for high-productivity precision fillet welds.

Evaluation of Innovative Two-wire GMAW Process Variants

Single-wire GMAW processes use one power source, one wire feeder, and a torch with a single contact tip. T-GMAW uses two power sources, two wire feeders, and a torch with two electrically insulated contact tips (see Figure 1). With T-GMAW, the two electrically-insulated filler wire electrodes are controlled independently and pulsed asynchronously to control the metal transfer behavior. TW-GMAW uses one power source, one wire feeder, and a single torch with a dual-bore contact tip (Figure 1 and Figure 2). The two filler wire electrodes are fed at the same rate through a single wire feeder, through a single contact tip, and are controlled by a single pulse waveform.



Figure 1. Tandem (left) and twin wire GMAW (right) processes



Figure 2. Lincoln HyperFill™ robotic TW-GMAW system installed in EWI's lab.

T-GMAW and TW-GMAW processes provide synergistic improvements in deposition by using two electrodes coupled in close proximity. The coupled arc improves the melting efficiency via synergistic electrode extension heating, reduces arc pressure, enhances bead profile, and minimizes susceptibility to plasma-jet induced defects. As noted above, the latter limits the productivity of conventional single electrode GMAW processes where finger-penetration can become unstable and cause porosity.

T-GMAW requires close control of the CTWD to achieve high-productivity precision welding performance. As a result, the process is used with either fixed mechanization or robotic welding applications. T-GMAW is also typically a directional process, meaning that the two electrodes most often need to be aligned with a defined travel direction. Although T-GMAW offers more process control than TW-GMAW, TW-GMAW offers several advantages over T-GMAW for ease of application and cost. The TW-GMAW process is omni-directional and has been shown to be less sensitive to CTWD variations. There are fewer system components since only a single power source and wire feeder are used with a custom torch and drive rolls. These characteristics enable the TW-GMAW process to be deployed with portable and fixed mechanization, robotically, and semi-automatically (i.e., manually).

TW-GMAW: Omni-directional Behavior and Sensitivity to Tip to Work Variation

Bead-on-plate tests were conducted to evaluate the sensitivity of the TW-GMAW process to the twin wire electrode orientation, and to variations in CTWD. ER70S-6 filler wire (0.040-in diameter), A36 steel plate, and Argon + 5% CO₂ shielding gas were used for these tests along with the robotic TW-GMAW system shown in Figure 2. The wire feed speed (WFS) of each wire was 470 ipm (combined WFS of 940 ipm), the travel speed was 25 ipm, and welding was performed in the flat position.

Omni-directional sensitivity tests were run in the following orientations using a constant CTWD: electrodes parallel (0 degrees), electrodes 45 degrees (45 degrees and 135 degrees), and electrodes perpendicular (90 degrees) to the travel direction (Figure 3). The tests showed no significant difference in the weld visual appearance and weld cross-sectional profile, and process stability was excellent for all tests. Metallographic cross-sections prepared from the four welds showed weld width variation of 0.03 in., reinforcement variation of 0.01 in., and penetration depth variation of 0.01 in. between the four welds. Based on these results, the TW-GMAW process was deemed omni-directional.

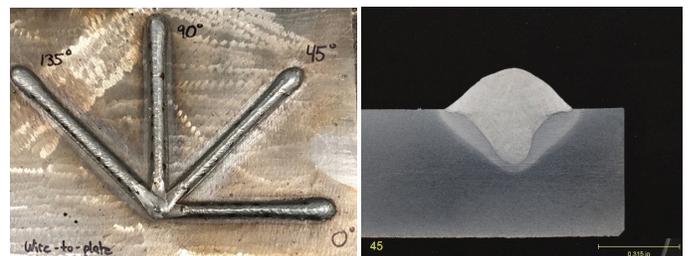


Figure 3. TW-GMAW omni-directional sensitivity tests: weld visual appearance (left) and metallographic cross-section of the weld made with the 45-degree twin wire orientation (right).

CTWD sensitivity was evaluated by producing bead-on-plate welds with CTWDs of $\frac{3}{8}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, and $1\frac{1}{4}$ in. (Figure 4). The results of these tests indicated that stability of the TW-GMAW process is not significantly affected by CTWD fluctuations. Metallographic cross-sections prepared from the five welds showed that penetration depth does reduce with increased CTWD: the penetration depth was 0.25 in. with a $\frac{3}{8}$ -in. CTWD, and 0.13 in. with a $1\frac{1}{4}$ -in. CTWD. Reduced weld penetration with increased CTWD was shown to coincide with reduced average current with increased CTWD.

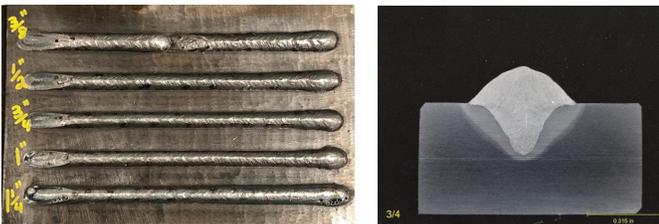


Figure 4. TW-GMAW CTWD sensitivity tests: weld visual appearance (left), and metallographic cross-section of the weld made with $\frac{3}{4}$ -in. CTWD (right).

Evaluation for Fillet Welding of Steel Joints

Trials were performed to evaluate TW-GMAW for high-productivity precision fillet welds. The robotic TW-GMAW setups utilized both Lincoln Electric's Power Wave S500 and Power Wave S700 power sources to evaluate deposition rate potential for both power source options. Fillet welds with minimum leg length of $\frac{1}{4}$ in. (6 mm) were produced in the horizontal position using $\frac{1}{2}$ -in. thick mild steel, ER70S-6 filler wire (0.040-in. diameter), $\frac{3}{4}$ -in. CTWD, and argon + 5% CO₂ shielding gas. Select fillet welds were visually tested in accordance with NAVSEA Technical Publication S9074-AS-GIB-010/271, with acceptance evaluated in accordance with the Class 1 requirements of MIL-STD-2035. Metallographic cross-sections were also prepared and evaluated to assess soundness and fusion at the root.

With the Lincoln S500 power source near the maximum power output of 450 amps at 100% duty cycle, fillet welds were produced at travel speed of 25 ipm that met the MIL-STD-2035 Class 1 visual testing requirements with fusion at the root (Figure 5). The weld surface was smooth with acceptable wetting at the toes. The penetration profile was wide and uniform. The wire feed speed was set at 470 ipm for a total wire feed input rate of 940 ipm, and a deposition rate of 20.1 lbs./hr.



Figure 5. TW-GMAW weld made at a total wire feed input rate of 940 ipm with a travel speed of 25 ipm: weld visual appearance (left) and metallographic cross-section (right).

The Lincoln S700 power source uses similar waveforms and provides higher maximum output of 700-A at 100% duty cycle. With this power source, tests were performed that showed that fillet welds could be produced at travel speeds up to 30 ipm that meet the MIL-STD-2035 Class 1 visual testing requirements with fusion at the root (see Figure 6). The weld surface was smooth with acceptable wetting at the toes. The penetration profile showed adequate bead shape, and the deep penetration may offer strength advantages for applications such as fillet welded corners and T-joints. The wire feed speed was set at 600 ipm for a total wire-feed input rate of 1200 ipm, and a deposition rate of 25.7 lbs./hr. This wire-feed rate was deemed maximum for this application as it was the maximum output of the synergistic line.

Based on the project results, the TW-GMAW process should be evaluated for high-productivity precision

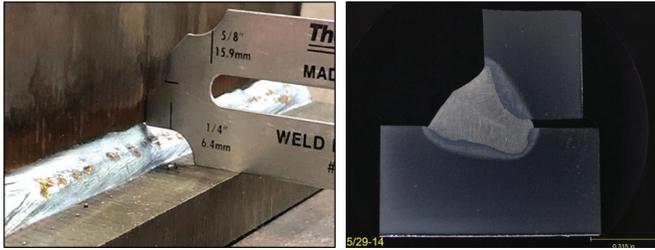


Figure 6. TW-GMAW weld made at a total wire input rate of 1200-ipm WFS with a travel speed of 30-ipm: weld visual appearance (left) and metallographic cross-section (right)

fillet welding applications. For the target application, the process provided similar weld quality and productivity benefits of T-GMAW, with a lower cost and simpler equipment setup. Even though T-GMAW may offer higher productivity, the TW-GMAW process may be preferred based on the application's requirements and cost-benefit analysis. To summarize, the TW-GMAW process offers the following benefits:

- High-productivity precision fillet welds
- Beneficial deep penetration, with a wide and smooth underbead profile
- Omni-directional
- Process stability with variations in CTWD
- Lower cost equipment setup compared to T-GMAW
- High deposition arc-DED building capabilities¹

Recommendations

Advanced GMAW processes should be evaluated for large-scale fillet welding applications. The preferred process will depend on the material type, weld joint design, weld sizes, positions, welding environment, and production volume. Twin-wire GMAW was demonstrated to show significant potential over conventional single-wire GMAW with a modest increase in cost. Large-scale fabricators should compare advanced two-wire GMAW systems to maximize productivity and business case of welding applications.

To learn more about advanced GMAW processes for large-scale fillet welding applications, contact Michael Carney at mcarney@ewi.org.

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Any reference to specific equipment and/or materials is for informational purposes only. Any reference made to a specific product does not constitute or imply an endorsement by EWI of the product, or its producer or provider.

References

- 1 Carney, M. and Harwig, D. "High Deposition Robotic Arc Additive Manufacturing Process Development". NSRP Project No. 2019-375-002 (EWI Project 58245GTH) final report.

Michael Carney, Applications Engineer for Arc Welding and Directed-energy Deposition Process Innovation, works with a variety of welding processes including advanced gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), and submerged arc welding (SAW). He has experience welding stainless steels, copper, nickel-based alloys, carbon and alloy steels, titanium, aluminum, and precious metals as well as expertise in electron beam welding (EBW) and friction stir welding (FSW) processes with a broad background in semiconductor, oil and gas, energy, and automotive industries.

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Nick Kapustka is Principal Engineer in the Arc Welding Group at EWI and also serves as the Engineering Group Leader. He has built a successful reputation in the field of arc welding and is experienced in developing and implementing mature and advanced fabrication technologies to various alloy systems. Nick has been involved in the National Shipbuilding Research Program since 2006. In 2015, Nick received the EWI Technical Excellence Award, which recognizes technology innovation that has an exemplary impact on EWI's reputation as a center of technical excellence in manufacturing.

Travis Peterson is a technician in the Weld & Test Labs at EWI where he focuses on arc welding, directed-energy process innovation, and robotics. He is skilled in programming robots such as ABB, Fanuc, OTC, and Motoman as well as CLOOS and Panasonic. Travis has a background of welding stainless steels, nickel-based alloys, carbon and alloy steels, titanium, and aluminum. He joined EWI in 2018 after earning his B.S. in Welding & Fabrication Engineering Technology from Pennsylvania College of Technology.