Research on Microstructure and Mechanical Properties of CMT and MIG Welded Joints of A6N01 Aluminum Alloy

Hongguang Wang* and Shengbo Cen
Liuzhou Railway Vocational Technical College, No.2, Wenyuan Road, Yufeng District, Liuzhou City, Guangxi, 545616, China
*Email: 26784839@qq.com

Abstract. Cold metal transition welding (CMT) and molten inert gas shielded welding (MIG) two welding processes were used to conduct butt welding tests on 2mm thick 6N01 aluminum alloy, and the microstructure and mechanical properties of the welded joints obtained by the two processes were tested. The results show that the welded joints of 6N01 aluminum alloy welded by CMT process have better appearance and less welding defects and welding spatter. The tensile strength of CMT welded joints is 213MPa and the elongation after fracture is 10.64%, which is slightly higher than that of MIG welded joints. The hardness distribution of CMT and MIG welded joints and the hardness values of each zone are basically the same. Compared with MIG welded joints, the grain structure of CMT welded joints and the equiaxed crystals on the side of the fusion zone near the base metal are smaller and more uniform.

1. Introduction
6N01 aluminum alloy has good extrusion formability and excellent weldability, and is widely used in the production of subway and high-speed train car bodies [1-2]. At present, domestic manufacturers mainly adopt molten inert gas shielded welding (MIG) method for the welding of thin walled hollow extruded 6N01 aluminum alloy profiles [3]. The MIG welding process is widely used in various industries due to its economic and high-efficiency advantages. However, due to its high heat input, unavoidable spatter, severe welding deformation, large residual stress after welding, and wide heat-affected zone, it will reduce the stability and dimensional accuracy of the welded structure, thereby limiting its application in some fields, especially welding thin plates below 1mm is a difficult problem to solve [4-5]. In order to solve these problems caused by MIG welding, Fronius had developed a cold metal transfer (CMT) welding technology suitable for thin plate welding, low heat input, and no slag spatter [6]. CMT welding technology has many advantages for the welding of aluminum alloy thin plates. Junjing Zhao et al. [7] comparatively studied on the CMT and MIG welding processes of 5A06 aluminum alloy sheet, and found that the joints obtained by CMT welding process had better appearance, less welding defects, less heat input, less spatter, and easy cleaning after welding. The welding deformation was smaller than that of MIG welding, and the grain microstructure was more uniform. Jinxu Zhou et al. [5] studied the microstructure and properties of 6005A aluminum alloy CMT and MIG welded joints, and found that the tensile strength of CMT welded joints was slightly higher than that of MIG welded joints, the fracture surface was ductile fracture morphology, and the weld microstructure size even smaller. Hongkun Yuan et al. [8] conducted a comparison of CMT and MIG aluminum alloy welding processes. The test results showed that the CMT process had a small amount of angular deformation after welding, the weld surface was well formed, the welding spatter was low, the pores are less, and the mechanical properties were slightly improved. CMT process could...
complete high-quality welding of 1mm thick aluminum alloy sheet. Liu Qiang et al. [9] studied the effect of wire feeding speed on the performance of 6061 aluminum alloy CMT welded joints, and found that with the increase of wire feeding speed, the width of the heat-affected zone of CMT joints increased, and the weak area of the entire welded joint was the heat-affected zone.

This article mainly focuses on CMT and MIG welding of 6N01 aluminum alloy, compares the microstructure and mechanical properties of the welded joints of the two welding processes, and provides data support for the application of CMT welding process on 6N01 aluminum alloy thin-walled profiles.

2. Test Materials and Methods

2.1. Test Materials and Welding Process

The material used in this article is 6N01 extruded profile, and the processing state is T5. The extruded profile is processed into an aluminum plate with a size of 200mm×140mm×2mm by wire cutting, and the welding filler material is selected from the aluminum alloy wire with the brand of ER5356, and the diameter of the wire is Ф1.2mm. The chemical composition of the base metal and welding wire is shown in Table 1. The welding is formed by butt welding of two aluminum plates, the welding aluminum plate does not open grooves, the pairing gap is 0.8mm, and the single-sided welding is formed on both sides. The welding shielding gas is 99.999% high-purity argon, and the shielding gas flow rate is 25L/min. P-CMT (pulse CMT, hereinafter referred to as CMT) welding equipment is TransPuls Synergic 4000 welding machine, welding process parameters are: wire feeding speed 5.5mm/s, welding speed 6.8mm/s, welding current 78A, welding voltage 16.2V; The equipment used in MIG welding is Kemp Arc-450 pulse welding machine, the welding process parameters are: wire feeding speed 6.5mm/s, welding speed 8.0mm/s, welding current 102A, welding voltage 18.2V.

| Material   | Si     | Fe  | Cu  | Mn  | Mg    | Cr  | Zn  | Ti  | Al |
|------------|--------|-----|-----|-----|-------|-----|-----|-----|----|
| A6N01      | 0.40   | ~   | 0.3 | 0.0 | 0.5   | 0.40 | 0.3 | 0.2 | 0.1 | Bal |
| 0.90       | 5      | 5   | 0   | 0.80| 0     | 0   | 5   | 0   | Bal |
| ER5356     | 0.10   | 0.4 | 0.1 | 0.1 | 4.80  | 0.1 | 0.1 | 0.1 | Bal |
| 0          | 0      | 0   | 5   | 0   | 0     | 0   | 3   | .   | .  |

2.2. Experiment Methods

After the test plates were welded, the welded test pieces were processed into tensile specimens, hardness specimens and metallographic specimens by wire cutting for mechanical performance testing and microstructure observation. The Zeiss-AIM metallurgical microscope was used to observe the metallographic structure of the joint. The corrosive solution used for joint corrosion was a mixed acid solution. The HVS-30D vickers hardness tester was used to test the joint hardness. The test points were distributed sequentially from the center of the weld to the base metal area on both sides, the test point interval was 1 mm, the loading load was 3 kg, and the load duration was 15 s. The tensile test adopts DNS300 universal tensile testing machine, and the tensile rate is 3mm/min.

3. The Results and The Discussion

3.1. Macroscopic Observation of Weld Seam Formation

Table 2 shows the surface forming conditions of CMT and MIG welded joints. It can be seen that compared to MIG welds, CMT welds are well formed and fused. The fish scales are very obvious, dense and beautiful, with less spatter and narrow weld width. The back of the weld was completely penetrated, and no defects such as weld cracks, incomplete penetration, undercut, and lack of fusion.
were found. The weld seam of MIG welding has high weld reinforcement, visible fish scales, splashes, and full penetration on the back.

Table 2. Surface forming of 6N01 aluminum alloy CMT and MIG welded joints.

| Welding method | Face of weld/back of weld | Weld surface formation |
|----------------|---------------------------|-----------------------|
|                | Face of weld               |                       |
| P-CMT          | Back of weld               |                       |
|                | Face of weld               |                       |
| MIG            | Back of weld               |                       |

3.2. Microstructure Observation

Figure 1 shows the microstructure of the base metal, welded metal, and the fusion zone of the 6N01 aluminum alloy CMT and MIG weld joints. Figure 1 (a) and (b) show the microstructure of the 6N01 aluminum alloy base metal. The base metal is a typical recrystallized structure and is equiaxed. The fiber orientation after extrusion processing can still be seen. There are many precipitated phases in the shape of dots, strips and rods in the base metal [2]. Figure 1(c) and figure 1(d) are the microstructure of CMT and MIG weld metal respectively. The weld metal microstructure of the two welding processes are all typical equiaxed dendritic as-cast structures. The weld metal mainly composed of equiaxed dendrites. α(Al) solid solution is the matrix, and α(Al)+Mg eutectic structure is mainly distributed between the grain boundaries and dendrites of α(Al), and there are also Mg2Si particles precipitated in the crystal [1]. Compared with the weld metal of MIG welding, the dendrite structure of CMT weld metal is finer. This is due to the lower welding heat input of the CMT welding process. The rapid cooling during the welding process makes the weld dendrite structure too late to grow. The cooling rate will also lead to higher undercooling of the weld and higher nucleation efficiency, thereby hindering the growth of grains [5]. Figure 1(e) and figure 1(f) show the microstructure of the fusion zone of CMT and MIG weld joints. Comparing the fusion zone microstructures of the two joints, it can be seen that the side of the fusion line close to the weld is coarse columnar grain, and the side close to the base metal is equiaxed crystals. The size of equiaxed grain of CMT weld joint fusion zone which is close to the base metal side is obviously smaller than that of MIG weld joint. This is mainly due to the low heat input of CMT welding, and the equiaxed crystal near the base metal of the fusion line does not have enough energy to grow, while the large heat input of MIG welding allows the equiaxed crystal to have sufficient energy and time to grow.
3.3. Mechanical Properties

Table 3 shows the tensile test results of CMT and MIG welded joints. It can be found from table 3 that the average tensile strength of CMT and MIG welded joints are 213MPa and 209MPa, respectively. The average values of elongation after fracture were 10.64% and 9.65%, respectively. The tensile fracture positions of welded joints of the two processes were mainly in the heat-affected zone. The tensile strength of CMT and MIG welded joints reached 69.6% and 67.6% of the base metal, and the elongation after fracture reached 84.7% and 76.8% of the base metal, respectively. This indicates that the tensile strength and elongation after fracture of CMT welded joints are slightly higher than that of MIG welded joints.

(a) (b) Base metal; (c) Weld metal of CMT; (d) Weld metal of MIG; (e) Fusion zone of CMT; (f) Fusion zone of MIG

**Figure 1.** Microstructure of CMT and MIG welded joints.
Table 3. Tensile test results of CMT and MIG welded joints of 6N01 aluminum alloy.

| Welding method | Sample No | Tensile strength Rm/MPa | Fracture position | Elongation A5/\% |
|----------------|-----------|-------------------------|-------------------|-----------------|
|                |           | Single value | Average value     | Single value | Average value |
| CMT            | 6-1       | 213          | 215               | HAZ          | 10.32         |
|                | 6-2       | 215          | 215               | HAZ          | 11.15         | 10.64         |
|                | 6-3       | 218          | 215               | HAZ          | 10.46         |
|                | 6m-1      | 223          | 215               | WM           | 10.12         |
| MIG            | 6m-2      | 202          | 209               | WM           | 9.20          | 9.65          |
|                | 6m-3      | 204          | 209               | HAZ          | 9.64          |
| Base metal     | B-1       | 309          | 309               | BM           | 12.56         | 12.56         |

Figure 2 shows the actual tensile specimen fracture location of the joints of the two welding processes. It can be seen from figure 2 that all tensile specimens fractured in the heat-affected zone, which is the weakest region of the welded joint.

Figure 3 shows the comparison of the hardness test results of CMT and MIG welded joints. It can be seen from figure 3 that the hardness distributions of the 6N01 aluminum alloy CMT welded joints and MIG welded joints are approximately symmetrically distributed in pairs with the centerline of the weld as the axis. In the entire joint, the hardness value of the weld metal is the lowest, about 50-60HV, the hardness value of the base metal zone is the highest, about 100-115HV, and the hardness value of the heat-affected zone is between the WM and BM, about 60-100HV. The distribution trend of the hardness value of CMT and MIG welded joints is first rise, then fall and then rise. There is a soft zone with a width of about 3mm, which is 10mm from the center of the weld. The hardness value of this zone is the lowest in the entire heat affected zone, which is the weakest area of the entire joint, the tensile fracture is mostly located in this zone. According to the comparison, it is found that the hardness distribution rules and hardness values of the joints obtained by the two welding processes are not much different, but the width of the heat-affected zone of the MIG welded joint is slightly wider. This is because the heat input of MIG welding is larger, the temperature gradient is wider, which results in a wider heat-affected zone.
4. Conclusions
The microstructure and mechanical properties of welded joints obtained by CMT and MIG welding processes were compared. The significant findings are drawn as follows.

1) Compared with MIG welding, 6N01 aluminum alloy welded joints with CMT welding process have better appearance, dense and beautiful fish scales, and less welding spatter.

2) From the comparison with the microstructure of the MIG welding joint, it can be seen that the grain structure of the weld metal of the CMT joint is smaller and uniform, and the equiaxed grain size of the fusion zone near the base metal side is smaller. This is due to the low heat input of the CMT welding process.

3) The average tensile strength of CMT and MIG welded joints are 213MPa, 209MPa, and the average elongation after fracture are 10.64% and 9.65%, respectively. The tensile strength and elongation after fracture of CMT welded joints are slightly higher than that of MIG welded joints.

Acknowledgements
This work was supported by the Project to Enhance the Basic Research Ability of Young and Middle-aged Teachers in Guangxi Universities (No. 2020KY44002).

References
[1] Zhu R D, Ma C P and Xu X L 2018 Electric welding machine 48 76-79
[2] Yang S L and Lin Q L 2012 The Chinese Journal of Nonferrous Metals 22 2720-2725
[3] Ye J H and Yang S L 2013 Electric welding machine 43 39-41
[4] Ren S M, Liu Q Y, Mao X D and Zhao P Z 2019 Light alloy fabrication technology 47 62-65
[5] Zhou J X, Li Y, Yang Y, Lin C D, Qi P P and Zhang C X Nonferrous Metals Processing 49 22-25
[6] Zhang M, Li N L, Lv J Q and Xu H B 2010 Welding & Joining 12 25-27
[7] Zhao J J, Dong J T, Liu Z B, Zhao X D, Li Z and Liu Y 2019 Welding Technology 48 44-47
[8] Yuan H K, Wei B Q, Guo Y K and Xu Y J 2018 Aluminium Fabrication 1 56-60
[9] Liu Q, Zhang Y X and Zhang N N 2016 Hot Working Technology 45 222-224