EFFECT OF ALLOYING ELEMENTS ON SOLIDIFICATION STRUCTURE OF 8090 Al—Li ALLOY WELDS

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Abstract

The influence of magnesium, zirconium and cerium additions on the hot crack sensitivity of 8090 aluminum-lithium alloy weld metal was investigated. Appropriately increasing the contents of these alloying elements in the weld metal significantly altered the morphology of the solidification structure, which promoted the coarse columnar grains to change into fine equiaxial dendrites with well developed secondary arms and the eutectic to be seperated in the form of dots spread over the matrix, so that caused the sensitivity to hot crack of 8090 Al-Li alloy welds to evidently decrease.

Introduction

With the advantages of low density and high elastic modulus compared with conventional aluminum alloys, 8090 Al-Li alloy is of particular interest for aircraft and aerospace industries as a new kind of light constructional alloy. However, relatively higher sensitivity to hot crack, which brings about the alloy difficult to be welded, restricts its further application. Studies have been performed to solve the problem[1,2]. Previous results shown that the sensitivity to hot crack of Al-Li alloy welds was evidently dependent on the solidification structures of welds while alloying in welds was an efficient way to improve microstructures of welds[3].

This paper, using filler metals with different chemical compositions, deals with the effect of alloying elements on the solidification structure of 8090 Al-Li alloy welds, and the relationship between microstructure and the tendency to hot crack has also been discussed.

Experimental procedures

8090 Al-Li alloy sheets with the thickness of 3. 0 mm were used. The nominal composition of the alloy is listed in Table I. The sheets were solid solution heat

Table I . Nominal composition of 8090 alloy (wt%)

Cu	Li	Mg	Zr	Ti	Al
1. 3	2. 4	1. 0	0. 1	0. 04	bal.

treated at 520℃ for 0. 5hr and artificially aged at 190℃ for 20hr prior to welding. To study the effect of alloying elements, two types of new fillers have been designed on the basis of Al-5Mg alloy by adjusting its components (See Table Ⅱ). For the sake of contrast, 8090 alloy was also used as a filler.

Table Ⅱ . Composition of new fillers (wt%)

No.	Mg	Li	Zr	Ce	Al
1	5. 0	1. 5	0. 2		bal.
2	6. 3	1. 5	0. 3	0. 1	bal.

Transverse-varestraint test was used to estimate the trend toward weld hot crack by using gas tungsten arc (GTA) welding with alternative current. Welding parameters listed in Table Ⅲ were held constant for each test and provided approximately a 50% depth of peretration through the thickness of the specimens. 0. 5% augmented strain was caused during solidification of weld metal in varestraint testing.

Table Ⅲ . Welding parameters

Arc current A	Arc length mm	Travel speed mm/s	Tungsten dia. mm	Ar flow L/min
70—75	2. 0	2. 3	2. 5	8

Solidification cracking fractured surfaces were observed with SEM to obtain fractographic morphology of solidification structure in welds.

Results

Total length (L_T) and number (N) of solidification cracks in weld metals obtained by means of adding different filler alloys are shown in Figure 1. It is suggested that the 8090 alloy filler is unsuitable for welding the alloy itself due to higher sensitivity to hot crack; Filler No. 1, however, tends to reduce the sensitivity to weld hot cracking to some extent, and filler No. 2 is even better than No. 1.

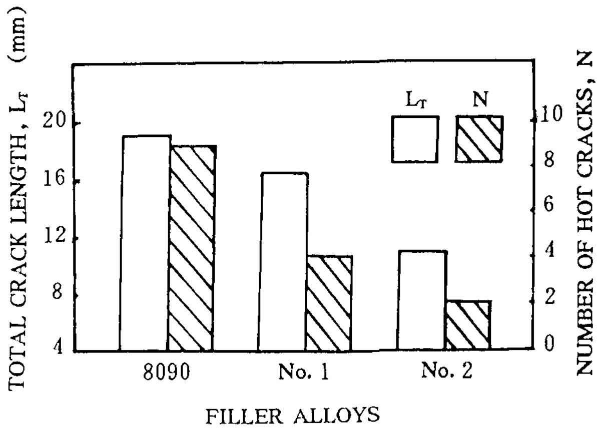

Figure 1. Total length and number of hot cracks in weld metals.

As the results of metallographic and fractographic analysis on welds and fractured surfaces of hot cracks respectively, it has been seen that there are considerable differences in solidification structures with various alloying additions. The microstructure of the weld with 8090 filler alloy is mainly composed of coarse, consecutive and regularly oriented columnar grains growing from the bottom of the weld to surface in the form of epitaxial growth, and the substructure is also coarse columnar dendrites without evident arms (Fig. 2). Increased magnesium and

Figure 2. Microstructure (a) and substructure (b) of weld metal with 8090 filler.

zirconium contents in weld metal through filler No. 1, the morphology of the solidification structure is changed to a certain extent. Figure 3 indicates that the solidification structure still consists of columnar grains but both the continuity and the directionality are weakened, and the embryoes of the secondary arms come out on the columnar dendrites. Containing more alloying elements, filler alloy No. 2, as shown in Figure 4, has changed the aforementioned microstructure of weld into fine equiaxial dendrites and grain orientation becomes not clear, furthermore, the secondary arms of equiaxial dendrites are well developed. It is obvious that the appropriate additions of alloying elements in 8090 alloy welds may improve the form of solidification structure and result in a reduction in hot cracking sensitivity.

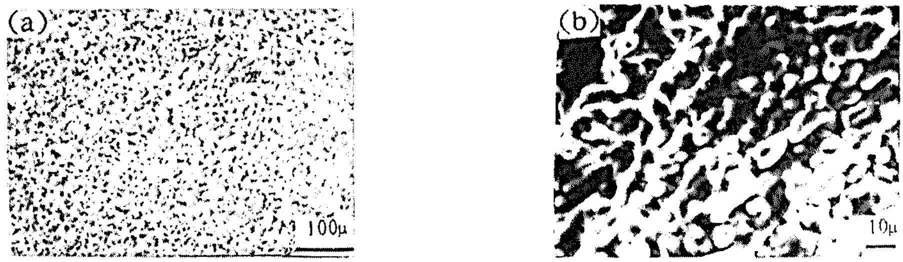

Figure 3. Microstructure (a) and substructure (b) of weld metal with filler No. 1.

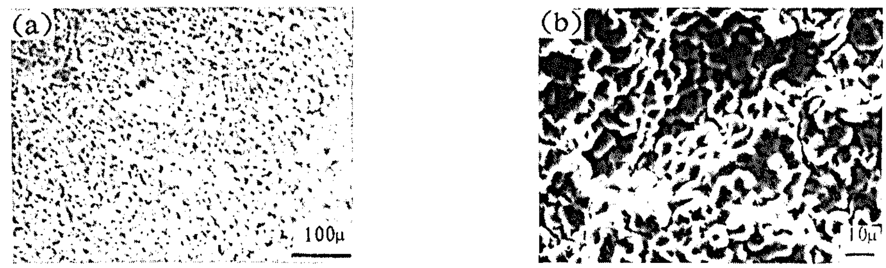

Figure 4. Microstructure (a) and substructure (b) of weld metal with filler No. 2.

Discussion

Effect of alloying elements

Zirconium is usually applied as a grain refiner to modify the solidification structure of weld. In aluminum alloys zirconium causes the formation of intermetallics $ZrAl_3$ with the melting point of 1577℃ during solidification[4]. The fine and dispersed $ZrAl_3$ particles may act as nuclei of heterogeneous nucleation to promote grain refinement. Meanwhile, such elements as magesium, lithium and cerium are all surface active agents in melted aluminum. Li and Ce have smaller atomic radius thus concentrating in the liquid adjacent to the solid-liquid interfaces and filling up α-Al crystal surface defects so as to retard grain growth. These elements can also reduce crystal surface energy efficiently to bring down the critical energy required for heterogeneous nucleation and to increase the rate of heterogeneous nucleation. Besides, because the distribution coefficient K_S/K_L of Mg, Li and Ce in aluminum alloys is less than 1, they are pron to be rich in the liquid of near surface layer to lead to contitutional supercooling and bring down the energy portion required for compensating interfacial energy consumption during the growth of the hillocks on the crystal caused by interfacial disturbance, thus, the formation of dendrite arms becomes easier. These effects produce a decrease in the stability of solid-liquid interface and therefore promote the development of secondary arms.

In addition to the functions mentioned above, rare-earth cerium can also play the role as an inoculant. Because cerium is chemically active and the solid solubility in α-Al is less than 0.05%, it tends to combine with aluminum to form intermetallic compounds such as $CeAl_2$ and $CeAl_4$ with melting points of 1465°C and 1250°C respectively[5], which are much higher than that of aluminum (660°C). The lattice type and size of the compounds are of less disregistry compared with that of aluminum so these particles would play the role as substrates for heterogeneous nucleation of aluminum and provide a high nucleation rate and iso-orientational growth so that produce the formation of fine equiaxial grains in welds.

According to the above-mentioned discussions and refering to Table I, it can be seen that using 8090 alloy as filler the content of zirconium as well as surface active element magnesium in weld metals are relatively fewer, and the effects of these elements on the solidification structure are yet weaker so that the weld structurd is mainly composed of the coarse columnar grains regularly oriented without any evidence on the formation of secondary arm. However, in filler No. 1, with the increase of zirconium and magnesium contents the effect of grain refinement is enhanced so as to impair the continuous growth of columnar grains, and to form the embryoes of secondary arms. Containing certain amount of rare-earth element cerium and more magnesium and zirconium, filler No. 2 is bound to exert a considerable influence on the microstructure. On one hand, the further increase of Zr content and addition of Ce would promote grain refinement more effectively, and on the other hand, Mg and Ce not only decrease the solid-liquid interface tention and critical nucleation energy but also increase the extent of constitutional supercooling as stated above. Therefore, in the weld metals of filler No. 2 the feature of columnar grain becomes unclear and a largy amount of equiaxial dendrites with well developed secondary arms appear instead.

<u>Effect of solidification structure on hot crack sensitivity</u>

It can be seen from the results of varestraint test that the hot crack sensitivity of 8090 Al-Li alloy welds may be reduced by alloying which promote grain refinement and development of equiaxial dendrites. The reasons are considered as follows:

1) The refined grains with equiaxial dendrite substructure, on one hand, make shrinkage strain produced during solidification to be carried by more grains; and on the other hand, may retard hot crack propagating continuously along grain boundaries which become tortuous and occupy extended total area. The change in substructure, i. e. , the appearance of secondary arms, may greatly expand the bridging area between dendrites, thus results in an acceleration in the strength restoration of weld metals in mushy solid-liquid condition, Therefore, with the decrease of temperature, it is necessary to tear more metal bridges between dendrites, and the consume more energy. As a result, to crack initiation and propagation become more difficult.

2) The change in substructure leads to an improvement of the eutectic distribution which in turn reduces the hot cracking susceptibility of 8090 Al—Li alloy weld metals.

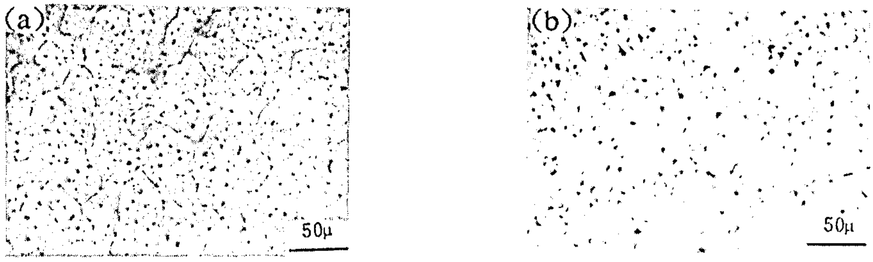

Figure 5. Eutectic distribution of weld with filler alloy 8090 (a) and No. 2 (b)

Figure 5 shows the distribution of eutectic in the middle of welds with filler alloys 8090 (a) and No. 2 (b) relatively, As said above, while using 8090 filler the microstructure presents the feature of coarse columnar grains with undeveloped secondary arms which have smaller total interface area. In the final stage of solidification liquid eutectic distributes in the form of continuous networklike film along the smooth grain boundaries and interfaces, thus producing low conjunct strength between interfaces and poor resistance to hot cracking. Nevertheless, in the weld with filler alloy No. 2. because of the formation of fine equiaxial grains with well developed dendrites the eutectic is seperated by the dendrite arms in the form of dots spread over the matrix and then the susceptibility to cracking is controlled.

Conclusions

1) Additions of magnesium, zirconium and cerium may significantly promote the grain refinement of 8090 Al-Li alloy weld metal.

2) It can evidently reduce the sensitivity to hot crack of 8090 Al-Li alloy welds that solidification structure changes into fine equiaxial dendrites, secondary arms are well developed, as well as eutectic is seperated in the form of dots spread over the matrix.

3) Designed filler No. 2 is suitable for welding 8090 Al-Li alloy without crack formation.

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