

The pulsed GMAW twin-wire (time deposition rate welding of thick section aluminium

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Natural gas is becoming an increasingly important component of the global energy supply. When liquefied at -162°C its volume is 600 times less than its gaseous volume and can be designated as Liquefied Natural Gas (LNG) and transported over long distances, in specially designed ships obviating the need for transmission pipelines. However, the construction of LNG carriers requires high levels of expertise with regard to both materials and welding engineering – one of the major reasons that worldwide just a few shipyards are capable of producing spherical LNG container vessels for incorporation into large seagoing tankers.

Spherical LNG Tanks – construction and state-of-the-art

Different tank construction principles are applied for carrying LNG by ship. Spherical tanks, originally based on the Moss-type sphere were first used in 1969. One of their benefits is that a separation between the individual LNG tank and the ship's hull may be achieved. Tank deformation, due to the cumulative effects of thermal expansion and contraction, are captured by the tank itself and are not introduced into the hull of the carrying ship [2].

Specialised manufacturing of Moss-type LNG carriers was therefore prescribed to meet the rigorous technical requirements of a world-leading Korean shipyard.

Tank building principle – base materials and consumables

The 4-tank system is the basic principle the shipyard is following, which when compared to the 5-tank system results in a reduction in construction costs without sacrificing significant storage capacity. Since the LNG container vessels have to be built in accordance with the International Code for the Construction of Equipment for Ships Carrying Liquefied Gases in Bulk (IGC Code), extensive know-how is necessary to produce these components so that they meet 'leak before failure' criteria. The spherical vessels are manufactured using specific aluminium alloys, which exhibit excellent mechanical properties, especially with regard to low temperature toughness.

Aluminium alloys for LNG applications are standardised within the ASTM B 928 code. The base material is alloy AA 5083 (Al Mg4,5 Mn0,7 according to EN 573-3). This work-hardenable alloy provides excellent corrosion resistance at moderate tensile strengths. The alloy is used either in the H321 (less work-hardened than controlled H32 condition) or in the 0 (annealed) temper condition. *Table 1* shows average mechanical properties of differently tempered alloy 5083 at distinct temperatures.

Both the yield- and tensile-strength increase as the

Alloy No and temper condition	Temperature ($^{\circ}\text{C}$)	R_m (MPa)	R_e (MPa)
5083-0	20	~320	~140
5083-0	-196	~435	~160
5083-0	-250	~620	~178
5083-H321	20	~335	~235
5083-H321	-196	~455	~274
5083-H321	-250	~590	~280

Table 1: Temperature dependent mechanical properties of the differently tempered alloy 5083.



Figure 1: Spherical tank LNG carrier [1] with a capacity of 137 000 m³.



Figure 2: A spherical aluminium LNG container vessel being mounted onto a ship hull using a gantry crane [4].

(twin) process for high



Figure 3: Automatic high-current GMAW of spherical aluminium LNG containers [4].

ambient temperature decreases and the material shows an excellent ductility even at temperatures towards absolute zero. AA 5083-H321 is thus one of the most suitable aluminium alloys for cryogenic applications in general.

Spherical LNG tanks are built by either following the so-called 3-division section erection method where the southern, equatorial and northern segment are integrated into the ship's hull after they have been put through different hot-forming and assembly stages, or the tanks are mounted as a whole LNG container vessel lifted by heavy gantry cranes, see Figure 2.

The wall thickness of these vessels is ≤ 200 mm in some cases and the large dimensions of the LNG container themselves (with diameters ≤ 45 m) lead to special welding conditions, as the components are not undergoing a preheating procedure. Presently, two single wire GMAW processes are being used at the shipyard. The semi-automatic single wire pulsed GMA welding with filler wire grade AWS A 5-10 ER 5183 ($\varnothing 1,6$ mm) is used for joining the different tank sections in the AWS 3G position. Considering the section's large wall-thickness, it is understandable that wire electrodes of greater diameters are being used to obtain appropriate weld deposition rates or welding efficiencies, respectively. As far back as the 1970s, investigations were being carried out with large diameter aluminium wire electrodes (from 2,0 to 6,0 mm) to increase the weld deposition rate with GMA welding thick aluminium sections. Even though promising results under laboratory conditions were achieved at that time, the large aluminium wire diameter process has – at least in Europe – never been applied on-site, one of the major obstacles being the restricted positional process capabilities, since the only position possible when using large wire diameters is the AWS 1G.

At the Korean shipyard, however, besides the GMAW-pulse process described, high-current GMA (400 to 850 A) is used semi-automatically with a 6,4 mm wire diameter to execute a significant fraction of the approximately 2 000 m of weld seam length required per sphere. Figure 3 shows high-current GMA welding. To achieve consistent welding results with high-current-GMA an additional purging nozzle has to be used trailing after the shielding gas

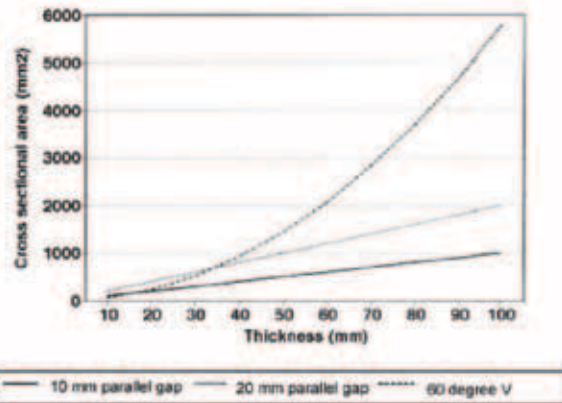


Figure 4: Effect of joint preparation on weld cross sectional area [6].

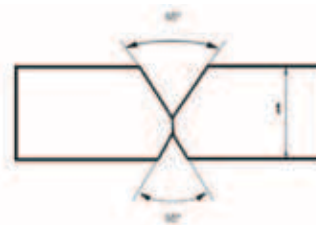


Figure 5: Schematic representation of previous welding joint design [4].



Figure 6: Special narrow gap joint design for thick aluminium section GMAW [7].

nozzle. 67%He/33%Ar is the shielding gas composition with pure argon used as the purging gas. Gas flow rates of ≤ 50 l/min for both nozzles are required to shield the weld pool against the environmental atmosphere.

Project requirements and approach

The main project goal was to improve the currently used low-current GMA welding technology (GMAW-pulsed at 200 to 300 A) to achieve an improvement in both welding-efficiency and quality. Fundamental to the idea was to use wire electrode diameters of greater than 1,6 mm, ie, 2,0 to 2,4 mm. Proportionality between wall thickness, joint preparation and weld cross sectional area is well-known, (see Figure 4) and weld cross sectional area directly relates to the production costs. A further project goal, therefore, was to optimise the joint design being used for low-current-GMAW-P or automatic GMAW, the process internally designed by the shipyard (see also Figure 5).

With respect to the particular wall thickness of the part to be welded – $t \leq 58$ mm – different flange heights and bevel angles are being used. A large number of single weld layers are needed when manufacturing a spherical LNG container using joint preparations like those represented in Figure 5 and each single layer has to be machined subsequent to

welding to avoid the risk of defects. Reducing the number of single layers by reducing the weld joint cross sectional area may lead to a significant reduction in production costs and a reduced risk of weld imperfections.

Hence, it was decided that narrow gap design would be used instead of the joint preparation shown in *Figure 5* above. *Figure 6* shows the particular bevel design for achieving a reduction in the number of layers required to be welded in the AWS 3G position, with thick aluminium section of spherical LNG container vessels. One of the main goals was to fill the gap with a lowest number of weld layers.

This was considered to advance already existing process know-how based on previous investigations in heavy aluminium section welding in the AWS 1G position. 150 mm thick aluminium plates have been manually welded here using ER 5183 single wire with 2,0 mm wire diameter and 70He/30Ar shielding gas. 96 single layers were welded to fill the gap, which was prepared according to *Figure 6* and sound results both in efficiency and quality were achieved (see also *Figure 7*). The process was stable and no significant weld defects could be detected.

However, the risk for obtaining weld flaws when processing large wire electrode diameters in the vertical up position is considerable. Proper control of large weld bead volumes is a sensitive undertaking and higher amounts of porosity are frequently found in large weld beads after solidification.

Due to the weldments not being preheated, the risk of lack of sidewall fusion within the narrow gap root pass became significant, which led to the need to reconsider the welding process. The main objective was to improve the weld pool control in the vertical up position and to take advantage of improved material deposition. Pulsed GMAW twin-wire (time twin) was the process chosen for examination in greater detail, in order to determine its suitability for spherical container vessel manufacture and its ability to provide an efficient alternative for large diameter single wire welding.

Narrow gap geometry, as already described above, requires an appropriate welding torch design. As the twin-wire trials started, tests were performed using two modified torches combined into one unit to test accessibility to the weld gap, (see *Figure 8*).

To obtain a higher weld deposition rate compared with a single wire electrode of 1,6 or 2,0 mm in diameter, it was decided to use two 1,6 mm wires. Hence, a further crucial area of investigation was to evaluate the process stability and establish whether an improvement could be observed compared with single wire pulsed GMAW. The system was equipped with the above-mentioned filler wires and the modified torch was adapted to suit a mechanical oscillation device in order to perform the root pass and subsequently obtain the necessary approval for the welding procedure (see *Figure 9*).

The next step was to generate a twin-wire tandem welding torch prototype to meet the stringent demands of shielding gas flow, weld pool controllability, and duty cycle.

In order to identify a suitable gap between the two contact tips and control the interaction between both arcs, a regular twin-wire torch was used, but equipped with an already modified narrow gap gas nozzle (see *Figure 10*).

Figure 10 (right) shows the relatively wide distance between both wires. It was first presumed that an increase of this gap value would improve both process stability and weld pool controllability due to reduced arc interference. It

was found, however, that to the contrary, a reduction of this distance led to a significant improvement in process stability. Once the optimal contact tube distance was determined, it was possible to create a specific twin-wire welding torch to include all components – special contact tubes and wear parts necessary to obtain an optimal high deposition welding process for positional heavy aluminium section manufacturing (see *Figure 11*).

After the welding torch and all of its sub-components were appropriately modified, the welding arcs and their behaviour could be investigated and optimised for positional welding. It is well-known that in twin-wire welding, electromagnetic induced interference can occur between the wire electrodes [5]. *Figure 12* depicts schematically the major parameters



Figure 7: Heavy section aluminium plate ($t = 150$ mm) manually welded using single wire narrow gap GMAW-P [7].



Figure 8: Initial trials using modified single wire GMAW welding torches [7].



Figure 9: First 3G narrow gap root pass welded with twin-wire technology [7].



Figure 10: Regular twin-wire torch equipped with modified prototype gas nozzle [7].

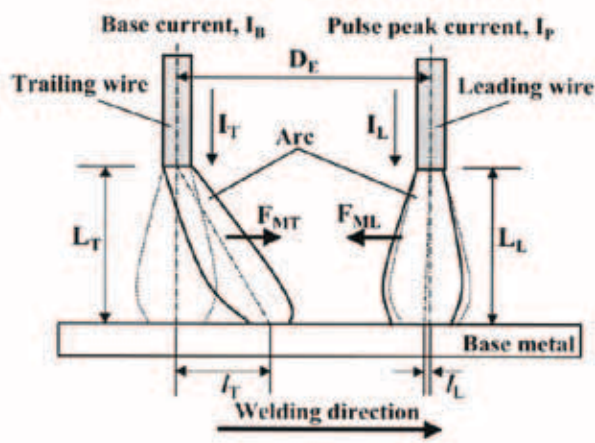


Figure 12: Schematic representation of electromagnetic interference in twin-wire welding [5].

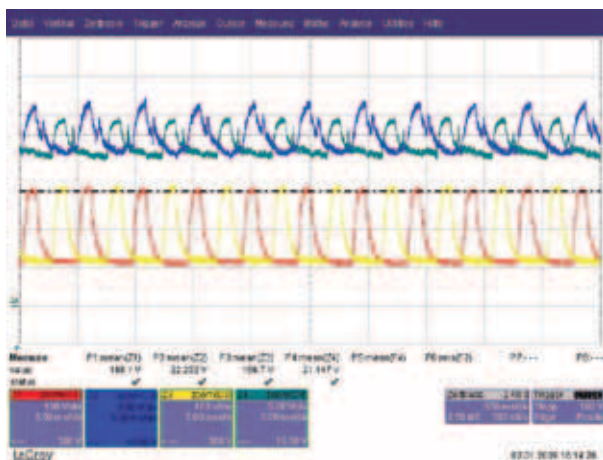


Figure 13: Typical transient regime of twin-wire aluminium tandem welding characteristics [7].

affecting the process stability. Even though aluminium twin-wire pulsed GMAW welding shows a greater arc stability compared with steel welding [5], it follows that using two wires within a narrow gap joint-preparation requires additional effort to synchronise the arcs one to another.

High arc stability had to be achieved to ensure sound and reproducible welds. Fully digitised welding power supplies – used for achieving best stability conditions – are equipped with welding characteristics based on software interacting with the power source’s CPU. Hence, it was relatively easy to evaluate the necessary background parameters to be optimised for assisting both precise droplet detachment and arc stability. Figure 13 shows a typical transient regime of the modified twin-wire welding characteristics.

Using both the tailored welding characteristics and the specially developed welding torch, final investigations using a specifically prepared weld specimen were possible. In the first trials, an attempt was made to reduce the number of weld layers in accordance with the technical requirements. Successful results were achieved by welding six weaved layers into the narrow gap on the front side of the plate (see Figure 14). Initially, a high helium-containing shielding gas composition (70He/30Ar) quite similar to the shielding gas used on-site (67He/33Ar), was used. Subsequent metallographic investigations showed surprisingly high amounts of porosity, which according to the WPS, had to be avoided.

Since good low porosity results were achieved in previous twin-wire welding trials with 70Ar/30He shielding gas [7]



Figure 11: Modified twin-wire torch for narrow gap thick section aluminium high deposition welding in the 3G position [7].



Figure 14: Initial results at reducing the number of weld layers – cap layer appearance (left) and transversal macro section (right) [7].

– which is a common composition in Europe – trials were started to evaluate this shielding gas. After an appropriate period of optimisation the 6-layer sequence could be obtained, which can be assumed to be the most effective way to fill the gap under consideration when using a high deposition welding process under positional welding conditions. Figure 15 shows both the schematic and the real macro section of the transversal cross section.

Metallurgical investigations proved that the results conformed to the WPS requirements and were free of excessive amounts of porosity or inner weld defects.

Final parameter settings for the 6-layer welding sequence are represented in Figure 15 and listed in Table 2. Both the newly developed twin-wire high deposition tandem welding torch for narrow gap welding and the

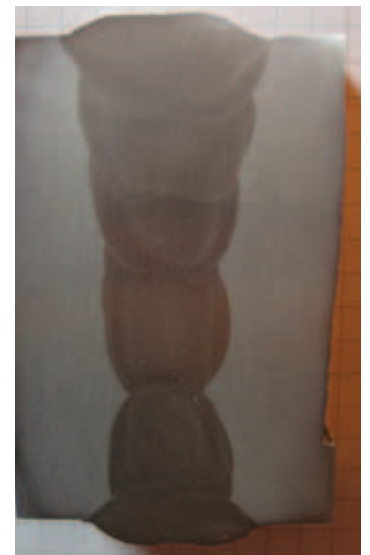


Figure 15: High deposition twin-wire pulsed GMAW weld layer sequence [7].

Weld layer	Weld deposition rate (kg/h)	Leading electrode wire feed speed (m/min)	Trailing electrode wire feed speed (m/min)	Welding speed (m/min)
1	~6,35	11,0	8,5	0,22
2	~4,72	8,5	6,0	0,18
3	~4,89	8,5	6,5	0,20
4	~2,93	5,0	4,0	0,18
5	~4,55	8,0	6,0	0,18
6	~3,91	7,0	5,0	0,18

Table 2: Parameter set-up for vertical-up position for twin-wire high deposition welding [7].

welding parameters could thus safely be approved as being most practically applicable for achieving high quality and reproducible weld results.

Conclusion and outlook

Liquefied Natural Gas (LNG) spherical container vessels made of high toughness aluminium alloys pose significant manufacturing challenges. Due to their extraordinary wall thicknesses, the heavy aluminium sections require welding processes that meet the highest quality demands efficiently. As an alternative to the manual pulsed GMAW process using large diameter single wire electrodes, the semi-automatic twin-wire tandem welding process was investigated for use in the narrow gap welding of heavy aluminium sections in vertical 3G welding position.

To meet the stringent requirements of a world-leading Korean shipyard, specialising in building large LNG carriers it was necessary to develop a new twin wire tandem welding torch to optimise the power source weld-

ing characteristics. Excellent results, both in terms of welding efficiency and quality, could be obtained. The described process, including the hardware, is not only applicable for LNG components but, in fact, for any heavy aluminium section, and is seen as having excellent advantages for all

manufacturers of these components. Follow-on investigations are already scheduled to extend the process to the 2G position, ie, welding horizontally on a vertical wall. The goal is to further advance the process applicability to all the important welding positions used on-site.

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