Experimental study on Tig welding properties of 6061 and 7003 aluminum Alloys

Qiang Zhu1, Han Yu1, Jiquan Zhang1, Miao Li1 and Xiaoguang Hu2*

1 Guangzhou Power Supply Bureau of Guangdong Grid Co, Guangzhou, 510000, China
2 China Electric Power Research Institute, Beijing, 100055, China
*Corresponding author’s e-mail: huxiaoguang@epri.sgcc.com.cn

Abstract. High Strength Aluminum Alloy is usually used in transmission line rush-repair tower to meet the requirements of component strength and structure weight. Aluminum Alloy has different composition and heat treatment state, and its properties vary greatly. In this paper, Al-Mg-Si Alloy 6061-T6 and Al-Zn-Mg Alloy 7003-T6 are selected to test. The test was carried out to reseach the Weldability of two kinds of Aluminum Alloy, with two Specifications and two kinds of welding wire. The purpose of this paper is to provide a reference for the selection of materials and the connection of members in the emergency repair tower of Aluminum Alloy.

1.Introduction
The density of high strength aluminum alloy material is about 1/3 of steel, and the elastic modulus is about 1/3 of steel. It is very convenient for the construction of high strength aluminum alloy material and can reduce labor cost and transportation cost. Aluminum Alloy has high strength, can approach or exceed high-quality steel. The corrosion resistance of aluminum alloy is much better than that of steel, which can not only improve the metal texture of aluminum alloy, but also greatly improve the surface hardness, corrosion resistance and wear resistance of aluminum alloy.

High Strength Aluminum Alloy is usually used in transmission line rush-repair tower to meet the strength requirement and the limit of structure weight. In this paper, 7003-T6 and 6061-T6 are selected to carry out the test of two kinds of material thickness and two kinds of welding wire[123], and the welding properties of two kinds of aluminum alloys are studied and compared.

The mechanical properties of 7003-T6 and 6061-T6 base materials are shown in table1, including tensile strength, specified non-proportional elongation strength and elongation at break.

| Alloy     | Tensile strength /MPa | Specified non-proportional extension strength /MPa | Elongation ratio /% |
|-----------|------------------------|---------------------------------------------------|---------------------|
| 7003-T6   | 350                    | 290                                               | 8                   |
| 6061-T6   | 260                    | 240                                               | 7                   |

2.Welding Test Plan
In the welding of aluminum alloy structure, the two most widely used methods are TIG and MIG, which have been developed for a long time. These two methods are also recommended in the main aluminum alloy structure codes abroad. During TIG welding, the solid-liquid Transition Between Base metal and
weld metal is a static equilibrium process, the welding process is easy to control, the forming quality is easy to be guaranteed, and the strength of welded joint is high. Therefore, in the aerospace industry, for the important structure, especially the sky structure, the ministry issued the standard mandatory requirements must use TIG welding. MIG welding method requires much less welding current, automatic, semi-automatic MIG welding than TIG welding has a much higher productivity. However, in the process of MIG welding, the solid-liquid transition between the Base metal and the weld metal is a Dynamic equilibrium process, which can be broken by chance, such as the non-uniform movement or sloshing of the welder’s torch, the quality of welding is affected. Therefore, in general, the joint quality of MIG welding is not as good as that of TIG welding with the same welding wire. Because there are few applications of welding aluminum alloy components in China, there are few researches on welding technology of aluminum alloy. Therefore, the TIG welding technology which is widely used in aerospace industry and has mature technology is selected in this test.

Test Material: 7003-T6, 6061-T6
Sample size: 153mm*200mm*4mm, 153mm*200mm*6mm
Welding current[3]: 120~140A
Type of welding wire: 5356 Welding wire /5183 Welding wire
Welding speed: 200mm/min

According to the welding test plan, the samples of 4mm and 6mm thick plates were extruded and the welding samples were carried out. 4mm sample can be welded directly, as 6mm thickness sample can not be welded through, so the groove was made after welding, as shown in figure1. The weld sample is shown in figure1.

![Image 1](image1.png)

(a) 4mm thickness sample flat welding (b) 6mm thickness sample groove welding

Figure 1 weld shape flat/groove

![Image 2](image2.png)

(a) 6061 Alloy Tig welding (b) 7003 Alloy Tig welding

Figure 2 Tig welding sample of each alloy

3. Test results
Take 3 parallel specimens for each set of process conditions and test them for mechanical properties. The average properties of the tested data are shown in table 2 below. The weldability of Alloy Tig welding can be expressed by the strength Coefficient of welded joint (the ratio of tensile strength of welded joint
to tensile strength of base metal).

Table 2 Weldability of Aluminum Alloy

| Alloy | Welding process | Tensile strength of substrate /MPa | Tensile strength of welded sample /MPa | Strength factor of welded joint |
|-------|-----------------|-----------------------------------|--------------------------------------|---------------------------------|
| 7003  | 4mm-5356 Welding wire | 365                               | 199                                  | 54.5%                           |
|       | 4mm-5183 Welding wire | 365                               | 185                                  | 50.7%                           |
|       | 6mm-5356 Welding wire | 368                               | 115                                  | 31.3%                           |
|       | 6mm-5183 Welding wire | 368                               | 113                                  | 30.6%                           |
| 6061  | 4mm-5356 Welding wire | 273                               | 192                                  | 70.3%                           |
|       | 4mm-5183 Welding wire | 273                               | 187                                  | 68.6%                           |
|       | 6mm-5356 Welding wire | 285                               | 175                                  | 61.4%                           |
|       | 6mm-5183 Welding wire | 285                               | 169                                  | 59.3%                           |

Magnify the welding seam of alloy 5356 welding wire welded sample 50 times and 200 times and there are different degree of porosity and micro-cracks in the weld microstructure[456]. The metallographic observations are shown in figure 3.

4. Analysis of test results

According to the test data, the results are as follows:

(1) Under the same welding process, 6061 alloy has better weldability, then 7003 alloy;
(2) The extrusion profiles with the same alloy thickness of 4mm have better properties than those with 6mm thickness, which indicates that the aluminum alloy with larger thickness may have incomplete penetration or large welding defects;
(3) The welding quality of 5356 wire is better than that of 5183 wire under the same welding conditions, but the joint strength of both wires is lower[7].

The most common defect in fusion welding of Aluminum and its alloys is weld porosity. During Tig
welding, when the penetration is not enough, the water absorbed in the oxide film which is not removed from the base metal groove root is often the main cause of weld porosity. Such an oxide film not only provides a source of hydrogen, but also allows bubbles to clump together. When the molten pool is just formed, if the oxide film near the groove is not completely melted and remains, the water in the oxide film will decompose hydrogen due to heating, and will form bubbles on the oxide film; because the air bubble is attached to the residual oxide film, it is not easy to detach and float out, and because the air bubble is formed in the early stage of melting and has the condition to grow, it often creates several forms of big air hole. Such porosity is more serious when the weld root has not fused. The pores caused by oxide film at the end of the groove are usually distributed along the original edge of the fusion zone, and the inner wall is of oxidation color, which makes it an important feature.

Heat affected zone (Haz), for the aging strengthened alloy, the main performance is the loss of strengthening effect, namely softening[8]. This is mainly due to the “over aging” softening of the Haz. This is an inevitable phenomenon in fusion welding. The degree of severity depends on the properties of the second phase of the alloy and is also related to the welding thermal cycle. The most fundamental is the sensitivity of the second phase to the aging reaction. The more easily the second phase is melted out and aggregated, the more likely it is to be “over-aged”, which leads to the sharp decrease of the strength of the welded joint.

5. Conclusion
(1) Considering the welding equipment, processing cost and production technology, TIG welding is more suitable for the welding of Aluminum Alloy repair tower structure;

(2) The welding quality of 5356 welding wire is better than that of 5183 welding wire when the high strength aluminum alloy 6061-T6 and 7003-T6 of transmission tower are welded;

(3) For 7003-T6 alloy TIG welding, the tensile strength welding coefficient of 4mm thickness welding sample is 54.5%, and the tensile strength welding coefficient of 6mm thickness groove welding sample is 31.3%; for 6061-T6 alloy TIG welding, the tensile strength welding coefficient of the 4mm thickness welded sample is 70.3%, and the tensile strength welding coefficient of the 6mm thickness groove welded sample is 61.4%.

Acknowledgments
This study was financially supported by "Research and application of Emergency Restoration System for overhead transmission lines” (Grant No. GZHKJXM20180109), Science and technology project of China Southern Power Grid.

References
[1] Li Y, Murr L E, McClure J C. Flow visualization and residual microstructures associated with the friction-stir welding of 2024 aluminum to 6061 aluminum[J]. Materials Science & Engineering A, 1999, 271(1-2):213-223.

[2] Zhu Z, Li Y, Zhang M, et al. Effects of stress concentration on the fatigue strength of 7003-T5 aluminum alloy butt joints with weld reinforcement[J]. International Journal of Modern Physics B, 2015.

[3] Yong H, Ding F, Qinghua F. Study of mechanism of activating flux increasing weld penetration of AC A-TIG welding for aluminum alloy[J]. Chinese Journal of Mechanical Engineering, 2006, 2(004):442-447.

[4] Manti R, Dwivedi D K. Microstructure of Al–Mg–Si Weld Joints Produced by Pulse TIG Welding[J]. Advanced Manufacturing Processes, 2007, 22(1):57-61.

[5] Pan P, Jun-Jie L, Ji M A. Influence of welding parameters of pulse TIG on weld microstructure and mechanical property of aluminum alloys[J]. Journal of Rocket Propulsion, 2013.

[6] Keng Y, Zhiquiang S, Xiling W. Influence of heat treatment on microstructure and mechanical properties of spray formed 7xxx series aluminum alloy TIG weld joint[J]. Transactions of the china welding institution, 2012.
[7] Haeufgloeccker J. Determination of a quality of an aluminum weld[J]. 2018.
[8] Jinguo Z. Effects of Post Weld Heat Treatment on Strength and Stress Corrosion Resistance of AA7003 Aluminum Alloy Welded Joints[J]. Hot Working Technology, 2019.