Pulsed Gas Metal Arc Welding of Copper-nickel Pipe Joints

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Introduction

Virtually all ship designs utilize copper-nickel alloys. Applications include fire mains and other piping for seawater and freshwater, tanks, and structures, such as rope guards and fairings. The vast majority of copper-nickel pipe joints are currently welded with manual gas tungsten arc welding (GTAW) at travel speeds of approximately 4 inches per minute (ipm). In comparison, pulsed gas metal arc welding (GMAW-P) can operate at travel speeds of 12-18 ipm with significantly higher deposition rates. As a result, implementing GMAW-P for these applications may yield significant productivity increases. Further, the rapid response rates of many modern digitally controlled GMAW-P power sources now enable more precise control of arc characteristics, an essential capability for semi-automatically welding historically challenging alloys such as copper-nickel. Under funding from the NSRP-ASE, EWI worked with Vigor Industrial and General Dynamics NASSCO to develop and implement GMAW-P procedures for the fabrication of copper-nickel pipe joints.

Applications

Two candidate copper-nickel pipe-joint applications were identified for the implementation of GMAW-P. For both applications, MIL-RN67 copper-nickel wire was selected as the welding consumable along with argon/helium shielding gas.

The first application was a butt joint between two 90/10 copper-nickel pipe sections using a backing ring of the same alloy (Figure 1). The pipe sections were 6 in. schedule 10, giving them an outside diameter of 6.625 in. and a 0.134 in. nominal wall thickness. For procedure qualification of this joint type, NAVSEA Technical Publication S9074-AQ-GIB-010/248 requires visual testing, liquid penetrant testing, radiographic testing, and mechanical testing including tensile, root-bend, and face-bend specimens.

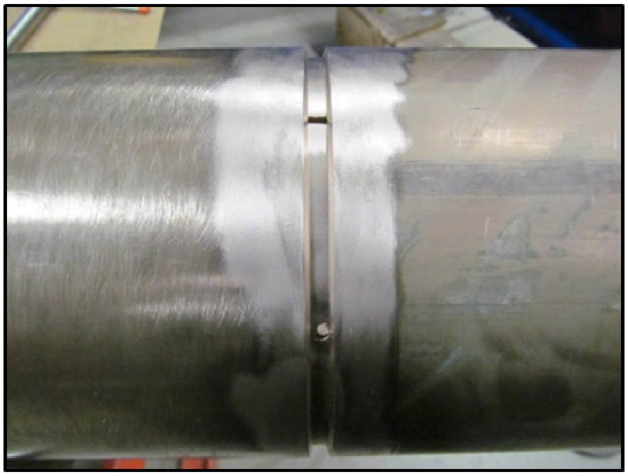

Figure 1: Butt joint with a backing ring

The second application was a fillet-welded coupling joint between two 90/10 copper-nickel pipe sections using a coupling ring of the same alloy (Figure 2). As in the first application, the pipe sections were 6 in. schedule 10. For procedure qualification of this joint type, NAVSEA S9074-AQ-GIB-010/248 requires visual testing, liquid penetrant testing, and metallographic evaluation.

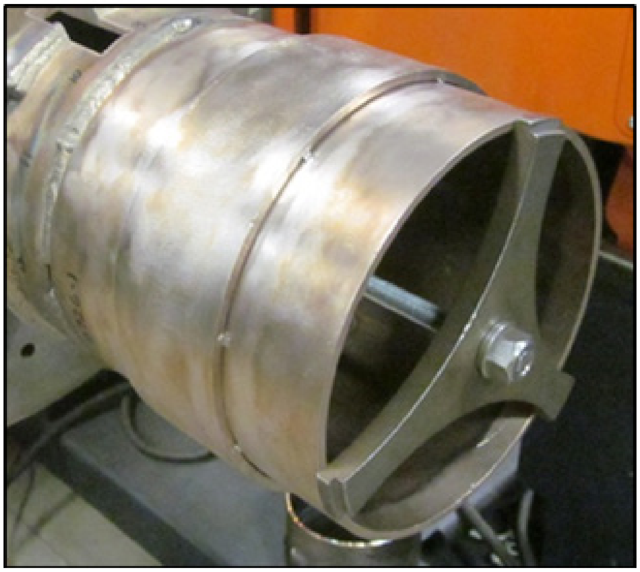

Figure 2: Coupling joint

Robotic Welding Development at EWI

Robotic GMAW-P procedures were developed at EWI for these two applications. For the butt-joint application, welds were made in the 1G-R position (pipe rolled) and in the 5G position (pipe fixed). The coupling joint was welded only in the 2F-R position (pipe rolled). Each weld was produced using three continuous 360-degree passes, and interpass cleaning was performed using only a stainless-steel brush.

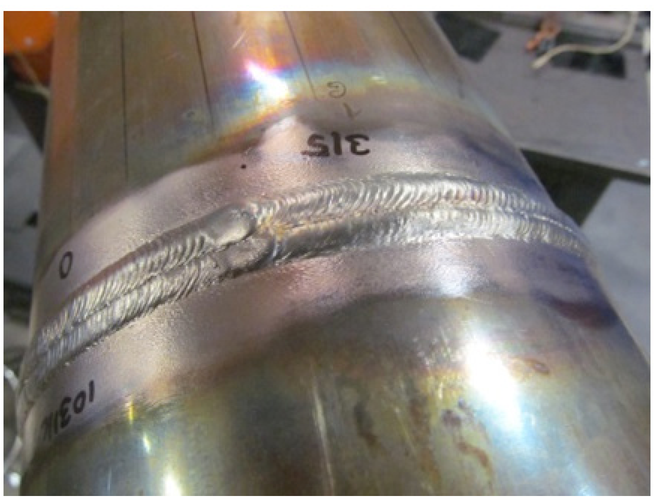

Figure 3: Robotic GMAW-P butt-joint weld produced in the 5G position

Average travel speeds for the butt joints welded in the 1G-R and 5G positions were 10.0 ipm and 7.4 ipm respectively. The average travel speed for the coupling joint welded in the 2F-R position was 13.8 ipm. A photo of the butt joint produced in the 5G position is shown in Figure 3, and a macrograph from the same weld taken at the 1:00 position is provided in Figure 4.

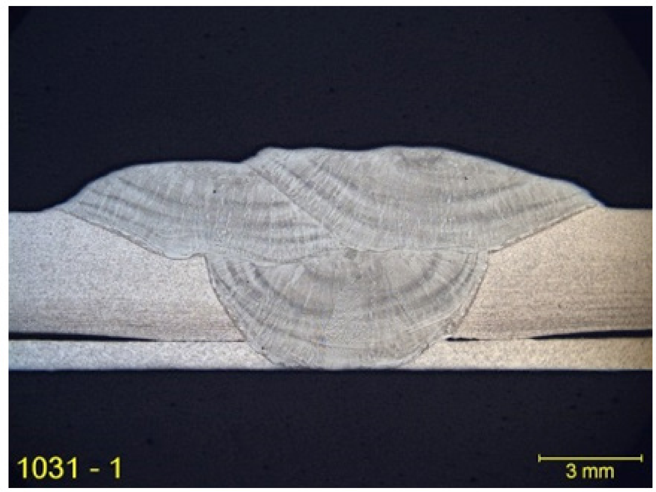

Figure 4: Macrograph from the robotic GMAW-P butt-joint weld produced in the 5G position

Shipyard Implementation

Trials were performed at Vigor Industrial to identify semi-automatic and robotic GMAW-P procedures meeting the requirements of NAVSEA S9074-AQ-GIB-010/248 for the butt joint welded in the 1G-R position. Productivity results were compared to a semi-automatic GTAW procedure for the same joint which required 3 passes at an average travel speed of 3.1 ipm, resulting in 20.9 minutes of total arc-on time.

A semi-automatic GMAW-P weld was produced using a program that was custom-designed by OTC Daihen and optimized for this application. This program produced a stable welding arc even with the changes in contact-tip-to-work distance (CTWD) that inherently occur when the torch is weaved in a v-groove joint. Interpass cleaning was performed using a stainless-steel brush.

The weld was completed in two continuous 360-degree passes at an average travel speed of 8.9 ipm. The total arc-on time was 4.8 minutes, representing a 77% reduction compared to the GTAW procedure. This weld met all applicable NAVSEA procedure qualification requirements, and the procedure qualification record data has been submitted to NAVSEA for approval. A photo of the completed weld is shown in Figure 5 and the corresponding macrograph is provided in Figure 6.

Figure 5: Semi-automatic butt-joint weld produced at Vigor Industrial in the 1G-R position

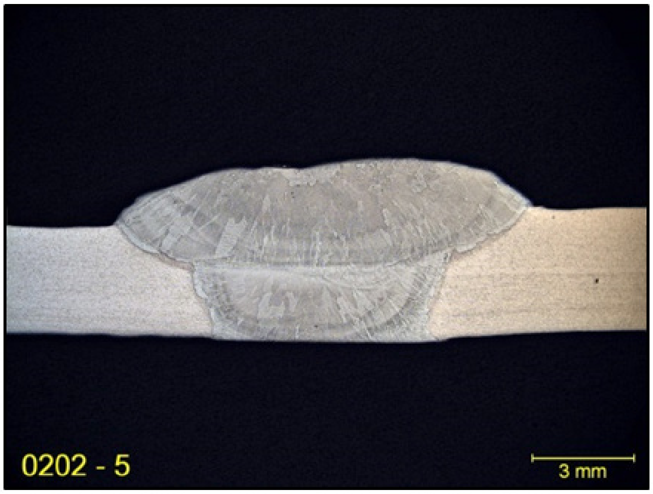

Figure 6: Macrograph from the semi-automatic butt-joint weld produced at Vigor Industrial in the 1G-R position

A robotic weld was produced in two continuous 360-degree passes at an average travel speed of 7.9 ipm, resulting in a total arc-on time of 5.3 minutes. Interpass cleaning was again performed using only a stainless-steel brush. This weld met visual testing, liquid penetrant testing, and radiographic testing requirements, and is undergoing mechanical testing. Provided that the mechanical test results meet the requirements of NAVSEA S9074-AQ-GIB-010/248, the procedure qualification record will be submitted to NAVSEA for approval. A photo of the completed weld is shown in Figure 7.

Figure 7: Robotic GMAW-P butt-joint weld produced at Vigor Industrial in the 1G-R position

Going from the Pipe Shop to the Ship

The semi-automatic and robotic 1G-R GMAW-P procedures for the butt-joint weldment described above are expected to be approved by NAVSEA and implemented at Vigor Industrial. EWI's work also demonstrated that robotic welding can be used to weld butt joints in the 5G position as well as coupling joints in the 2F-R position, and that both would meet applicable NAVSEA procedure qualification requirements. These four combinations of joint type, position, and torch manipulation method are best suited for pipe-shop fabrication. The shipyards also have a strong need to implement GMAW-P to fabricate copper-nickel pipe joints on-board ships. This will require semi-automatic welding and/or orbital welding of butt joints and coupling joints in all positions.

Future Work

Out-of-position GMAW-P of copper-nickel pipe joints is challenging and has not seen widespread implementation in the U.S. shipbuilding industry. The 5G robotic butt-joint weld procedures developed during this project will require transfer to orbital welding equipment to allow their implementation on-board the ship.

Semi-automatic out-of-position GMAW-P of copper-nickel pipe joints has been challenging in the past. Work performed by EWI and participating shipyards under this NSRP-ASE-sponsored project strongly suggests that it may be possible to semi-automatically weld copper-nickel pipe joints out-of-position if the welding system can maintain stable arc characteristics regardless of fluctuations in the CTWD. As was discovered during this project, an optimized welding program and a digitally controlled power source with the ability to respond rapidly to changes in the welding arc are both required for in-position, semi-automatic welding of copper-nickel pipe joints, and may also enable semi-automatic out-of-position welding of these joints.

Nick Kapustka *is an applications engineer in EWI's Arc Welding group. He is widely recognized as an expert of arc welding with a focus on aluminum, titanium, magnesium, nickel-based alloys, and advanced high-strength steels (AHSS). Nick is proficient in applying gas metal arc welding (GMAW) processes for critical applications such as the repair of aerospace components, and has completed extensive work on the arc welding of magnesium and nickel-based alloys.*

Paul Blomquist *has worked for more than 25 years in the shipbuilding and heavy construction industries. He is a contributor to several innovative shipbuilding technology concepts and serves as the Technical Director for the Center for Naval Metal Working. Paul is recognized throughout industry for his joining expertise and his record of developing, winning, executing, and implementing government- and industry-funded joining-related R&D projects. He has managed numerous multi-million-dollar projects related to building, maintenance, and repair of naval combatant and commercial vessels.*

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