Influence of Filler Wire Feed Speed on Microstructure and Properties of MIG Welding of 7005 Aluminum Alloy

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Abstract. Metal inert-gas welding (MIG) test was carried out using ER5356 welding wire as filler metal and 7005 aluminum alloy plate as base material. Different welding samples were obtained by changing the filler wire feed speed, and their microstructure and mechanical properties were observed and tested. The results show that the MIG welding joint of 7005 aluminum alloy usually consists of 3 parts: welding metal, heat affected zone and base material zone. The lowest hardness of the MIG welding joint is in the weld seam, which is the weakest position of the welding joint. The largest tensile strength of all the test samples is 303Mpa, which is 76.3% of the tensile strength of the base metal. The tensile fracture mode of all the test samples is dimple fracture, and the dimple fracture of the sample with a filler wire feed speed of 9.8m/min is small and dense, with the deepest depth of all the samples.

1. Introduction
Aluminum alloy has the characteristics of low density, good corrosion resistance and easy processing [1-3]. It is the main lightweight material in the aerospace industry as well as bridges, buildings and other civilian industry [4, 5]. 7005 aluminum alloy belongs to Al-Zn-Mg series alloy which can be strengthened by heat treatment [6-8]. It not only has good mechanical properties, corrosion resistance, thermal stability and weldability, but also has good extrusion performance and on-line quenching performance. It can be extruded into various complex large thin-walled hollow profiles, which can be used as body materials for high-speed trains, Metro trains, urban light rail cars and automobiles. It greatly reduces the weight of the vehicle, improves the running speed of the vehicle, and obtains comprehensive economic and social benefits.

Metal inert-gas (MIG) welding is being widely utilized to join 7005 aluminum alloy [9-11]. However, the properties of 7005 aluminum alloy after welding are affected by many factors, among which filler wire feed speed is an important factor [12, 13]. This is due to the influence of welding heat input in the welding process, the weld structure will change significantly, which will seriously affect the overall strength of 7005 aluminum alloy welded structural parts. Therefore, using MIG welding technology as a tool and ER5356 welding wire as filler metal, butt welding experiments of 7005 aluminum alloy sheet were carried out to explore the influence of welding parameters, especially filler wire feed speed, on the performance of MIG welding joint.
2. Experimental Procedures

2.1. Experimental Materials
As-extruded 7005 aluminum alloy sheet with 5 mm thickness is used as the welding base material, and the filler metal is ER5356 with a 1.2 mm diameter. Chemical composition of 7005 aluminum alloy and ER5356 filler metal are presented in table 1.

| Material                  | Mass fraction(%) |
|---------------------------|------------------|
|                           | Al   | Zn   | Mg   | Cu   | Si   | Fe   | Mn   | Cr   | Ti   | Zr   |
| 7005 aluminum alloy       | Bal. | 4.43 | 1.63 | 0.06 | 0.09 | 0.15 | 0.49 | 0.12 | 0.03 | 0.14 |
| ER5356 filler metal       | Bal. | 0.09 | 4.92 | 0.015| 0.13 | 0.14 | 0.138| 0.102| 0.102| -    |

2.2. Experimental equipment and Methods
The welding machine selected in the test is Aristo MIG 5000 welding equipment produced by ESAB Company of Sweden. Before the test, the oxide film on the surface of aluminum alloy sheet is removed by a corner mill within 10 mm from the weld seam, so that the sample shows metallic luster, then it is cleaned with acetone and dried to be welded. Type I butt welding with 2 mm gap is selected. The synergic-pulsed MIG process parameters were listed in table 2.

| Sample No. | Welding current/A | Welding voltage/V | Wire Feed Speed/m min⁻¹ | Argon gas flow/L min⁻¹ |
|------------|-------------------|-------------------|--------------------------|------------------------|
| 1#         | 149               | 22.5              | 8.6                      | 16                     |
| 2#         | 151               | 22.7              | 9.2                      | 16                     |
| 3#         | 154               | 23.2              | 9.8                      | 16                     |
| 4#         | 156               | 23.5              | 10.6                     | 16                     |

After welding, the samples were cut from the MIG welding joint using a line cut machine. After grinding and polishing, the metallographic specimens were corroded by Kohler reagent (1%HF+1.5%HCl+2.5%HNO₃+95%H₂O). Microstructure was observed by means of Leica DMI 5000M metallographic microscope. Micro-hardness test were conducted across the welds using a KB30S type Vickers hardness tester with a load of 200 g and a dwell time of 10 s. Tensile test was performed according to the GB/T 2651-2008[14]/ISO 4136:2001 standard[15]. Tensile test were carried out in SHIMADZU 100 kN electronic universal testing machine. FEI Inspect S50 type scanning electron microscope (SEM) was used to observe the tensile fracture morphology.

3. Results and Discussions

3.1. Microstructure
The microstructure of the welding joint is shown in figure 1. The MIG welding joint of 7005 aluminum alloy usually consists of 3 parts: welding metal (WM), heat affected zone (HAZ) and base material zone (BM). As can be seen from figure 1, there are areas with different color shades in all the welding tissues. This is because the base metal and other areas of the corrosion time are different; the base metal needs a longer time to corrosion so that the grain boundary can be clearly displayed. The grain size in the heat-affected zone is several times larger than that of the base metal. This is because the heat in the heat-affected zone during the welding process causes the grain size to grow and become coarsened, which is a kind of superheated structure. Moreover, the grain size becomes smaller as the distance from the welding seam increases.
As can be seen from figure 2, with the increase of filler wire feed speed, welding current and welding voltage increase accordingly. According to the expression $E=UI/V$ of the arc input energy during welding, the heat input during welding increases gradually, and the heat conduction becomes more and more remote when the welding cools down. It can be seen from the metallographic structure that the width of the heat affected zone shows an increasing trend. And it is obvious that there are columnar crystals near the fusion line and the columnar crystals are in the direction of heat conduction. However, no columnar crystals were observed near the base metal.

![Figure 1: Microstructures of welding joints.](image)

3.2. **Micro-hardness**

Along the direction of the joint perpendicular to the weld, the joint was measured from the center of the weld to the direction of the base metal every 0.5 mm, and the average value of the three points around each point was measured. Make micro-hardness distribution curve of the joint with Origin software, as shown in figure 3. It can be seen that the micro-hardness values of the four samples were first increased, then decreased and then increased to the base metal hardness. The hardness values of the 4 samples all reached the minimum value in the center of the weld seam, among which the minimum value of the 3# sample was greater than that of the other 3 samples, so the hardness value of the 3# sample was better. The first peak value of hardness is reached near 4.0 mm from the center of the weld. During welding, due to the influence of thermal cycle, the temperature of the base metal exceeds the solid solution temperature of the base metal, so solid solution strengthening occurs at this position, and the hardness value increases. Subsequently, the hardness values of the four samples were all reduced again, which entered the softening zone of the welded joint and was affected by the thermal effect. At this time, the temperature exceeded the aging temperature but did not reach the solid solution temperature, which was similar to the occurrence of over-aging, resulting in the reduction of the hardness value of the material. Then slowly into the base metal area, the micro-hardness value maintained at a stable value, that is, the base metal hardness.
3.3. Tensile test
The tensile properties of the 7005 aluminum alloy and its welding joint were listed in table 3. It can be seen from table 3 that all the order of the tensile strength, yield strength and elongations: 7005 base metal > 7005 welding joint. The tensile samples of welding joint all fail in weld metal, and the strength is much lower than that of base metal. The weld zone is the weakest part in welding joint due to effects of chemical components of filler and crystallization process. The tensile strength of 3# sample is the largest, 303 Mpa, which is 76.3% of the tensile strength of the base metal. The tensile strength of 2# sample is the smallest, 278 Mpa, which is 70.0% of that of the base metal. It can also be seen from figure 2 that a very low value of hardness in the welding metal zone can be obviously observed through the measurement of micro-hardness, so it can be confirmed that the welding metal zone is the place with the worst mechanical properties of the welded joint.

| Sample       | No. | UTS(MPa) | YS(MPa) | A(%) | Fracture Location |
|--------------|-----|----------|---------|------|-------------------|
| 7005 joint   | 1#  | 281      | 212     | 4.6  | WM                |
|              | 2#  | 278      | 197     | 5.9  | WM                |
|              | 3#  | 303      | 221     | 3.9  | WM                |
|              | 4#  | 290      | 200     | 5.4  | WM                |
| 7005-T5(BM)  | -   | 397      | 343     | 14   | BM                |

3.4. Fracture Analysis
The tensile fracture morphology of the welding joint is shown in Fig. 3. It can be seen that the mode of the tensile fracture are all dimple fracture. This indicates that the tensile fracture morphology of the welding joints characterized by ductile rupture. In addition, the fracture shows that there is no porosity or crack. This illustrates that it is not the defects such as the porosity or crack but the low tensile strength which lead the specimens to fracture. When the filler wire feed speed is low (1# and 2# sample), the size of the dimple is relatively large and the depth is relatively shallow. When the filler wire feed speed is high (3# and 4# sample), the size of the dimple is relatively small and the depth is shallow. Comparing with all the dimple fracture of the welding joint, the dimple fracture of the 3# sample is small and dense, with the deepest depth, and the dimple structure is less obvious. This is consistent with the above mechanical property test conclusion.
Figure 3. Micro-hardness of 7005 aluminum alloy joint.

4. Conclusion
The MIG welding joint of 7005 aluminum alloy usually consists of 3 parts: welding metal, heat affected zone and base material zone. The grain size in the heat-affected zone is several times larger than that of the base metal, and the grain size becomes smaller as the distance from the welding seam increases. There are columnar crystals near the fusion line and the columnar crystals are in the direction of heat conduction.

The lowest hardness of the MIG welding joint is in the weld seam, which is the weakest position of the welding joint. The minimum micro-hardness value of the 3# sample was greater than that of the other 3 samples.

The tensile results showed that the weakest part of the whole welding joint was in the welding seam, in which both the tensile strength and yield strength of 3# sample were higher than those of the other 3 samples. The tensile fracture mode of all the 4 samples is dimple fracture, and the dimple fracture of the 3# sample is small and dense, with the deepest depth of all the samples.

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