Influence of Tack Weld on Physical and Mechanical Properties of MIG Welding of AA5083H116

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Abstract. The research objective is to determine the effect of tack weld on physical and mechanical properties of tandem-MIG (T-MIG) welding of AA5083H116 materials. A Tenjima 2008 MIG machine, sample dimension of 300mm × 75mm × 3mm, and 0.8mm diameter ER5356 electrode were used. The distance between electrodes of T-MIG was varied of 18, 27, 36mm. Welding speed of 12.5mm/s, and welding process was shield using argon gas. First, T-MIG welding were employed for untacked and tacked welding. The leading current was 125A and trailing current was 120A, but current wave of each T-MIG welding machine was not taken into account. The welding voltage was set the same. Second, parameters resulting in better physical and mechanical properties were then employed for single-MIG (S-MIG) tack weld using 8, 10, 12mm/s welding speeds. The result shows that T-MIG tacked weld produced in bowing distortion and T-MIG untack weld in downward bending distortion. Higher peak temperature resulted in larger distortion. T-MIG tacked weld results in welding efficiency 76% being similar with that of bending strength (75%) in comparison with that of as received material. T-MIG tack weld results in better penetration and 37% shorter welding time in comparison with S-MIG tack weld.

Key words: T-MIG welding, tacked weld, AA5083H116, ER5356, physical properties, mechanical properties

1. Introduction

Aluminum alloys have widely been used in marine transportation. Ship-building industries currently concern with reducing the manufacturing time by employing tandem-MIG welding in manufacturing process. AA 5083H116 mainly containing Al - 4.5% Mg-0.15% Cr-0.7% Mn possessing density of 2.66 gr/cm³ [1], lighter but with mechanical properties comparable to A36 steel (density of 7.85 gr/cm³), and after being H116 treated being corrosion resistant and ease of welding has been extensively used [2]. Considering these, AA5083H116 has been used in ship building, especially for small size ships replacing A36 steel. Welding is the main process in ship manufacturing. Tandem-MIG welding [3] of Q690 steel can increase the welding speed, deposition rate, and welding quality. In tandem welding (two feeding units and two power sources), the wires may have different potentials, and the welding parameters can be set freely for each wire [4]. Numerical and experimental studies of double-wire gas metal arc welding (DW-GMAW) in plasma environment [5] show that welding defects such as undercut and humping is less in double wire-GMAW than those in single wire-GMAW. In comparison with single-MIG, tandem-MIG can refined microstructure in both weld and heat affected zone, narrowing HAZ and improving joint strength. In addition, energy efficiency and welding cost can also be saved [6]. Partially melted zone (PMZ) is an important zone of aluminum alloy welds, because PMZ in these materials is weak link in the weldments and significantly affected by welding parameters. Microstructure changes in PMZ are related not only to welding input, but also depend on the thermal history of alloy [7]. The tensile strength of a sound welded joint with proper preheating reached 90% of that of the base metal. The efficiency of MIG welding using aluminum electrode can reach up to 0.73 - 0.91 [8]. A study on the influence of clamping on welding distortion [9] of 1 mm thick DP600 overlap joint and 6 mm thick S355 T-joint
showed that the final residual stresses and distortions depend strongly on the clamping conditions. Based on the tack welding modeling of single welding processes like in real fabrication conditions results in a final distortion about 23% higher than the case of neglecting tack welding [10]. Distortion as weld defect due to extensive heat input causes the weld metal experiences sudden shrinking due to uneven thermal expansion. MIG welding of aluminum alloy plates results in relatively larger distortion [11]. In order to overcome this problem, welding of plates are commonly clamped to restrain the workpiece, increase welding speed, use smaller current, and applying tack weld. Using clamping device can only avoid distortion during welding but not for weld result. Increasing weld speed should be combined with the increase of weld current in order to reach melting point of the weld metal, such that it required more energy and frequently result in uncomplete weld pool due to over speed and the weld metal has not reach root section. Effects of phase difference on the behavior of arc and weld pool in tandem pulsed GMAW of mild steel has been investigated [12]. By increasing the phase difference, the height of bulged molten metal between the two wires decreases, the weld appearance becomes worse with decreased weld width and increased weld penetration and reinforcement. Untack and tack T-MIG weld of AA5083H116 materials have not been studied. The objective of this research is to determine the effect of tack-weld on the physical and mechanical properties of T-MIG welding of AA5083H116 materials.

2. Materials and Methods

2.1 Welding Conditions

In order to obtain consistent result, semi-automatic Tandem-MIG welding using ER 5356 electrode and AA5083H116 material containing composition a presented in Table 1 were used. Two pieces of AA5083H116 plate of 300 mm × 75 mm × 3 mm was welded using butt joint along 300 mm transverse to the rolling direction. Two Tenjima MIG 200S machines and argon were used. During the welding, the distortion at the outer side of the plate was measured using dial indicator and recorded using a video camera. The detail of the welding parameters of the T-MIG untack weld and tack weld, single MIG tack weld have been presented in Table 2, and the welding process illustrated in Fig. 1. The current wave of each welding machine was not taken into account in this welding process, and the voltage was set the same, and leading current of MIG1 was 125 A and the trailing current MIG2 was 120 A [13].

| Elements (wt%) | Al | Mg | Mn | Fe | Si | Cr | Ti | Cu | Zn | Ni |
|----------------|----|----|----|----|----|----|----|----|----|----|
| AA5083H116     | 94.31 | 4.50 | 0.57 | 0.29 | 0.16 | 0.088 | 0.027 | 0.022 | 0.021 | 0.008 |
| ER5356         | 0.9305 | 0.50 | 0.20 | 0.40 | 0.25 | 0.20 | 0.20 | 0.10 | 0.10 | - |

\(^{1)}\text{Alcoa certificate, }^{2)}\text{ASME (2001)\)

| Parameter                  | MIG1 | MIG2 | Single-MIG tack weld |
|----------------------------|------|------|----------------------|
| Electrode distance (d)     | 18, 27, 36 mm | 10 mm | 10 mm | 10 mm |
| Electrode distance to specimen (h) | 10 mm | 10 mm | 10 mm |
| Welding speed (S)          | 12.5 mm/s | 12.5 mm/s | 8, 10, 12 mm/s |
| Welding angle (°)          | 80° | 80° | 80° |
| Mean welding voltage (V)   | 19 V | 19 V | 19 V |
| Mean welding current (I)   | 125 A | 120 A | 120 A |
| Filler rate (mm/s)         | 27 mm/s | 27 mm/s | 27 mm/s |
| Filler diameter (mm)       | 0.8 mm | 0.8 mm | 0.8 mm |
2.2 Thermal cycles

Thermal cycle measurement was carried out by installing four type-K wire thermocouples as illustrated in Fig. 2. The data being obtained were then analyzed using an NI USB-9162 hardware from National Instrument and the result was displayed using the Signal Express 2010 software and further calculated using the Microsoft Excel software to produce thermal cycle curves.

Fig. 2. Specimen cut showing thermocouple, right to left: BM (base metal), HAZ (heat affected zone), PMZ (partially melted zone), weld metal (WM), and dial indicator location at welding specimen.
2.3 Distortion Patterns

The distortion of the welding results were measured along x-axis, i.e. along the welding line, on a milling machine table in z-axis direction, i.e. perpendicular to weld surface, using a dial indicator possessing an accuracy of 0.001 mm attached to a magnetic base stand. The measurement was done every 10 mm long of las deposit. Along y-axis the measurement were done every 12.5 mm as presented in Fig. 3. The data being obtained were then calculated using Microsoft excel software for 3D surface plotting.

![Distortion points measurement](image)

2.4 Macro and microstructure, Vickers hardness, Tensile, and bending test

Tensile and bending test were carried out using a 20-T capacity Servopulser machine and Torse universal testing machine. Observation of macro and microstructures were carried out by means of an optical microscope (OM), and a scanning electron microscope (SEM). The points being observed were the weld metal (WM), partially melted zone (PMZ), and heat affected zone (HAZ) as shown in Fig. 2. Micro Vickers hardness test was done using a 100-g load after the AA5083H116 specimen were welded using untack and tack T-MIG weld, and S-MIG tack welding process using ER5356 electrode.

3. Results and Discussion

3.1 Temperature distributions

The best weld result was obtained when at electrode distance being 18 mm of the untack weld and tack weld T-MIG, and at 8 mm/s welding speed of the Single-MIG as has been illustrated in Fig. 4. The distribution of peak temperature has also been illustrated in Fig. 5. The highest peak temperature was obtained at 328.8°C for the T-MIG tack weld, and 282.8°C for the T-MIG untack weld, where 46°C difference were noticed where the heat input was from both leading and trailing torches. The amount of heat input can be calculated using $q = \eta \frac{VI}{v}$ where $\eta$ is welding efficiency, i.e. tensile strength of welded divided with that of the as received material, $V$ is voltage in Volt, $I$ is the current in A, and $v$ is welding speed in mm/s. The welding parameters were set the same for both tack weld and untack weld T-MIG, but resulted in 46°C peak temperature difference. This difference may be caused by the current setting was being manual and current fluctuation of the MIG welding cannot be avoided due to the melting process at the electrode tips then the drop of melted weld deposit continuously happened during the welding process.
Fig. 4 Thermal cycles: (a)-(b) T-MIG untack weld and T-MIG tack weld with electrode distance of 18 mm and welding speed of 12.5 mm/s, (c) S-MIG tack weld with welding speed of 8 mm/s.
Table 2. Peak temperatures

| Welding methods     | Thermocouple temperatures (°C) |
|---------------------|--------------------------------|
|                     | 1     | 2      | 3      | 4      |
| T-MIG untack weld   | 282.8 | 183.1  | 143.8  | 111.0  |
| T-MIG tack weld     | 328.8 | 207.9  | 143.3  | 122.4  |
| S-MIG tack weld     | 254.0 | 166.6  | 128.0  | 101.8  |

Fig. 5. Peak temperature distributions (°C) vs distance from weld center (mm) of T-MIG untack weld and T-MIG tack weld with d=18 mm, and S-MIG tack weld from Fig. 4 (a-c).

3.2 On line bending distortion

Fig. 6 shows displacement pattern during untack and tack T-MIG welding, and S-MIG tack welding. The untack T-MIG welding exhibited positive displacement, the magnitude of displacement increased with the increase of time showing that the welded materials had gained more heat than they released though there was no change in heat input. For the T-MIG tack welding, the displacement was observed to negative direction and smaller magnitude. For the S-MIG tack weld, the displacement was in positive-negative-positive direction forming a sine curves with 0.22 mm minimum peak. There was fluctuation in heat input due to instability of the power supply where the magnitude of the current was fluctuated. Fig. 6 shows that the welding time for 300 mm long deposit for the T-MIG tack weld is 24 seconds and that for the S-MIG tack weld is 38 seconds, thus, there is a 37% shorter time.

Fig. 6. Experimental development of displacement at dial indicator point, u: T-MIG untack weld and T-MIG tack weld, and S-MIG tack weld
3.3 Distortion Patterns

Fig. 7 shows the 3D distortion for (a) T-MIG untack weld, (b) T-MIG tack weld, and S-MIG tack weld. The distortion of the T-MIG untack weld was observed downward, while that of the T-MIG tack weld was upward or bowing with slightly larger distortion for the T-MIG tack weld. This may be caused by peak temperature of the T-MIG tack weld being 46°C higher than that of the T-MIG untack weld, different from that of the S-MIG tack weld which distorted downward with smaller magnitude. Such phenomena may be caused by the peak temperature of the S-MIG tack weld being 75°C lower than that of the T-MIG tack weld, such that the amount of heat input being smaller leading to smaller distortion. T-MIG tack welding resulted in bowing (upward distortion) with peak temperature being ~328.8°C at 10 mm distance from welding line, while that of the T-MIG untack weld the distortion was downward with peak temperature being ~282.8°C. Therefore, tack weld of the specimens affected the magnitude of the on line displacement and the magnitude of the distortion after welding.
3.4 Macrostructures and microstructures

Macrostructures of the T-MIG untack weld, T-MIG tack weld, and S-MIG have been presented in Fig. 8 (a), (b), (c). Fig. 8 (a) shows a lack of penetration on lower left side due to movement farther from the weld center during the welding. This result is consistent with that showed in Fig. 6 for the T-MIG untack weld where $u_z$ displacement has been developed until the completion of the welding. Fig. 8(b), the T-MIG tack weld $u_z$ displacement being the smallest in comparison with that of T-MIG untack weld, and better fusion can be observed, but some porosity can be found that may be caused by the lack of argon gas flow rate causing intrusion of oxygen from its surrounding. This has been confirmed by the SEM and EDS as presented in Fig. 9, where ‘EDS spot’ (red color) analysis shows 24.13 wt% oxygen (O) content and part of it reacts with the base metal to produce $\text{Al}_2\text{O}_3$ and the other part forms porosity. At this spot, Al and Mg produce $\text{Al}_3\text{Mg}_2$ precipitate. SEM image shows porosity, micro cracks due to different cooling rate between larger and finer grains, as well as columnar structure at WM. Macrostructure of Fig. 8(c) where there was a misalignment between the two plates being welded, this was confirmed by Fig. 6 for S-MIG tack weld where $u_z$ sines wave displacement can be observed.
In correlation to macrostructure (Fig. 8), Vickers hardness can be divided into weld metal (WM), partially melted zone (PMZ), heat affected zone (HAZ), and base metal (BM). Weld metal was indicated by dark spots that may be porosity due to the technical argon gas being used may contain oxygen as has been explained earlier. The PMZ obtained from this process was the same as previously reported [7].
Microstructures of WM, PMZ, and HAZ regions have been depicted in Fig. 10. PMZ of untack T-MIG weld and tack weld, as well as S-MIG show different microstructures in comparison with those of WM. The microstructure of PMZ tends to be equiaxed, whole that of WM are columnar and equiaxed structure. In correlation with Vickers microhardness (Fig. 11), PMZ and WM possess considerably similar hardness, and transition can be observed in HAZ that may be caused by partial recrystallization of the 5083H116 base metal due to heating during the welding.
3.5 Vickers hardness test

The result of Vickers micro-hardness test has been depicted in Fig. 11. The hardness of the T-MIG untack weld, T-MIG tack weld, and S-MIG tack weld tend to possess similar values for BM, HAZ, PMZ and WM. For the T-MIG untack weld, the hardness was found being fluctuated that can be caused by inhomogeneous grain size being among indentation points. According to Hall and Petch equation, finer grain will result in higher hardness. Average widths of the untack T-MIG weld are ~7.0 mm, ~1.0 mm, ~4.5 mm for the WM, PMZ and HAZ, respectively. Those of the tack T-MIG weld are ~9.0 mm, ~1.0 mm, and ~7.5 mm for the WM, PMZ and HAZ, respectively. While those of the tack S-MIG weld are ~6.0 mm, ~7.0 mm and ~4mm for the WM, PMZ, and HAZ, respectively. The hardness of the three welding procedures was found being noticeably proportional with that of tensile and flexural test result as presented in Fig. 12 and Fig. 13.

Fig. 10 Microstructures at HAZ, PMZ, and WM zone: (a) T-MIG untack weld, (b) T-MIG tack weld, and (c) S-MIG tack weld
3.6 Tensile tests

Tensile test result has been presented in Fig. 12. The T-MIG tack weld resulted in 16% higher tensile strength compared to that of the T-MIG untack weld, but 6% lower than that of the S-MIG tack weld, and 24% lower than that of the as received material. Thus, the efficiency of the T-MIG tack weld, 76%, is still applicable for being used in welding of AA5083H116 plates of ship structures.

3.7 Bending test

The result of flexural test has been presented in Fig. 13. The strength of the face and root bending for the T-MIG tack weld is similar with that of the T-MIG untack weld and S-MIG tack weld, and 75% of the bending strength of as received materials. During the bending, the outer face suffers tension and the inner face suffers compression, so that they are in good agreement with those of tensile test of the T-MIG tack weld for 76% weld efficiency, and the test are valid and reliable.
4. Conclusions

Based on the test and analyses, the following conclusions can be drawn.

1. Whilst the distortion of T-MIG tack weld distorts upward (bowing), that of the T-MIG untack weld distorts downward.

2. Tensile strength of T-MIG tack weld were found being 16% higher than that of T-MIG untack weld where the tensile weld efficiency being 76% and consistent with bending weld efficiency being 75% with respect to those of respective as received material.

3. T-MIG tack welding can save welding time up to 37% based on the distortion measurement time during the welding.

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6. References

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