Article ID: 1003-6326(2003)04-0781-04

Al-Cu based welding wire with minor Sc-Zr alloying and its application①

YIN Zhi-min(尹志民), GUO Fei-yue(郭飞跃), PAN Qing-lin(潘青林), SONG Lian-peng(宋练鹏)
(School of Materials Science and Engineering, Central South University, Changsha 410083, China)

Abstract: A kind of Al-Cu-(Sc, Zr, Mn, Ti, V, B) welding wire was developed by adding minor Sc, Zr, Mn, V, B, and was used for welding 2195 aluminum alloy plate with a thickness of 2 mm. Mechanical properties and microstructure of welding wire and welding joint were studied. The results show that strength coefficient of the welding joint is 0.70 and the weakest area lies in the softened zone of HAZ. It is indicated that this welding wire adding minor Sc, Zr, Mn, V, B is an ideal welding wire for 2195 Al-Li alloy plate. The high strength of the weld comes from grain-refining strengthening and precipitation strengthening of Al_2Cu, Al_3Sc and Al_3Zr.

Key words: 2195 aluminum alloy; Sc; welding joint; microstructure; mechanical properties
CLC number: TG 146.2 **Document code:** A

1 INTRODUCTION

2195 aluminum-lithium alloy is a new kind of aerospace structural materials with low density, high specific strength and specific modulus as well as excellent low temperature performances[1-3]. Although 2195 alloy has excellent combined properties, there is still a problem of how to guarantee its welding joint with also such good combined properties[4]. Due to the influence of welding heat input during welding, microstructure and properties of aluminum-lithium alloy will be changed a lot, and the strength of HAZ (heat-affected zone) obtained by T8 heat treatment will be lost a lot[4], which will affect seriously the overall strength of welded units. At present, research of 2195 alloy mainly focuses on the relationships among composition, technology and properties. The literature on welding of 2195 alloy is still very rare, therefore it is very necessary to develop welding wire suited to welding 2195 alloy and study the microstructure and properties of its welding joints.

2 EXPERIMENTAL

2.1 Materials preparation

The 2195 alloy with a thickness of 2 mm and a composition of Al-4Cu-1Li-0.4Mg-0.54(Ag, Zr, Ti) (mass faction, %) was supplied by South West Aluminum Ltd, China. The plate was experienced solution heat treatment at 505 ℃ for 40 min in a salt bath, then water quenched and followed by T8 aging treatment (6% prior rolling+ 160 ℃, 10 h aging treatment).

The welding wire is a kind of Al-Cu-(Sc, Zr, Mn, Ti, V, B) welding wire developed by the authors with a diameter of 3 mm. The preparing route is as follows: microalloying composition designing, degassing melting in a 50 kg melting furnace, semi-continuous casting to *d* 115 mm ingot, homogenization treatment, hot work (extruded to *d* 6 mm bar), annealing, cold drawing to *d* 3 mm wire by many passes, then surface treatment.

2.2 Experimental methods

The welding experiment was done in Institute of Aerospace Materials and Processing Technology, China. Prior to welding, the surface of the 2195 base plate was chemically cleaned and the oxide film was removed. The plate was TIG welded by Fronius welding machine in argon atmosphere. The welding parameters of single-sided forming are as follows: welding current, 80 A; welding voltage, 12-13 V; welding speed, 2.3 mm/s; flux of argon, 8-10 L/min.

The specimens of base metal and welding joint (with reinforcement) were cut from the plate in the transverse direction (T.D. as shown in Fig. 1). Tensile samples were tested on CSS-44100 tensile testing machine and the tensile ratio is 2 mm/min. Hardness measurement was made on HVA-10A low-load Vickers hardness tester with the load of 5 N. Metallography samples were observed on Nephot-II microscope after etched by mixed acid. Samples for transmission electron microscopy (TEM) analysis were prepared by conventional twin-jet polished in an electrolyte of 1/3 nitric acid and 2/3 methanol (volume fraction) at -30 ℃. Microstructure observations were carried out on Hitachi-800 microscope operating at 200 kV.

① **Foundation item:** Project (G1999064911) supported by the National Key Fundamental Research and Development Program of China
Received date: 2003-01-15; **Accepted date:** 2003-04-20
Correspondence: YIN Zhi-min, Professor, PhD; Tel: +86-731-8830262; E-mail: yin-grp@mail.csu.edu.cn

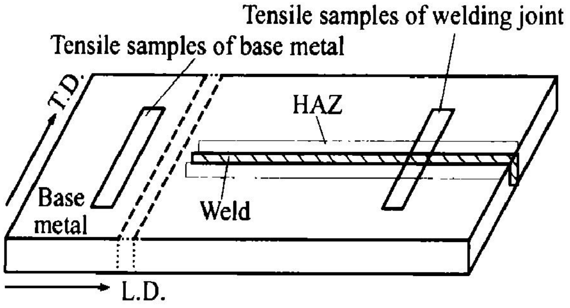

Fig. 1 Schematic of 2195 alloy welding joint

3 RESULTS

3.1 Hardness distribution of welding joint

The hardness distribution of welding joint is shown in Fig. 2. The result shows that the hardness of welding joint is approximately symmetrically distributed along the weld center line. The hardness of the weld is 102 HV, and the hardness of the heat affected zone (HAZ) is lower than that of the base metal. With the increase of the distance from the weld center, the hardness increases. In the HAZ, the hardness descends to 115 HV at a distance of 10 − 12 mm from the weld center, then ascends up to the hardness of the base metal.

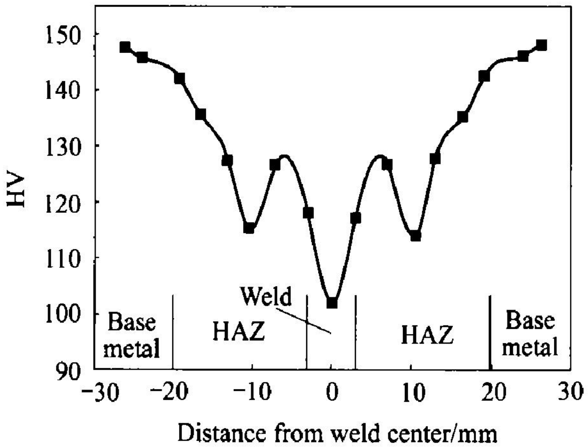

Fig. 2 Hardness distribution of 2195 welding joint

3.2 Mechanical properties of welding joint

The mechanical properties of the base metal and welding joint using Al-Cu-(Sc, Zr, Mn, Ti, V, B) welding wire are listed in Table 1. The results indicate that the weakest area of 2195 alloy welding joint lies in the softened zone of HAZ, and the welding coefficient of the welding joint can reach 0.70.

3.3 Optical microstructure of welding joint

The optical microstructures of the base metal and welding joint are shown in Fig. 3. The result shows that the weld exhibits complete equiaxial microstructure with small grains, while the HAZ exhibits complete recrystallization microstructure. Grain growth has obviously occurred in the area close to the weld. For the base metal, it remains fibrous.

Table 1 Tensile properties of base metal and welding joint

Alloy		σ_b/MPa	$\sigma_{0.2}$/MPa	δ_5/%	Fracture zone
Base metal	B1	550	466	10.2	–
	B2	552	472	10.4	–
	B3	550	470	10.5	–
	Mean value	550	469	10.3	–
Welding joint	W_1	382	312	4.3	HAZ
	W_2	387	315	4.2	HAZ
	W_3	384	318	4.2	HAZ
	Mean value	385	315	4.2	HAZ

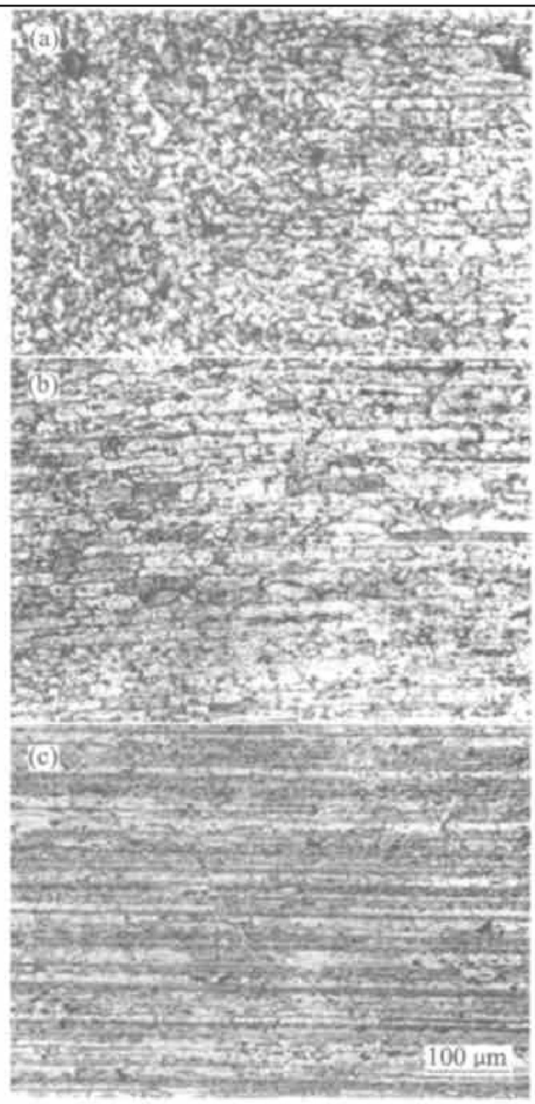

Fig. 3 Optical microstructures of base metal and welding joint
(a) —Boundary between weld and HAZ; (b) —HAZ; (c) —Base metal

3.4 XRD analysis of welding wire and weld

The XRD analysis of the welding wire and the weld are shown in Fig. 4. It can be seen in the weld-

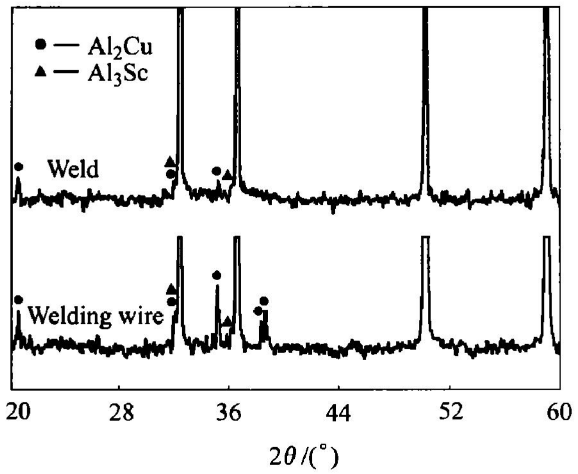

Fig. 4 XRD analysis of welding wire and weld

ing wire and weld, besides α(Al) matrix, there are still a few θ(Al_2Cu) and Al_3Sc phases.

3.5 TEM microstructure of welding joint

Fig. 5 presents the TEM microstructure of the welding joint. In the welding wire alloys, many small needle-like and granular precipitates are found (Fig. 5(a)). The corresponding selected area electron diffraction (SAED) pattern reveals that they are θ (Al_2Cu), Al_3Sc and Al_3Zr phases, respectively (Fig. 5(b)). In the weld, many small needle-like and granular precipitates can also be found (Fig. 5(c)). In addition, some eutectic phases can be observed along the boundaries (Fig. 5(d)). 2195 base metal exhibits many needle-like and plate-like precipitates (Fig. 5(e)). The SAED pattern reveals that the spots belong to the T_1 (Al_2CuLi) phases and the streaks belong to the θ(Al_2Cu) phases. Fig. 5(f) shows that in the HAZ, the main strengthening phases T_1 and θ have coarsened.

4 DISCUSSION

4.1 Microstructure and properties of weld

The result of tensile experiment shows that the strength coefficient of welding joint (with reinforcement) can reach 0.70, which is high for high-strength aluminum alloys without postweld heat treatment. The result also shows that the weakest area of the welding joint is not in the weld, but in

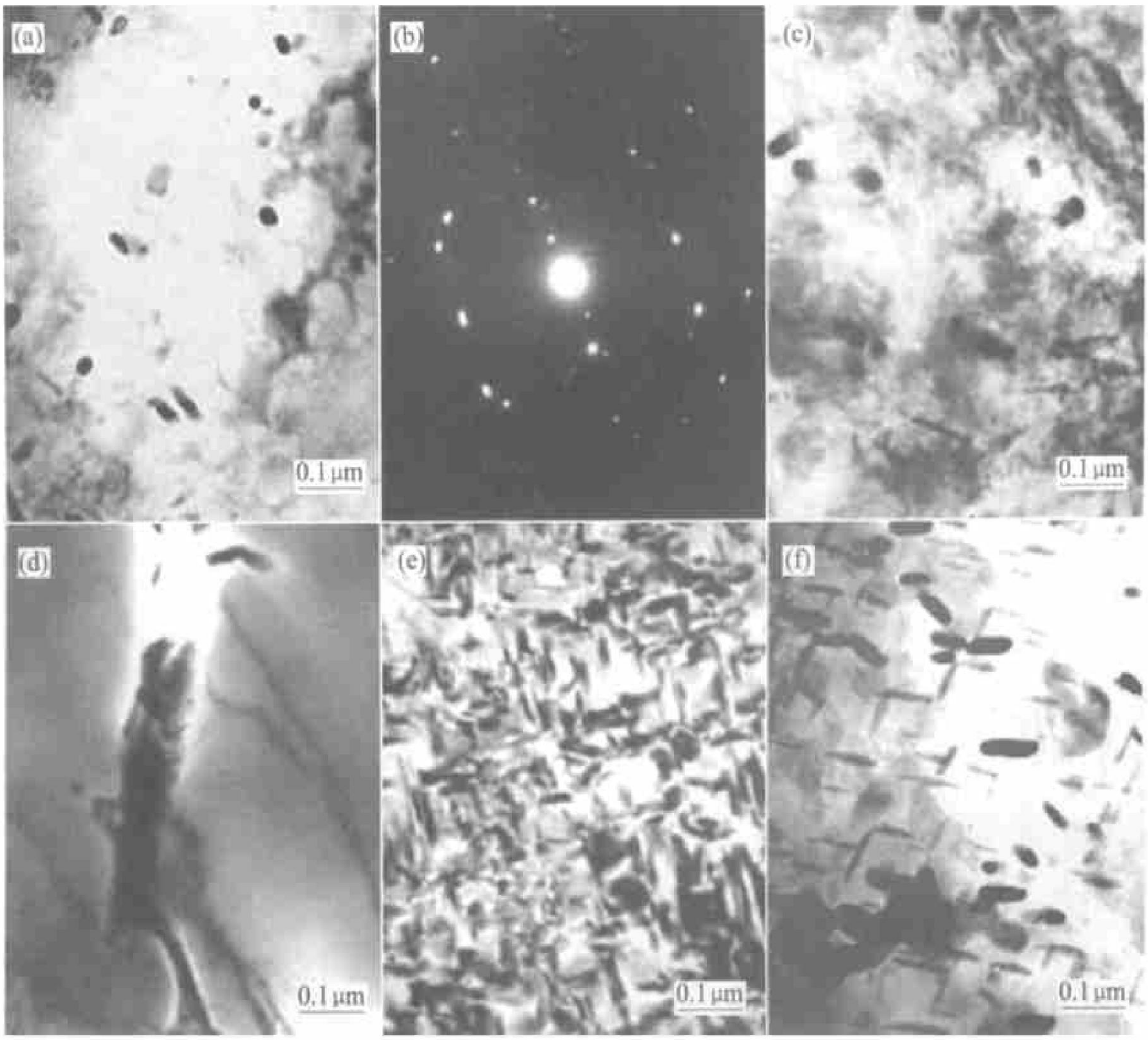

Fig. 5 TEM microstructures of welding joint
(a), (b) —Welding wire alloy; (c), (d) —Weld; (e) —Base metal; (f) —HAZ

the HAZ. This suggests that Al-Cu-(Sc, Zr, Mn, Ti, V, B) welding wire weld has high strength. The high strength mainly comes from three aspects: First, both the welding wire alloy and 2195 alloy belong to Al-Cu based alloys, their main phase microstructures are α(Al) and θ(Al_2Cu), which leads to a good compatibility between them (Fig. 3(b)); Second, adding minor Sc, Zr, Ti, B to Al-Cu alloys, small grains after solidification are obtained, which leads to remarkable fine-grain strengthening; Third, besides grain refinement, microalloying of Sc and Zr results in dispersive precipitation of Al_3Sc and Al_3Zr during solidification without heat treatment (Fig. 5 (a)), which obviously improves the strength of the weld. In addition, TEM microstructures indicates that, along the boundaries, some eutectic identified as α(Al) + θ(Al_2Cu) can be found (Fig. 5(c) - 5 (d)), which leads to step solidification. Eutectic liquid can "cure" hot cracks produced during solidification[5], which is also a main reason why this kind of welding joint has such a high strength.

4.2 Microstructure and properties of HAZ

The microstructure of 2195 plate at T8 treatment primarily exhibits unrecrystallized fibrous (Fig. 3(d)), in which the main phase are α(Al) matrix, plate-like T_1 (Al_2CuLi) phases and needle-like θ (Al_2Cu) phases[6-8]. Generally, the recrystallization temperature of aluminum alloys is 200 - 300 ℃. During the welding heat input, in the base metal close to the weld, the temperature is high up to solution temperature, the majority of strengthening particles obtained at T8 treatment solution into the α(Al) matrix. During the welding cooling, the cooling velocity is high, this part of base metal is rapidly quenched and forms supersaturated solid solution. At room temperature, the supersaturated solid solution discomposes slowly and secondary phases precipitate, producing partial natural aging strengthening. During the welding heat input, the temperature of HAZ far from the weld is not so high that overaging occurs in this area[9, 10] (Fig. 5(f)), which reduces the original aging strengthening effect of alloy and results in formation of "softened zone" within the HAZ.

5 CONCLUSIONS

1) Aluminum alloy welding wire microalloyed by minor Sc, Zr, Ti, V, B has good compatibility with 2195 alloy. At TIG welding condition, the strength coefficient of welding joint can reach 0.70.

2) High strength of the weld joint mainly comes from fine-grain strengthening and dispersive precipitation strengthening caused by Al_2Cu, Al_3Sc and Al_3Zr.

REFERENCES

[1] Pickens J R. Review recent developments in the weldability of lithium-containing aluminum alloys [J]. Journal of Materials Science, 1990, 25: 3035 - 3047.

[2] Fielding P S, Wlof G J. Aluminum-lithium for aerospace [J]. Advanced Materials and Processes, 1996(150): 21 - 23.

[3] Lin W E, Baeslace W A II, Xia D S, et al. Weld cracking susceptibility of aluminium-lithium alloys[J]. Missiles and Space Vehicles, 1996(5): 53 - 60. (in Chinese)

[4] ZHANG Zheng. Development and application of weldable Al-Li alloys[J]. Materials Engineering, 1998(9): 39 - 41. (in Chinese)

[5] REN Jia-lie, WU Ai-ping. Connection of Advanced Materials [M]. Beijing: Mechanical Industry Press, 2000. 39 - 74. (in Chinese)

[6] Kumar K S, Brown S A, Pickens J R. Microstructural evolution during aging of an Al-Cu-Li-Ag-Mg-Zr alloy [J]. Acta Mater, 1996, 44: 1899.

[7] ZHENG Zi-qiao, HUANG Bi-ping, YIN Deng-feng. Alloying role of Ag and Mg in 2195 alloy [J]. J Central South University of Technology, 1998, 20(1): 42 - 45. (in Chinese)

[8] LIU Gong-lang, BO Qiang-hen, JIANG Na. Effect of heat treatment technology on microstructure and properties of 2195 aluminum-lithium alloy [J]. Aluminum Fabrication, 2000, 23(2): 37 - 42. (in Chinese)

[9] YIN Zhi-min, ZHANG Ai-qiong, WANG Yan-jin. Microstructure and properties of welded joint of extruded 6005A aluminium alloy [J]. Light Alloy Fabrication Technology, 2001, 29(1): 32 - 34. (in Chinese)

[10] PENG Yun. Mechanical properties of aluminum alloys [J]. Light Alloy Fabrication Technology, 1994, 22 (3): 33 - 36. (in Chinese)

(Edited by YANG Hua)