Effects of post weld enhanced-solution on the microstructures and mechanical properties of 2519A aluminum alloy welded joints

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Abstract: The effects of enhanced-solution plus aging treatment on the microstructures and mechanical properties of 2519A aluminum alloy welded joints were investigated by optical microscope, mechanical test, scanning electron microscope (SEM) and transmission electron microscope (TEM). The results show that the heat-affected zone (HAZ) is a soft zone due to over-aging caused by heat input during welding. After enhanced-solution plus aging treatment, the soft zone disappears, and fine strengthened precipitates emerge in weld zone and HAZ. The 4h→535℃/2.5h enhanced-solution can increase the final solution temperature without the formation of overheated microstructure, and improve the solution of second phase, then more fine strengthened precipitates can be attained during aging treatment, so the hardness and tensile properties of the welded joints can be further increased.

1. Introduction

2519 high strength aluminum alloy has gathered wide acceptance in the fabrication of lightweight structures requiring high strength-to-weight ratio, such as transportable bridge girders, military vehicles, road tankers and railway transport systems [1,2]. Though 2519 aluminum alloy has got an edge over its counterparts in terms of weldability, it also suffers from poor as welded (AW) joint tensile strength. The joint strength is only about 60% when compared to the base metal strength in T87 condition [3]. It is well known that the mechanical properties of aluminum alloy weld joint are related to welding wire, welding parameters and post weld heat treatment et al [4-5]. Li [6] studied the microstructures and properties of 2519 aluminum alloy welded joint by using 4047 welding wire. Xu [7] pointed out that the microstructures and mechanical properties of welded 2519 aluminum alloy were improved after heat treatment. From the literature review, it can be found that the mechanical properties of welded joint have been improved after aging treatment due to the fine precipitate in weld joint during aging treatment. The effects of post weld solid solution plus aging treatment are better than that of aging treatment because the eutectic structures in weld joint are dissolved, and there are more fine precipitates in weld joint during aging treatment [8-9]. The enhanced-solution treatment can improve the solid solubility of aluminum alloy, and was used to improve the mechanical properties of aging strengthening aluminum alloys [10-12]. But few research studies have been published so far about the effects of enhanced-solution on the microstructures and mechanical properties of weld joints. In this paper, an attempt was made to enhance mechanical performance of 2519A aluminum alloy welded joints by post weld enhanced-solution plus aging treatment, and the effects of post weld...
enhanced-solution plus aging treatment on the microstructures and mechanical properties of 2519A aluminum alloy welded joints are studied in this article.

2. Experimental Procedure

The thickness of weld 2519A-T87 aluminum alloy plate was 20mm, and the samples were cut and machined to the required sizes (200mm×130mm). Double ‘V’ butt joint configuration of 90° was prepared to fabricate metal inert gas(MIG) weld joints with ER2319 filler metal. Argon (99.99% pure) was used as the shielding gas. The welding equipment was TPS5000 multifunctional digital welder, and the welding conditions and process parameters were presented in table 1.

| Welding parameter | Wire feeder speed (m·min⁻¹) | Pulse time (ms) | Frequency (Hz) | Welding speed (cm·min⁻¹) | Current (A) | Voltage (V) |
|-------------------|-----------------------------|----------------|---------------|--------------------------|-------------|------------|
| value             | 6.7                         | 2.2            | 220           | 37                       | 260         | 22.5       |

In order to examine the influence of heat treatment on the microstructures and mechanical properties of weld joint, the weldments were subjected to different post weld heat treatments, as shown in table2 (1) AW(as welded); (2) GS(General solution treatment plus T6 aging treatment); (3) ES1(heating from room temperature to 535℃ in 4h, remaining 2.5h plus T6 aging treatment); (4) ES2(heating from room temperature to 535℃ in 8 hours, remaining 2.5h plus T6 aging treatment). Standard tensile tests were performed on the specimens with weld seam positioned transversely across the middle of tensile sample, and the final result of tensile test was the average of three samples. The microstructures and fracture morphology were observed by optical microscope, TEM and SEM.

| sample | heat treatment parameter |
|--------|-------------------------|
| AW     | As welded               |
| GS     | Solid solution 530℃/2.5h +165℃/16h |
| ES1    | enhanced-solution 4h→535℃/2.5h +165℃/16h |
| ES2    | enhanced-solution 8h→535℃/2.5h + 165℃/16h |

3. Results and Discussion

3.1. Microstructure

The optical micrographs of welding zone after different solution plus T6 aging treatments are displayed in figure 1. In the as weld sample, the eutectic structure is distributed along grain boundaries. The weld seam is typical dendritic microstructure, and there are network eutectic phases along grain boundary and precipitates in grains, as shown in figure 1(a). For the GS sample, a large number of second phases were formed in the sample, and there are some undissolved particles, as shown in figure 1(b). But for ES1 and ES2 samples, the quantity of coarse undissolved particles decreases, as shown in figure 1(c) and 1(d). Because the sample is heating from room temperature to 535℃, the intermediate phases are dissolved gradually, and the solution temperature can be higher than general solution treatment, and the intermediate phase will not overburn. But for general solution treatment, if the sample is treated at 535℃, the intermediate phase may overburn. Because the intermediate phase can be dissolved into the matrix at its appropriate temperature as much as possible through enhanced-solution treatment, the phases are dissolved sufficiently in enhanced-solution treatment, and the precipitates for ES1 and ES2 are more than that of GS.
The optical micrographs of HAZ after different post weld solution plus T6 aging treatments are shown in figure 2. The grain size of HAZ grows due to the effect of weld heat input, and there are some coarse particles and precipitates, as shown in figure 2(a). The strengthened precipitations coarsen due to the effects of weld heat input, and the HAZ is under the over-aged condition. For the GS sample, the coarse precipitates are dissolved during post weld solid solution, and fine precipitates generate during aging treatment, as shown in figure 2(b). Because the solution effects of ES1 and ES2 are better than GS, the quantity of fine precipitates is more than that of GS, as shown in figure 2(c) and 2(d).
TEM images of the welded joints after different heat treatments are shown in figure 3. Figure 3(a) is the microstructure of AW, and there are a small amount of needle-shaped precipitates, and the precipitates are coarse. After general solid solution plus aging treatment, the quantity of fine precipitates increases, as shown in figure 3(b). From figure 3(c) and 3(d), it can be found that the precipitates formed after enhanced-solution are denser and smaller. Because the solution temperature is higher than general solution treatment, and the intermediate phase can be dissolved into the matrix at its appropriate temperature as much as possible through enhanced-solution treatment, the fine precipitates of enhanced-solution are more than that of general solid solution, which can be found in figure 3(b), 3(c) and 3(d). From figure 3, it can be found that the enhanced-solution treatment plus aging treatment is favorable to refining θ’ phase. Compared figure 3(a), 3(b), 3(c) and 3(d), the precipitates of ES1 are more than the others, so the post weld heat treatment of ES1 is better than the others.
3.2. Hardness and tensile properties

The Vickers hardness (HV) curves of the welded joints of 2519A aluminum alloy after different heat treatments are shown in figure 4. The hardness of as welded joint is lower than that treated by different solid solution plus T6 aging treatments. The joint shows the lowest hardness at the weld center due to the ‘as cast’ nature of the microstructure, which is characterized by coarse dendritic grains, interdendritic segregate phases and the lack of strengthening phases. As seen in figure 4, there is a remarkable softened zone in HAZ in the as welded joint. In HAZ, the hardness is low because of the coarsening of strengthened phases under the effect of thermal cycling. It indicates that the region is in the over aged condition. But after post weld solution plus aging treatment, the soft zone in HAZ disappears, which may relate to the fact that coarse precipitates are dissolved during post weld solution, and the solidified atoms in the Al base matrix can achieve precipitation hardening effect through aging heat treatment. Because the solution effect of ES1 is better than the others, the hardness of ES1 is higher than the others.

Table 3 shows the tensile strength of different solution plus T6 aging treatment applied to 2519A aluminum weldments. It is well known that the continuous and thick eutectic phase along the grain boundary can result in low strength in the as weld joints, so the tensile strength of AW is the lowest. From prior analysis, it is also found that the reduction of dendrite arm and sufficient solution of second
particle can increase the tensile strength of weld metal after post weld heat treatment. It is obvious that the density of $\theta'$ phase in the weld zone of ES1 is larger than the others, so higher strength can be obtained by hindering dislocation movement. In table 3, the tensile strength of ES1 is 368MPa, which is about 80% of base metal.

Table 3. Tensile strength of different post weld treatments

| Temper | Tensile strength (MPa) | Ductility(%) | Fracture path |
|--------|------------------------|--------------|---------------|
| AW     | 310                    | 8.7          | welding zone  |
| GS     | 326                    | 11.2         | welding zone  |
| ES1    | 368                    | 18.1         | fusion line   |
| ES2    | 347                    | 13.1         | welding zone  |
| BM     | 460                    | 9.8          | -             |

3.3. Fracture analysis

Figure 5 shows the fractographs of the tensile specimen after different solution plus T6 aging treatment. In the as weld joint, the eutectic phases along the grain boundary are brittle, and the eutectic phases are the initiation of crack, so the fracture of AW sample is predominantly intergranular fracture, as shown in figure 5(a). After post general solution plus aging treatment, the eutectic phases along the grain boundary decrease, the fracture of GS is a mixture of ductility fracture and brittle fracture mode, and there is obvious trace of brittle failure, as shown in figure 5(b). After post weld enhanced-solution plus aging treatment, the eutectic phases along the grain boundary and the second phases are sufficient dissolved, and the crack initiation decreases. From figure 5(c) and (d), it could be seen that there are some dimples in fracture plane, which is the feature of ductility fracture. The dimples in figure 5(c) are bigger and deeper than that in figure 5(d).
4. Conclusions
The temperature of enhanced-solution can be higher than general solution treatment, and the intermediate phase can be dissolved into the matrix at its appropriate temperature as much as possible through enhanced-solution treatment, so the fine precipitates of enhanced-solution are more than that of general solid solution.

The microstructure and tensile strength of 2519A aluminum alloy weld joints can be improved by enhanced-solution plus aging treatment. Good mechanical properties can be obtained by using 4 hours continuous heating to 535°C solution /2.5 h + 165°C×16h aging treatment(ES1).

The eutectic phases along the grain boundary and the second phases are sufficient dissolved after enhanced-solution, and the crack initiation decreases, and the fracture morphology of weld joints of 2519A aluminum alloy is ductile fracture.

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