

EFFECT OF RESTRAINT STRENGTHENING OF VACUUM-PRESSURED BRAZED JOINT^①

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ABSTRACT A restraint strengthening model of brazed joint was developed according to vacuum brazing of AlLi alloys containing cerium under constant pressure. The effects of several brazing filler metals on restraint strengthening were also examined. The results indicated that the theoretically trend of strength change of brazed joint was basically consistent with experimental data.

Key words AlLi alloys containing cerium vacuum-pressured brazing restraint strengthening

1 INTRODUCTION

The initial mechanical properties of brazing fillers and the size of brazing gap have great effects on the strength of joint. Generally the brazed joint consists of three zones, that is, diffusion zone, bond zone and central zone. The former two zones are microalloying zones formed through diffusion of filler elements to base metal and fusion of elements in base metal to filler respectively. With lower alloying degree and much larger size, the central zone of joint keeps initial components so the strength of that zone is lower than that of the joint. Adjusting joint gap size can not only change volume fraction of central zone to joint but also control the degree of interaction of base metal and filler, so, the gap size, with which the strength of joint is greater than that of filler, is called the best brazing gap^[1]. Because AlLi alloy containing cerium has lower melting point, and its overheating temperature is about 530 °C^[2], it is more difficult to improve the strength of brazed joint. The paper, combining matching filler with definition of brazing clearance, and introducing constant pressure in the process of vacuum brazing of 2090Ce alloy other than analyzing isolately the relationship among filler type, gap size and strength of the joint, tries to accurately control the size of joint

gap and improve alloying extent so as to increase the joint strength, and develop a quantitative relationship among joint strength of AlLi alloy with cerium, filler type and brazing clearance.

2 RESTRAINT STRENGTHENING MODEL OF BRAZED JOINT

The brazed joint is an uneven body. When a tensile force acted on it, the plastic deformation of braze metal will be rigidly restrained by base metal so that a triaxial tensile stress should be created. Thus, the relationship between strength of brazed joint and joint gap size can be expressed as follows^[3]:

$$P_{CY} = 2 \int_0^{w-a} \sigma_s B [1 + \ln(1 + \frac{x}{a})] dx \quad (1)$$

where $2w$ and B are width and thickness of specimen respectively; a is radius of uneven zone. Under the conditions of the paper, if $2a$ in Eqn. (1) is replaced by joint gap h , σ_s is replaced by tensile strength of the brazing filler metal σ_y , and then $2(w-a) \cdot B$ is replaced by $(2w-h) \cdot B$, adding a revising coefficient A , then through integral, we get from Eqn. (1):

$$P_{CY} = A \sigma_y (2w-h) B (1 + \frac{h}{2w-h}) \cdot \ln(1 + \frac{2w-h}{h}) \quad (2)$$

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thus, the strength of joint, σ_b , is

$$\sigma_b = A \sigma_y \left(\frac{2w}{2w-h} \right) \ln \left(1 + \frac{2w}{h} \right) \quad (3)$$

The revising coefficient A is proposed due to the difference of plasticity between filler and base metals. When the difference is greater, A will be a lower value; otherwise, A should be higher. Now when knowing the data of width of specimen and strength of filler metal, according to Eqn. (3), we can obtain the theoretic result used for experimental verification.

3 EXPERIMENTAL

The base metal was 2090Ce Al-Li alloy sheet with a thickness of 2.0 mm, the brazing filler metals were Al-Si-Ge and HL401 alloys, the compositions and main mechanical properties of materials are shown in Table 1.

Table 1 Composition (%) and mechanical properties of tested materials

Alloys	Li	Cu	Zr	Ti	Ce	Ge
2090Ce	2.4	2.7	0.1	0.05	0.2	-
Al-Si-Ge	-	-	-	-	-	34
HL401	-	30	-	-	-	-
Alloys	Si	Al	σ'_1 /MPa	σ'_{y1} /MPa	σ'_{y2} /MPa	δ /%
2090Ce	-	bal.	440	-	-	4.3
Al-Si-Ge	4	bal.	-	167	-	20.7
HL401	13	bal.	-	-	50	1.7

a — tensile strength of base metal;

b — tensile strength of filler metal

The dimension of the specimen was 75 mm \times 20 mm \times 2 mm, the specimen was chemically milled to 0.1 mm thick by NaOH and then assembled accurately on a vacuum-pressured brazing apparatus prior to brazing. The joint gap size was 0.025, 0.05, 0.075, 0.10, 0.15, 0.175, 0.25 and 0.35 mm respectively. The vacuum-pressured brazing conditions were: vacuum 0.5 mPa, restraint pressure 0.8 MPa, heating temperature/holding time 500 °C/3 min for Al-Si-Ge filler, and 525 °C/5 min for HL401 filler, respectively. The microstructure of brazed seam was examined and the size of joint gap was mea-

sured through metallography. The auger energy spectrometer (AES) was used to obtain the distribution of chemical elements of seam surface and inside the seam, the strength of brazed joint was also examined using Instron tensile tester.

4 RESULTS AND DISCUSSION

The theoretical data and experimental are shown in Fig. 1. It is clear that when $A = 0.2$ and $h \geq 0.05$ mm, the evaluated result is consistent with experiment one for Al-Si-Ge filler; and when $A = 0.4$ but $h \geq 0.10$ mm, the two results are in good agreement for filler HL401. The plasticity of filler Al-Si-Ge is about 5 times of that of base metal, and plasticity of filler HL401 is inferior to half of that of base metal, so the former has stronger restraint strengthening effect than the later. The results coincide with the condition of determining revising coefficient A in the restraint strengthening model. Meanwhile, when $h < 0.05$ mm and $h < 0.10$ mm, the large difference between evaluation and measurement of the two kinds of seams is consistent with poor compactness; at this time brazing gap just likes a closed cavity with lower vacuum, in which oxide film can not be efficiently eliminated and liquid brazing filler may flow out of joint gap, thus the seam of poor compactness is formed. In Eqn.

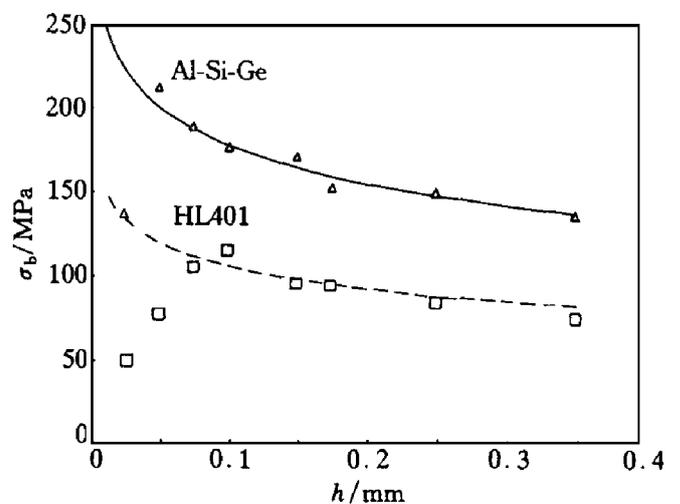


Fig. 1 Relation curves of σ_b vs h

Solid line — evaluated value, $A = 0.2$;

Dotted line — evaluated value, $A = 20.4$;

Δ , \square — experimentally measured value

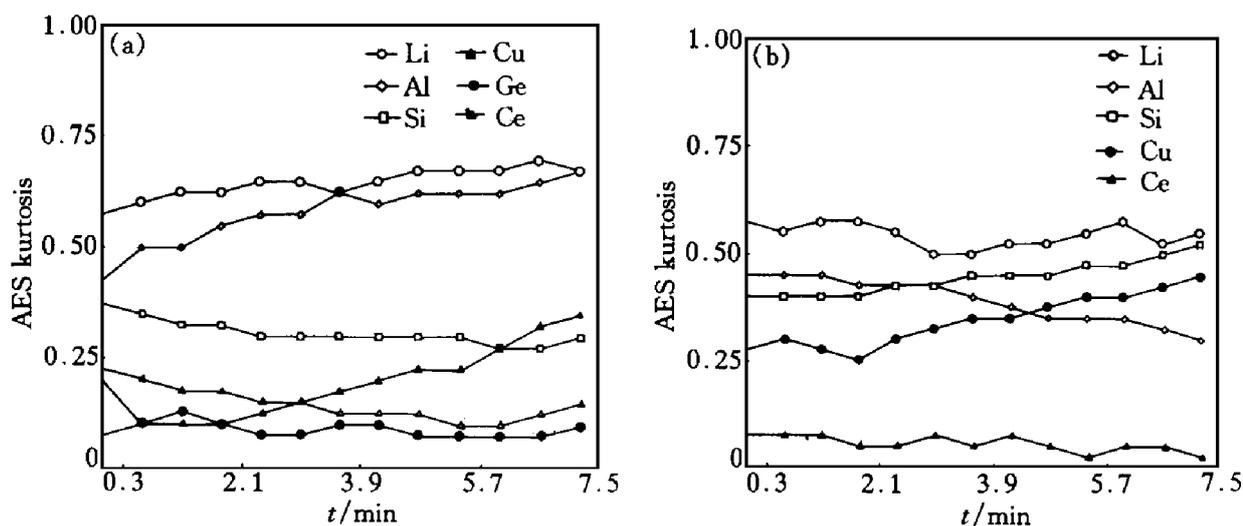


Fig. 2 Distribution curves of elements in brazing seam

(3), coefficient A is not suited to this condition, in other words, it is unnecessary to study it due to poor compactness defects in brazing joint.

In order to further reveal effecting mechanism of restraint strengthening of the two brazing fillers, the element distributions in seams were examined through AES method, as shown in Fig. 2, in which the ordinate is amplitude of differential $dN(E)/dE$ of Auger electronic energy produced from the seam surface excited by incident 10^2 eV electronic energy, that is, the ordinate indicates the half-quantitative result of element distribution on the seam surface. Under condition of constant electronic beam radius d_p , with time going on, Auger electrons in different depth can be stimulated out to be used for half-quantitative analysis, so, according to this method, the abscissa reflects the element distribution trend along direction of seam thickness.

In comparison with the crystal structures of the addition elements Ge, Si and Cu, the effect of pressure on diffusion of Ge and Si is greater than that of Cu because Ge and Si have larger atomic diameter than Cu^[4]. Under the condition of vacuum-pressured brazing, Ge and Si in AlSiGe filler diffuse from brazing seam to base metal to increase relative amount of aluminium in seam, at the same time, lithium and cerium in base metal diffuse into seam to increase their amount in seam (Fig. 2(a)). For the same reasons, the amount of aluminium in the seam of HL401 filler keeps almost constant, so the

amounts of lithium and cerium in the seam appear to decrease (Fig. 2(b)). When seam metal solidifies, lithium and cerium in it are prone to be rich in the solid-liquid interface acting as surface active agents in melted metal, because the distributing coefficient K_S/K_L of Li and Ce in liquid Al alloys is less than 1. So the increase of amounts of lithium and cerium in seam can efficiently reduce interfacial energy of grains and critical energy required for heterogeneous nucleation, and increase the rate of heterogeneous nucleation. Therefore, it is beneficial to refine solidification structure to expand the bridging area between dendrites, which results in an acceleration in the plasticity and strength restoration of seam metal. These physicom metallurgical functions of the main additions in base metal and fillers lead the seam structure of AlSiGe filler (Fig. 3(a)) to mainly consist of α -Al (white phase) and AlSiGeLi tetra-eutectic (strip phase); and that of HL401 to consist of α -Al (white phase), θ -CuAl₂ (black phase) and eutectic Si (strip phase). Compared with the seam microstructure features, it can be seen that α -Al in Fig. 3(a) is finer and eutectic strip is thicker. As a result, the plasticity of AlSiGe seam metal is certainly better than that of HL401. Besides heat circle history during brazing, the differences of microstructure and properties between two kinds of seams depend clearly upon the physicom metallurgical functions of Li and Ce.

According to fracture mechanical theories,



Fig. 3 Micrographies of brazed seams

activated by external force, the stress distribution in seam of Al-Sr-Ge filler with good plasticity changes, that is, compression stress at the edges of seam may gradually decrease and change to tensile stress, and tensile stress in the center increase continuously till σ_3 , then the stress is gradually and evenly distributed on the section. Nevertheless, due to higher restraint of base metal, the seam metal may be forced by triaxial tension so that the plastic deformation is in fact difficult to develop, *i. e.*, the seam is strengthened by restraint. On the other hand, with poor plastic deformation ability, brittle seam metal of HL401 filler has not the even distributing process as described above with the increase of external tension, so the stress increases continuously till σ_b , as a result, the restraint strengthening effect is not clear.

5 CONCLUSIONS

(1) The experimental results indicate that, under condition of vacuum-pressured brazing, the restraint strengthening effect of Al-Li alloy brazed joint can be expressed by Eqn. (3);

(2) Putting specified pressure on joint during brazing can result in improvement of interac-

tion between base metal and filler so as to increase restraint strengthening effect. Moreover, the joint formed by the filler with higher plasticity has better restraint strengthening effect;

(3) It is an important method for improving brazed joint strength of Al-Li alloy containing cerium to use the fillers of lower melting point, and good plasticity during vacuum pressured brazing;

(4) Under the condition of vacuum pressured brazing, the best joint gap size, if using Al-Sr-Ge and HL401 fillers, is 0.10~0.20 mm for 2090Ce Al-Li alloy, and the size is less than those for general aluminium alloys.

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