Study on Heat Treatment of Aerospace Aluminum Alloy Welded FSW

Luo Chuanhong [1,2,a], Dong Fengbo [3] and Guo Lijie [3]

[1]*Key Laboratory of Hydraulic Machinery Transients (Wuhan University), Ministry of Education, Wuhan, 430072*
[2]*School of Power and Mechanical Engineering, Wuhan University, Wuhan, 430072*
[3]*Shanghai Aerospace Equipments Manufacturer, Shanghai, 200245*

Abstract: The precisely controlled heat treatment was researched to meet the special requirements of the aerospace industry on materials. 2219 aluminum alloy plate was obtained by friction stir welding, and the microstructures and mechanical properties were investigated correspondingly. The causes of the weakened joint strength in friction stir welding were analyzed and summarized. The tensile properties show that the average tensile strength of the samples was increased to 393MPa and the elongation was increased to 12.6% of the base metal. Through the special recrystallization technology with high temperature oscillating heat treatment to hold the fine grain at short time, the ductility can be restored and softening can be eliminated, which will improve the performance in mechanical intensity of aerospace aluminum alloy.

1 Introduction

Aluminum alloy is the main structural material of the equipments in the aerospace industry, which is undergone five generations to promote the development of the aerospace technology. The first was with aging heat treatment for high strength aluminum alloy; The second was with overaging heat treatment for perfect corrosion resistant; the third was based on high purity for high corrosion resistant and high tenacity; The fourth was based on the precise control of multi-scale second phase for super high corrosion resistant and high fatigue resistance of the aluminum alloy; the fifth was with high hardenability for comprehensive performance of aluminum alloy[1]. With the development of the aerospace industry and other materials technology, the aluminum alloy are seriously challenged in the history of performance, such as structure weight loss, high reliability and long life. Moreover, 2XXX and 7XXX aluminum alloy with high strength and high tenacity were mainly applied in aerospace launch vehicle, for example, as shown in figure 1. Friction stir welding (FSW) is a new kind of solid connection technology to solve the traditional problem in welding 2XXX and 7XXX aluminum alloy[2-5], which is now widely used in aerospace structures of the manufacturing process.

[a] Corresponding author: chluo@whu.edu.cn

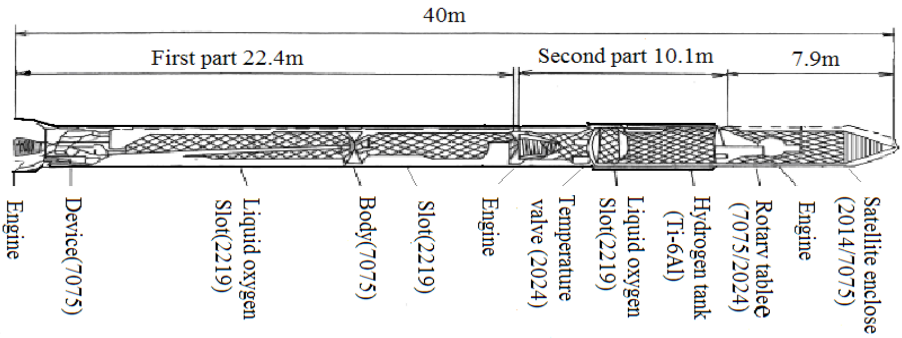


Figure 1 Materials of rocket parts

There are many researches focused on the mechanism and properties of aluminum alloy welded by FSW[6,7]. However the mechanics performance will decline due to material thermal damage and mechanical damage after welding. Generally, the research results and the engineering practices have shown that the ratio of weld metal strength to base metal strength is only about 50%~85%, which apparently makes no full use of the advantages of high strength aluminum alloy[8,9]. It requires precise control by heat treatment to meet the strict requirements of the aerospace industry on materials. After analyzing the joint of 2219 AA weld by FSW, the precipitating of θ phase are argued for the degradation of joint performance, and the heat treatment is put forward that can improve the joint's tensile strength. This research will provide beneficial reference to high strength aluminum alloy used in the aerospace industry.

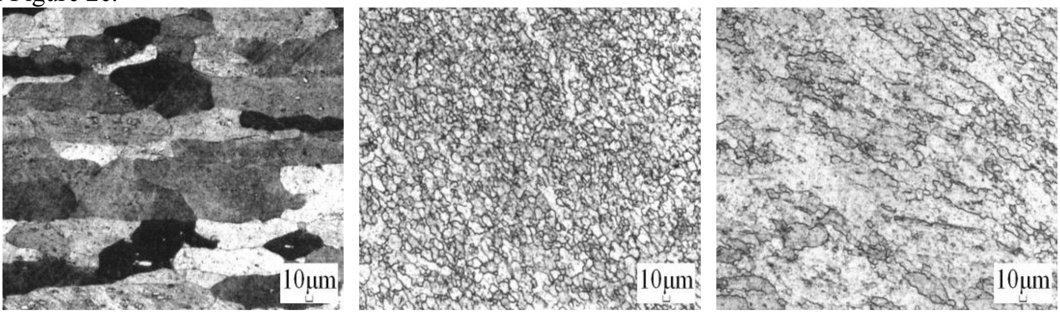
2 Experimental materials and method

The experimental material is 2219AA plate, whose size is 300×200×6 mm. The stirring needle's diameter is 6 mm, while its shoulder's diameter is 20 mm. The welding method is single butt welding. the post welding heat treatment (PWHT) at high temperature and short time is taken to deal with the weldments, and then an artificial aging at 165℃ × 24h. Two kinds of PWHT for weldments are conventional heat treatment and high temperature oscillation heat treatment. The method of high temperature oscillation heat treatment is as follows: a short stay above the solution temperature about 530℃, and rapidly fall temperature lower than the solution temperature, repeatedly, to realize temperature oscillation around solid solution temperature line of 2219AA. This process can be completed by the two furnaces, it also can be completed by a furnace. After welded or PWHT, the samples are taken along the weld beam and polished, and corroded by mixed acid(1.0%HF +1.5%HCL +2.5%HNO3 +95.0%H2O), and finally observed under OLYMPUS optical microscope, tested tensile by CSS44100 electronic tester, and measured hardness by HXZ 1000 digital tester.

3 Results and discussion

3.1 Morphology and microstructure

The clear boundaries existence on the macroscopic structure of the welded joints, so the welded joints are divided into three zones: the nugget zone (NZ), the thermo mechanical affected zone (TMAZ), and the heat affected zone (HAZ) [10]. The morphology of all regions is shown in fig.2. In the HAZ, the welding thermal cycle causes the original grain coarsening of material, as shown in figure 2a. However, in NZ the grains are broken, and then many small equiaxed structures are formed during grains growth, because the grains undergo a drastic stir and dynamic recrystallization after intense friction. These fine grains have strong strength for whole or the part of compact structure, and have a good metallic luster, when observed under optical microscope, as shown in fig.2b. Moreover, in TMAZ a combined action of strong stirring and welding thermal cycling performs in FSW, resulting in local fragmentations and the adherent growth, where grain size is larger than that in NZ, as shown in Figure 2c.

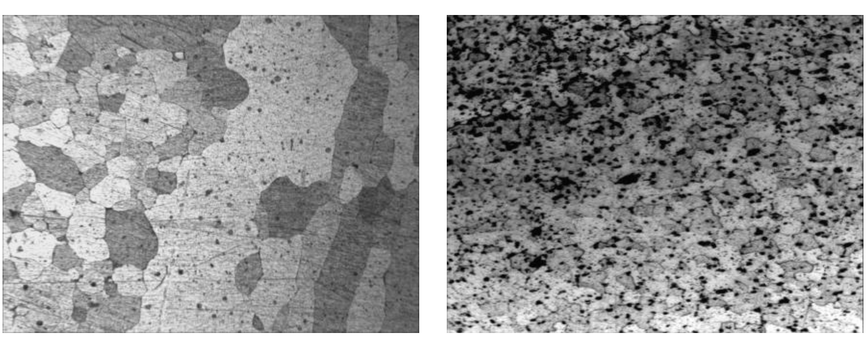


(a)HAZ (b)NZ (c)TMAZ

Figure 2 Microstructures in joint of 2219AA

The normal solid solution heat treatment is that the weldment is maintained at a constant temperature for a long time, but comparatively, a precisely controlling heat treatment of high temperature oscillation is that the weldment is stayed for short-time above the solution temperature, then slightly lower than the solution temperature for short-time to realize heating oscillation near the line of the solid solution temperature. The PWHT has great influence on the microstructure and properties, Microstructures is as shown in Fig.3 and Morphology is as shown in Fig.4.

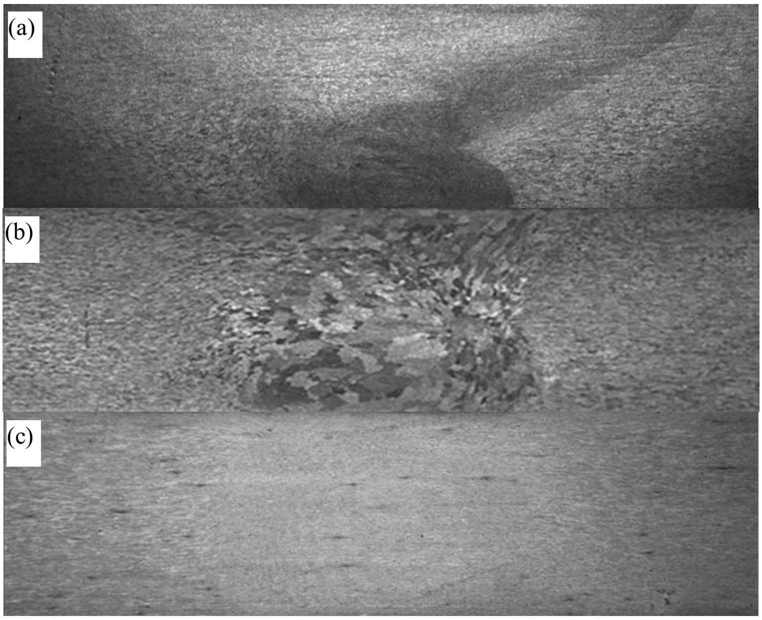
After normal PWHT, as shown in Fig.3a, it can be seen from the figure that the grains undergo the high temperature recrystallization, the organizations in BM and HAZ remained the same grain size or slightly increased, but those in NZ or TMAZ appear to abnormally grow up. The larger grain size existence at the junction of NZ or TMAZ and the grain boundary is very clear, and the grain growth direction is along the thickness direction of the samples. The research shows that the grain boundary is broken and the organization is formed in NZ under the mechanical action, so no second phase particles on grain boundary, resulting in boundary energy is low. However, much distortion energy and a large number of dislocation is stored in the grains, so the energy threshold of grain growth is reduced. The adjacent grain even with high angle grain boundaries are easy to merge. Therefore, in the process of heat treatment after welding, the abnormal grain growth phenomenon is easy to occur, and the grain size in NZ has a great thermal instability. Traditionally, the abnormal grain growth usually occurs in the conditions that the second phase particles solutes into matrix above solution temperature, such as austenitizing process of the steel, but in aluminum alloy welded by FSW, the abnormal grain growth occurs in the recrystallization process under lower temperature.



(a) Normal PWHT (b) Temperature oscillation PWHT

Figure 3 Microstructures in joint of 2219AA after PWHT

DOI: 10.1051/matecconf/201711403010

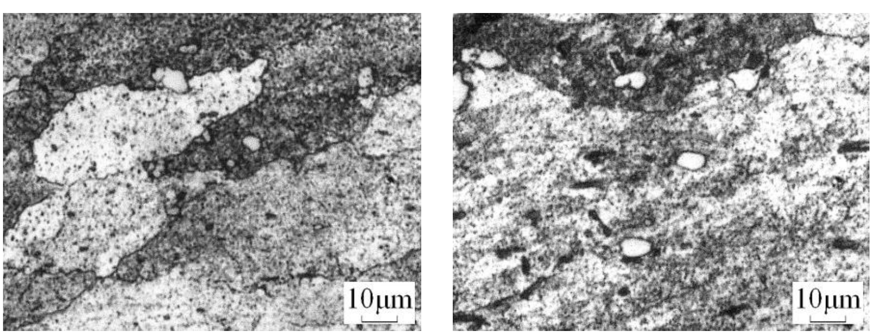


(a) Welded (b) Normal PWHT (c) Temperature oscillation PWHT

Figure 4 Morphology of FSW joints

3.2 Behavior of θ phase in PWHT

Heat has a great influence on aggregation and growth of the precipitation of θ phase (A12Cu) in the matrix of α (Al) in 2219AA, in which the precipitation is distributed in the matrix to strengthen the material. In the welding process, the precipitation is gradually separated and gathered. It is difficult to form large particles because of the fragmentation of the precipitation. Thus, there are no large particles of the precipitation in NZ. However, in the HAZ, the deformation is small, so the precipitation is easy to gather and grow, and the particle reaches a maximum size of about 15 μm, as shown in the fig.5a. After PWHT, when temperature oscillated around the low limit of solution temperature, the stable precipitates preferentially formed in grain boundary to anchor grain boundary and can restrain the generation of coarse grain effectively. Meanwhile, in HAZ there are some changes of the precipitation in form, but there is no obvious evidence of precipitation in number. Due to the short duration of high temperature, the transferring velocity of copper atoms is slow, so the large precipitation still exists, as shown in the fig.5b. These aggregated particles would reduce the number of precipitation surrounding matrix and weaken the intensity of the heat affected zone.



(a) welded (b)PWHT

Figure 5 Distributions of the θ particles in HAZ

3.3 Results of mechanical tensile test

Table 1 shows the test results of mechanical tensile properties of 2219 aluminum alloy. The base material has good plasticity about 23% under the condition of annealing. The plasticity is poorer and the fractures of most samples are located in HAZ when the material is welded by F SW. The plasticity is further reduced but the tensile strength is higher in the condition of solution and aging with normal PWHT. The elongation is about 7.5% and decreased about 50% of welded joints, the average tensile strength is 300MPa, most of the fracture position on the advancing side. After the high temperature solution, the average tensile strength of the samples was increased to 393MPa, the elongation was increased to 12.6%. It means if grain size can be controlled in the heat treatment, the plasticity will be improved. The results show that the grain size is controlled by the high temperature oscillation and the fine grain structure is maintained, thereby the plasticity is improved to a certain extent as well as the tensile strength recovery.

Table 1 Mechanical properties of base metal and joints of 2219AA

Sample number	Ultimate tensile [Mpa]	Elongation [%]	Fracture location	Note
1	150.3	23.1	-	BM
2	156.4	13.4	RS	Welded Joints
3	300.4	7.5	AS	Normal PWHT
4	393.0	12.6	AS	Precisely PWHT

4 Conclusions

This experiment try to improve the tensile strength of joints through heat treatment, which can restore the metal's plasticity, redistribute θ phase, prevent the softening of heat affected zone and eliminate the influence of those inherent weakening factors. It develops the advanced heat treatment technology to improve the comprehensive performance and meet the requirements of the aerospace aluminum alloy.

When temperature oscillated around the low limit of solution temperature, the stable precipitates preferentially formed in grain boundary to anchor grain boundary and can restrain the generation of coarse grain effectively; when the temperature oscillation amplitude is greater than 90℃, the grain size is about 20 μm in diameter. The joint can restore the ductility and eliminate the softening. High temperature oscillatory solution heat treatment can effectively solve the problem of thermal instability in the nugget of friction stir welding.

Acknowledgment

This work was supported by Shanghai Aerospace Science and Technology Innovation Fund under grant no. 2015056.

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