Effects of Welding Currents on Microstructure and Properties of 5052 Aluminum Alloy TIG Welded Joint

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Abstract. To study the influence of welding current on the welding quality of 5052 aluminum alloy TIG welding, the microstructure, mechanical properties and corrosion resistance of the welded joints obtained under different currents from 100 A to 120 A were discussed. The results showed that when the welding current is 100～120 A, with the increases of welding current, the strength of the welded joint (of 5052 aluminum alloy TIG) increases, while the plasticity decreases.

1. Introduction
5052 aluminum alloy belongs to Al-Mg series aluminum alloy. It has good fatigue performance and welding performance, and it is resistant to marine atmospheric corrosion. Therefore, it is widely used as a welded component in ships [1-2], aviation [3-4] and vehicles [5], etc. Among many aluminum alloy welding methods, friction stir welding [6-9] and laser welding [10-13], which have outstanding welding quality, are studied most. However, friction stir welding is limited to the welding of rotary parts, while laser welding has high energy coupling barriers for highly reflective and highly thermally conductive materials (such as aluminum and copper) [14], which has extremely high requirements for the output power of the laser and beam quality while welding. Therefore, based on practicality and cost considerations, it is still necessary to study other welding methods besides the above two welding methods.

During the process of TIG welding, groove form, fixture and pad design, and welding parameters, etc. directly affect weld formation, welding quality and the strength of the welded joint. Among them, the most important thing is to adjust the welding parameters; in the welding parameters, the welding current plays the leading role. Kumar and other people [15, 16] studied the influence of peak current, base current and welding speed on the welding quality of AA 5456 aluminum alloy plate pulsed tungsten argon arc welding, and found that the welding current has great influence on the melt depth: If the current is too large, the workpiece is easily burnt through; if the current is too small, it may cause incomplete soldering. Xu Zheng [17] used the TIG welding method to weld 7075 aluminum plates at the currents of 160 A and 200 A, and found that the tensile strength was only 219 MPa and 188 MPa, and he did not conduct studies on lower-current welding. Wang Xiling [18] studied the TIG welding process with welding currents of 170 A and 180 A; Liao Chuanqing et al [19] studied the TIG welding process with the welding current of 250 A; the TIG welding current studied by Wang Peiji et al [20] is higher, 300 A. The above literature [18-20] only studied the TIG welding with single-current parameters, and did not conduct TIG welding research under different currents; and the welded joints obtained from the 7-
The microstructure of the welded joint during TIG welding at 100~120 A current is shown in Fig. 2. When the welding current is changed from 100 to 120 A, the microstructure of the 5052 welded joint is mainly composed of weld zone, fusion zone and heat affected zone, but the boundaries between the regions are not obvious. When the welding current is 100 A, 110 A and 115 A respectively, the matrix is equiaxed crystal, the weld zone is dendritic crystal, and the fusion zone and the heat affected zone are between the equiaxed crystal and the dendritic crystal. As the welding current increases from 100A to 115A, the fusion zone and the heat-affected zone become larger. The morphology of these regions is between equiaxed crystal and dendritic crystal, and is biased toward the finer dendritic crystal; when the
welding current is 120 A, the heat affected zone is larger and the structure is larger, because the welding current is larger, the welding heat input is also increased, and the heat affected zone is enlarged and the structure is larger.

Fig. 2 Microstructure of TIG joints with welding currents of 100 ~ 120 A

Note 1: WZ represents the weld zone; HAZ represents the heat affected zone; BM represents the Base Metal zone.

3.2. Mechanical properties of welded joints

Table 2 shows the mechanical properties of TIG welded joints at the welding current of 100 ~ 120 A. The shrinkage of the joint section decreases as the welding current increases, indicating that the plasticity of the joint decreases as the welding current increases. As the welding current is increased from 100 A to 115 A, the tensile strength of the joint is gradually increased from 160.4 MPa to 212.1 MPa, reaching 90.8% of the tensile strength of the base material. At 100-110A, the tensile strength of the joint is the most sensitive as the change of the welding current, and the tensile strength is increased from 160.4 MPa to 201.9 MPa. When the welding current is increased to 120 A, the tensile strength of the joint is 210.2 MPa, which is almost unchanged compared with the joint at the welding current of 115 A.

| Welding current /A | Tensile strength /MPa | Percentage of base metal strength % | Reduction of area % |
|-------------------|-----------------------|------------------------------------|---------------------|
| Base metal        | 233.5                 | 90.0                               | 50.5                |
| 100               | 160.4                 | 68.7                               | 46.8                |
| 110               | 201.9                 | 86.5                               | 31.9                |
| 115               | 212.1                 | 90.8                               | 28.9                |
| 120               | 210.2                 | 90.0                               | 16.3                |

When the welding current is too small, the temperature of the molten pool is too low, and the solidification speed is increased, thus the solute in the molten pool is too late to be diffused and easy to get segregated, and the strength of the welded joint is reduced. When the welding current is increased, the degree of segregation is reduced and the mechanical properties are also improved. However, the increase of the welding current will make the grain in the weld zone coarse, and the heat affected zone will be "softened" because the heat is higher than the recrystallization temperature, which will also affect
the strength of the joint [21-22]. This is also the reason why the tensile strength of the joint no longer increases when the welding current increases from 115 A to 120 A.

The microhardness of the TIG welded joint at 100~120 A welding current is shown in Figure 3. The HV of the fusion zone is the highest, 63 to 68; the HV of the matrix is 60 to 63; the HV of the weld zone is 50 to 55; A “softening” zone appears in the area close to the matrix, with a minimum HV of 51, called heat affected zone. These four regions are consistent with the microstructure of Figure 2: the matrix is equiaxed crystal, the weld zone is dendritic crystal, and the mixed region between equiaxed crystal and dendritic crystal. The hardness is the lowest in the weld zone and rises to the highest in the fusion zone. After the “softening” in the heat-affected zone, the hardness gradually increases toward the hardness of base metal (63 HV) as the distance from the center of the weld increases. The order of microhardness in the weld zone is 115 A>110 A>100 A>120 A; the order of microhardness in the fusion zone is 115 A >100 A>120A >110 A; the hardness of microhardness in the heat affected zone is 115 A>120 A>110A>100 A. In weld zone, fusion zone and heat affected zone of the TIG welded joint, the hardness is the highest when the welding current is 115 A.

![Microhardness of welding TIG joints with welding currents of 100~120 A](image)

**Fig. 3** Microhardness of welding TIG joints with welding currents of 100~120 A (perpendicular to the welding direction)

![Tensile fracture morphology of TIG joints](image)

**Fig. 4** Tensile fracture morphology of TIG joints with welding currents of 100~120 A
Figure 4 shows the tensile fracture morphology of TIG welded joints at 100-120 A welding current. When the welding currents are 100 A and 110 A, it is a ductile fracture, and the dimple is smaller and shallower; but when the welding currents are 115 A and 120 A, it’s mainly brittle fracture, and has a small number of dimples.

3.3. Corrosion resistance of welded joints

As shown in Figure 5, the relationship between the weight-loss rate and time of the TIG welded joint in the salt spray box at the welding current of 100~120 A. The corrosion rate of the sample decreases with increasing corrosion time, and the weight loss rate of the sample is the highest during the 24 hours before corroding. Because the sample which is initially placed in the salt spray corrosion chamber is not protected by a dense oxide film, the corrosion rate is very fast; especially when the welding current is 120 A, the corrosion rate is at most 0.86 g / (m2 · h). The corrosion rate of the sample is significantly reduced from 24 to 96 hours, because the aluminum in the sample reacts with the oxygen in the chamber to form a dense oxide film, which is in the magnesium-rich region, while being eroded by the salt spray atmosphere at 35 °C. Magnesium will also react with oxygen in the tank to form a corrosion-resistant magnesium hydroxy carbonate film [23], and also copper and iron in the wire will shift the surface of the 5052 aluminum alloy from the corrosion potential to the right [24], improved corrosion resistance of the 5052 aluminum alloy, and reduced corrosion rate.

![Fig. 5 kinetics curve of salt spray Corrosion of TIG welded joints with current of 100~120 A](image)

Figure 6 shows the morphology of TIG welded joints after being corroded by salt spray for 168 h at 100 to 120 A welding current. The weld zone of welded joints with welding currents of 100 A and 110 A is mainly pitting, and the weld zone of welded joints with welding currents of 115 A and 120 A is mainly pitting and intergranular corrosion. In the environment of neutral salt spray corrosion, as the TIG welding current of the 5052 aluminum alloy increases, the tendency of intergranular corrosion in the weld zone gradually increases. Intergranular corrosion greatly weakens the bond between the grains and reduces the strength of materials.

The Cl- in the small droplets of NaCl has a destructive effect on the passivation film on the surface of the 5052 sample. The oxygen in the salt spray corrosion chamber forms OH- and O2-in the small droplets of NaCl through the reaction formulas (1) and (2). In addition, since the chemical sites of Al3+ and Mg2+ in the NaCl solution are not equal to those of 5052 aluminum alloy, Al3+ and Mg2+ in the 5052 aluminum alloy will be transferred to the solution, through the reaction formulas (3) and (4) Al3+ and Mg2+ are formed in NaCl solution. Finally, corrosion products such as Al2O3, MgO, Al(OH)3, and Mg(OH)2, etc. are formed. Combined with the A-point energy spectrum analysis, see Table 3, it is known that the corrosion product is mainly Al2O3. Because in the 5052 aluminum alloy, there is less alloying element of magnesium, and the spray is neutral, Mg2+ and OH- are produced less, and the formed Mg(OH)2 does not exceed its solubility in brine [24], so the corrosion product observed was mainly Al2O3.
O2+ 2H2O + 4e$^{-}$ $\rightarrow$ 4 OH$^{-}$ \hspace{1cm} (1)
O2+4e$^{-}$ $\rightarrow$ 2O2$^{-}$ \hspace{1cm} (2)
Al $\rightarrow$ 3e$^{-}$ $\rightarrow$ Al3$^+$ \hspace{1cm} (3)
Mg $\rightarrow$ 2e$^{-}$ $\rightarrow$ Mg2$^+$ \hspace{1cm} (4)

Fig. 6 Microstructure of TIG joints with welding current of 100~120 A after being corroded in Salt spray for 168 h

Figure 6 shows the morphology of TIG welded joints after being corroded by salt spray for 168 h at 100 to 120 A welding current. The weld zone of welded joints with welding currents of 100 A and 110 A is mainly pitting, and the weld zone of welded joints with welding currents of 115 A and 120 A is mainly pitting and intergranular corrosion. In the environment of neutral salt spray corrosion, as the TIG welding current of the 5052 aluminum alloy increases, the tendency of intergranular corrosion in the weld zone gradually increases. Intergranular corrosion greatly weakens the bond between the grains and reduces the strength of materials.

| Element | Mass percentage /wt% | Atomic percentage /% |
|---------|----------------------|---------------------|
| O       | 53.13                | 65.77               |
| Mg      | 0.62                 | 0.50                |
| Al      | 44.94                | 32.99               |
| Cl      | 1.32                 | 0.74                |

Figure 7 shows the Tafel curve for a TIG welded joint at the welding current of 100 ~ 120 A. Table 4 shows the corrosion current density and corrosion potential of TIG welded joints at the welding current of 100 ~ 120 A. The corrosion potential of the TIG welded joint at 100 to 120 A is between -720 and -680 mV, and the corrosion current density is -5.22 to -4.48 mA/cm2. The corrosion potential and corrosion current density of all samples were slightly shifted to the right compared with the parent metal.
The electrochemical corrosion tendency of all joints and the corrosion rate after corrosion were smaller than that of the parent metal. When the welding current is 115 A, corrosion tendency of the joint is the smallest; when the welding current is 100 A, the corrosion rate after corrosion is the smallest. When the welding current is 110 A, the corrosion current density and the corrosion potential are both negative; compared with the joints under the other welding currents, the corrosion tendency and corrosion rate are both at a high level, and the corrosion resistance is the worst.

**Fig. 7** Tafel curves of the TIG welded joints at different welding currents

**Tab. 4** Corrosion current densities and the corrosion potentials of TIG welded joints at different welding currents

| welding current /A | Corrosion current density / (mA·cm$^{-2}$) | Corrosion voltage /mV |
|--------------------|------------------------------------------|-----------------------|
| 0(Base metal)      | −5.72                                    | −725                  |
| 100                | −4.78                                    | −720                  |
| 110                | −5.12                                    | −716                  |
| 115                | −5.22                                    | −680                  |
| 120                | −5.07                                    | −700                  |

4. Conclusion
All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. Should authors use tables or figures from other Publications, they must ask the corresponding publishers to grant them the right to publish this material in their paper. As show in Fig. 1 and Table 1, three scheme comparing.

TIG welding of 5052 aluminum alloy at the welding current of 100~120 A: when the welding current is 115 A, the welded joint has better mechanical properties. The tensile strength of the joint is 212.1 MPa, which is 90.8% of the tensile strength of the base metal, and the reduction ratio of the section is 28.9%, which is nearly half of the reduction of the section shrinkage of 50.3% of the base metal.

The salt spray corrosion after 168 h showed that when the welding current is 100 A and 110 A, TIG welded joint of the 5052 aluminum alloy is mainly pitting corrosion and the corrosion was average; when the current is 115 A and 120 A, intergranular corrosion intensified, and converted to pitting and intergranular corrosion. When the welding current is between 100 and 120 A, the change of corrosion current density is not obvious, which is related to the unevenness of the weld structure.

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