DOI: 10.4149/km_2013_2_129

Microstructure characteristics near the interface of vacuum brazing of Al/Cr18-Ni8 stainless steel

Y. Li*, J. Wang, N. Wu

Key Laboratory for Liquid-Solid Structural Evolution and Processing of Materials (Ministry of Education), Shandong University, Jinan 250061, P. R. China

Received 8 May 2012, received in revised form 20 July 2012, accepted 10 September 2012

Abstract

The microstructure characteristics of vacuum brazing interface of Al/Cr18-Ni8 stainless steel was researched by means of SEM micro-hardness test and X-ray diffraction (XRD). The test results indicated that the adhesion brazing interface was excellent, and there was no porosity or micro-crack near the interface. The microstructure of the Al/18-8 brazing joint was mainly composed of equiaxial crystal and column crystal. The fracture morphology of the brazing joint mainly consists of coarse and gray fiber-shape fracture, and the fracture was mainly the mixed fracture of the toughness and cleavage. The brazing interface consists of δ(Al, Fe, Si) phase and α-Al(Si) solid solution, without obvious brittleness phase of the high hardness.

Key words: vacuum brazing, interface, microstructure, fracture X-ray diffraction

1. Introduction

In recent years, the layer clad structure of aluminum and stainless steel (Al/Cr18-Ni8) combined the thermal strength and the corrosion resistance of stainless steel as well as the low density and high heat conductivity of aluminum, was paid more attention by many researchers [1–4]. The demand for joints of aluminum and stainless steel has greatly increased in a wide range of industrial applications from automobile, rail, aviation industries to smaller and more commonly used products, such as saucepans [5, 6]. Due to the difference of the melting point, coefficient of heat conductivity and specific heat volume, the clad structure can produce thermal stress. The refractory oxide film results in inclusions of the brazing metal. So it is difficult to welding aluminum and Cr18-Ni8 stainless steel together [1, 7, 8].

In this paper, Al/Cr18-Ni8 dissimilar materials are successfully welded together by means of advanced vacuum brazing technology. The unfavorable effect of physics state of the brazing interface can be avoided by means of vacuum brazing technology, and the reliable brazing metal can be obtained. The microstructure and hardness distribution of the brazing interface were researched by means of scanning electron microscope (SEM) and micro-hardness test. The phase constitution was analyzed by X-ray diffraction (XRD). The microstructures performance of the brazing joint were further analyzed, and the brazing technology parameters are emphasized, which is important for enlarging the application of the clad structure of Al and 18-8 stainless steel.

2. Experimental

Vacuum brazing was performed using a 2.5 mm thick aluminum (1060) of 10 mm × 30 mm in size for the top sheet. The bottom sheet was 2.5 mm thick Cr18-Ni8 stainless steel (1Cr18Ni9Ti) of similar size with that of aluminum. The brazing filler alloy was Al-Si-Cu alloy. Chemical composition and thermophysical performance of the test materials were shown in Table 1 and Table 2.

Before brazing, the oxide film on the surfaces of Al

*Corresponding author: tel.: +86-0531-88392924; e-mail address: yajli@sdu.edu.cn

Table 1. Chemical composition of the base metal in the test

Materials	Chemical composition (wt.%)									
	Al	Cu	Fe	Si	Mn	Mg	C	Cr	Ni	Ti
Al 1060	**Balance**	0.05	0.35	0.25	0.03	0.05	–	–	–	–
1Cr18Ni9Ti	–	–	other	1.0	2.0	–	0.12	17.0–19.0	8.0–11.0	0.5–0.8
Al-Si alloy	**Balance**	3.4	–	9.15	–	–	–	–	–	–

Table 2. Thermo-physical performance of the base metal in the test

Materials	Melting point (℃)		**Density ($kg\ m^{-3}$)**	Average specific heat volume ($J\ kg^{-1}\ K^{-1}$)	Melting potential heat ($kJ\ mol^{-1}$)	Heat conductivity ($W\ m^{-1}\ K^{-1}$)
Al 1060	657		$\mathbf{2.07 \times 10^3}$	917	10.47	238
1Cr18Ni9Ti	1539		$\mathbf{8.03 \times 10^3}$	451.4	–	71.17
Al-Si alloy	Solidus line 577	Liquidus line 582	$\mathbf{2.90 \times 10^3}$	–	–	–

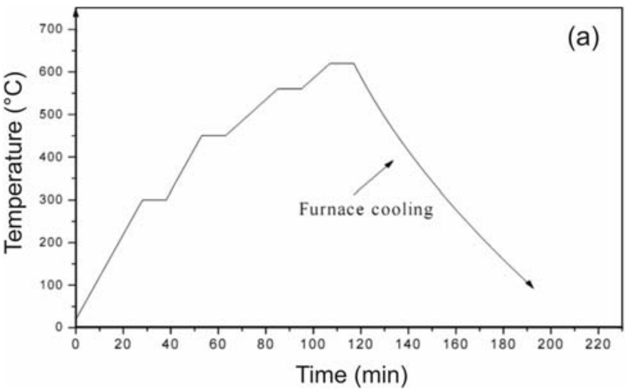

Fig. 1. Technology parameters (a) and brazing equipment (b) for vacuum brazing of Al/Cr18-Ni8 stainless steel.

and Cr18-Ni8 stainless steel was cleaned by HF solution with a concentration of 10 %. Brazing equipment and technological parameters of the vacuum brazing in the test were shown in Fig. 1. The peak heating temperature was 620 ℃ and the holding time was 10 min. Three temperature holding steps were conducted to improve the consistence of temperature in the whole furnace. Parameters in the vacuum brazing equipment were: the heating power 45 kW, the vacuum degree 5×10^{-5} Pa.

After brazing, a series of specimens were cut from the location of the Al/Cr18-Ni8 brazing joint. The metallographic samples were prepared by being grounded, polished and etched in a solution of hydrochloric acid (concentration is 36.5 %) 10 ml, ferric chloride 5 g and water 100 ml for 5–10 s. Then they were observed and analyzed by means of microscope and SEM. Fracture of the Al/Cr18-Ni8 brazing joint was analyzed by means of SEM.

3. Results and analysis

3.1. Microstructure and micro-hardness in the brazing interface

Microstructure of Al/Cr18-Ni8 vacuum brazing joint observed by SEM is shown in Fig. 2a–d. There was no porosity and crack near the brazing interface. The obvious microstructures of columnar crystal can be observed. The columnar crystals grow and stretch from Al side into the brazing metal. The morphology

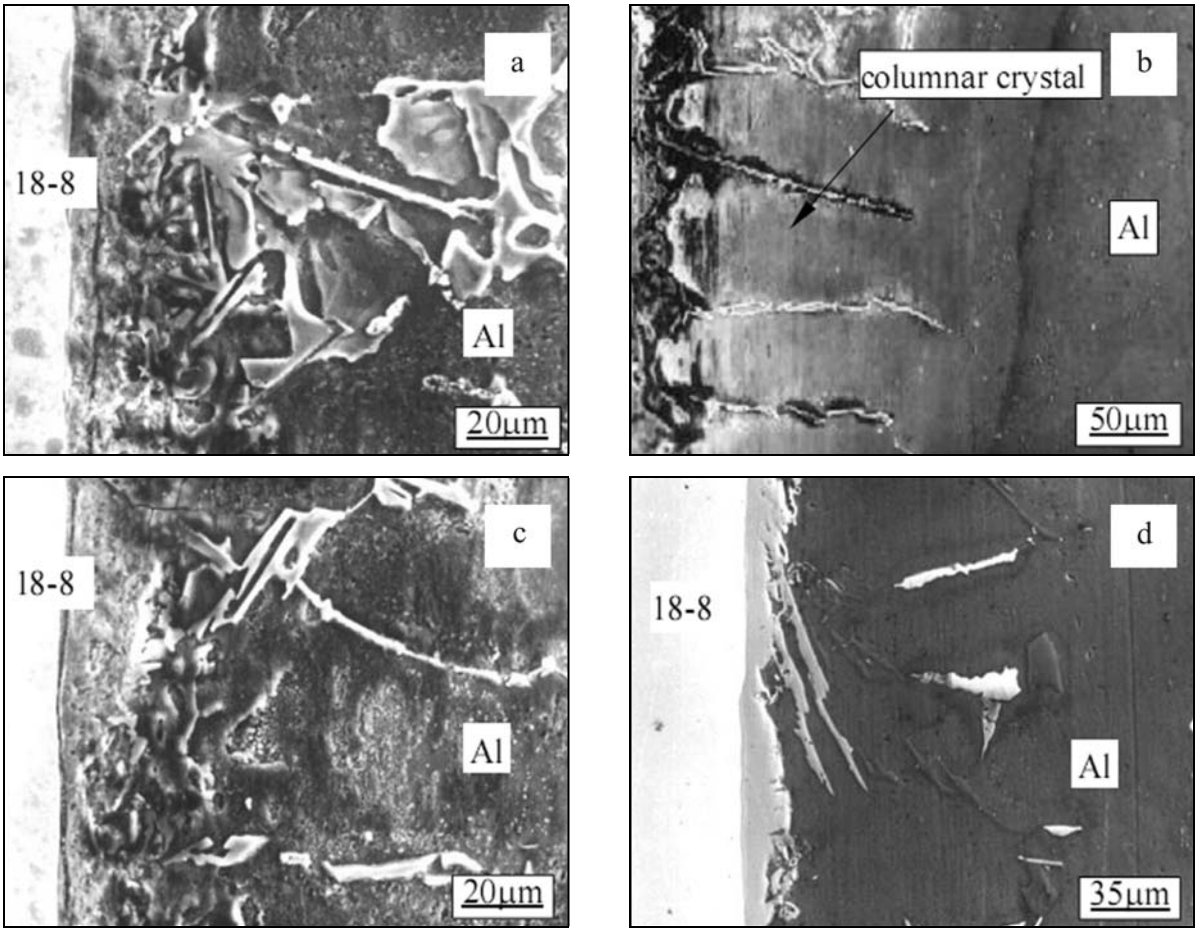

Fig. 2. Microstructure near the interface of Al/Cr18-Ni8 vacuum brazing joint: (a) brazing metal, 200×, (b) columnar crystal, (c) dendrite crystal, 500×, (d) primary crystal Si, 300×.

of the Al matrix close to the brazing metal is shown in Fig. 2b. The position of the microstructure is parallel in relation to the interface. There are new phases in the surface of the Al matrix.

The dendrites in the brazing interface can be observed (Fig. 2c). The composition measured by the energy dispersive X-ray (EDX) analysis indicated that the bulk and white crystals in Fig. 2d were the primary crystal Si, the fine and white strip crystals were the eutectic Si, and the black matrix was α-Al(Si) phase. At 577 ℃, the largest solubility of the Si in α-Al(Si) phase is 1.65 % [7]. In the center of the brazing metal, the state of the brazing filler metal was Al-Si eutectic, and the α-Al(Si) phase can be also observed in the brazing interface. During the vacuum brazing α-Al phase would be firstly separated from the brazing interface, and then separated from the primary crystal Si and the eutectic Si. The α-Al(Si) phase is favorable for the microstructure performance of the Al/Cr18-Ni8 brazing joint.

The micro-hardness of Al/Cr18-Ni8 brazing interface was measured by means of the Shimadzu type micro-sclerometer, using 15 g loading and a load time of 10 s. The test result of micro-hardness is shown

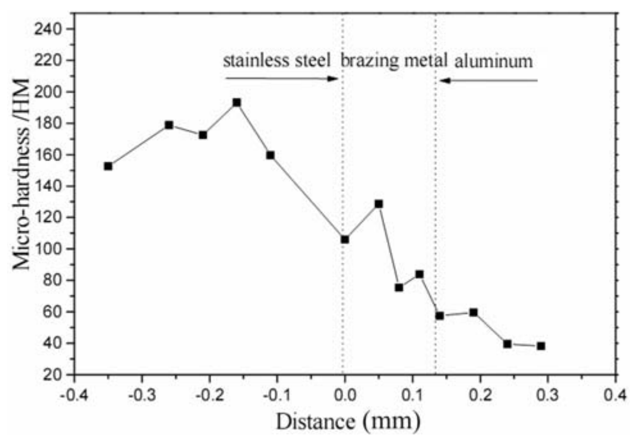

Fig. 3. Micro-hardness near the brazing interface of Al/Cr18-Ni8 stainless steel.

in Fig. 3. The micro-hardness from the Al side to the Cr18-Ni8 steel side firstly increased, and then decreased. The micro-hardness close to the brazing metal was higher than the one away from the brazing metal. When the distance of the brazing metal center close to

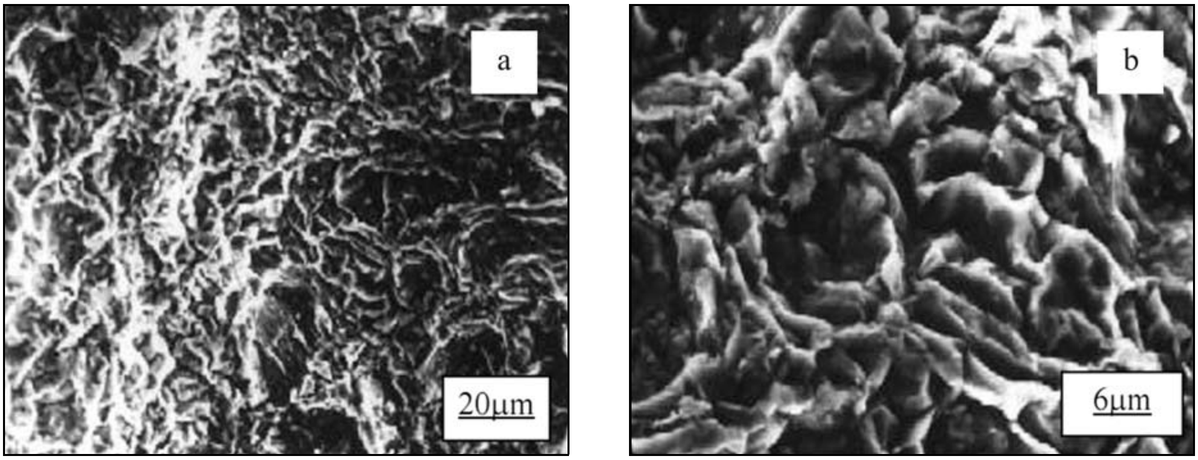

Fig. 4. Fracture morphology of the brazing interface of Al/Cr18-Ni8 stainless steel (SEM): (a) fracture morphology, 500×, (b) local toughness zone, 1500×.

the Cr18-Ni8 steel side was about 0.4 mm, the micro-hardness decreased gradually. When the distance of the brazing metal center close to the Al side was about 0.25 mm, the micro-hardness also decreased gradually. There was no obvious brittleness phase of the high hardness near the interface.

With the composition change of Al and Cr18-Ni8 steel matrix close to the brazing metal, the micro-hardness of Al/Cr18-Ni8 brazing interface was also changed. At 630 ℃ (the holding time $t = 10$ min), the Al and Fe diffused to a small extent. The diffusion of the Al was larger due to the melting point (660 ℃) of Al near to the brazing temperature (620–640 ℃). Therefore, the composition of Al matrix close to the brazing metal was changed.

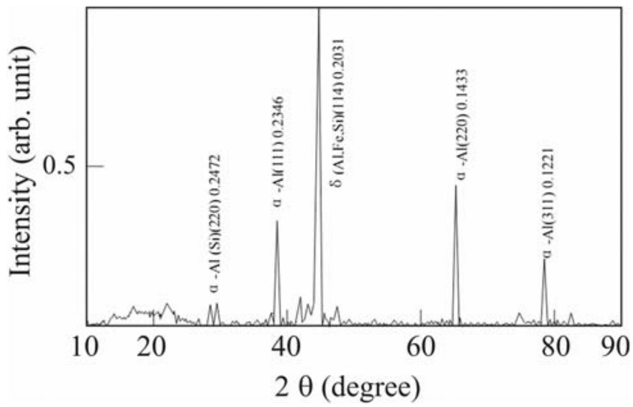

Fig. 5. X-ray diffraction diagram for the brazing interface close to aluminum side.

3.2. Fracture morphology of the brazing joint

The obvious fracture morphology of the cleavage and toughness can be observed (Fig. 4a) by means of the JXA-840 scanning electron microscope (SEM). The fracture morphology of the brazing metal mainly consists of coarse and gray fiber-shape fracture. The inter-atomic bond between the brazing filler metal and the matrix was destroyed and produced the trans-granular fracture. The cleavage and second-fracture would be also produced together, but the second-fracture was quite small. The mixed fracture of the cleavage and toughness can be observed, where the proportion of the toughness fracture was quite large. The fracture morphology consisted of dimple, observed by means of SEM (Fig. 4b). There were the impurity and the second-phase particles in the center of dimple. The dimple was produced due to the difference of ductility and toughness of the second-phase particle and the matrix. With the increasing of ductility deformation and the dimple, the gather and joining of the micro-hole produced the fracture.

There were different mechanical bond zone and freedom surface in the fracture of brazing joint. The dimension of the mechanical bond zone was small. The metal of two sides was combined closely and formed the metallurgical bond. The dominant feature of the brazing interface fracture was the mechanical bond and the freedom surface. The test results indicated that the fracture morphology was mainly the mixed fracture of the toughness fracture with a little cleavage, and had certain toughness. It is favorable for the performance of the Al/Cr18-Ni8 brazing joint.

3.3. X-ray diffraction analysis in the brazing interface

The sample of brazing interface of Al/Cr18-Ni8 steel was analyzed by means of X-ray diffraction (XRD), using a copper target. The working voltage was 25 kV and the working current was 150 mA. The X-ray diffraction result of phase constituents for the brazing interface is shown in Fig. 5. The comparison of results with data, which were published by

Table 3. X-ray diffraction analysis results for the Al/Cr18-Ni8 brazing interface

Testing value	Data from JCPDS								
	δ(Al, Fe, Si) phase			Al			α-Al(Si) phase		
d (nm)	*d* (nm)	hkl	I/I_0	*d* (nm)	hkl	I/I_0	*d* (nm)	hkl	I/I_0
0.3149	0.312	003	5	–	–	–	–	–	–
0.3056	0.304	200	5	–	–	–	–	–	–
0.2473	–	–	–	–	–	–	0.2465	220	50
0.2347	0.236	112	20	0.234	111	100	–	–	–
0.2032	0.207	114	100	0.2024	200	47	–	–	–
0.1742	–	–	–	–	–	–	0.1749	400	50
0.1484	–	–	–	–	–	–	0.1486	332	20
0.1433	–	–	–	0.1431	220	22	–	–	–
0.1296	–	–	–	–	–	–	0.1298	520	20
0.1221	0.1228	207	5	0.1221	311	24	–	–	–
0.1171	–	–	–	0.1169	222	7	–	–	–

the Joint Committee on Powder Diffraction Standards (JCPDS), is shown in Table 3.

The XRD test results indicated that the Al/Cr18-Ni8 brazing metal consisted of δ(Al, Fe, Si) phase, α-Al(Si) solid solution and Al. The existence of δ(Al, Fe, Si) phase increased the hardness of the brazing metal. The chemical composition of δ(Al, Fe, Si) phase was: Fe 15 %, Si 20 % and Al 65 %. So the high aluminum content provided ductility and toughness for the Al/Cr18-Ni8 brazing joint. The eutectic microstructure of α-Al(Si) solid solution increased the strength and hardness of the brazing joint, and improved the corrosion resistance.

4. Conclusions

1. Al/Cr18-Ni8 dissimilar materials are successfully welded together by means of the vacuum brazing technology (the heating temperature $T = 620–640$ ℃, the holding time $t = 5–10$ min). The adhesion of the brazing interface was excellent. There was no porosity and crack near the brazing interface. The microstructure of the brazing joints was mainly composed of equiaxial crystal and columnar crystal.

2. The micro-hardness from the Al side to Cr18-Ni8 stainless steel side firstly increased and then was reduced near the interface. The micro-hardness of the brazing metal was obviously higher than that of the Al matrix. The fracture morphology of Al/Cr18-Ni8 brazing joint mainly consisted of coarse and gray fiber-shape fracture, and the fracture morphology was the mixed fracture of the toughness and cleavage.

3. X-ray diffraction test indicated that the brazing metal consisted of δ(Al, Fe, Si), α-Al(Si) and Al. The existence of δ(Al, Fe, Si) increased the hardness of the brazing metal. The eutectic structures of α-Al(Si) phase provided ductility and toughness for the Al/Cr18-Ni8 brazing joint.

Acknowledgements

This project was supported by the National Natural Science Foundation of China (51175303).

References

[1] Lin Sanbao, Song Jianling, Yang Chunli, Ma Guangchao: Acta Metallurgica Sinica, *45*, 2009, p. 1211.
[2] Song Jianling, Lin Sanbao, Yang Chunli, Ma Guangchao: Chinese Journal of Nonferrous Metals, *19*, 2009, p. 1209.
[3] Abhijit, K., Mainak, G., Kumar, R. A., Kumar, R. A.: Materials Science and Engineering A, *498*, 2008, p. 283. doi:10.1016/j.msea.2008.07.060
[4] Song Jianling, Lin Sanbao, Yang Chunli, Ma Guangchao: Science and Technology of Welding and Joining, *15*, 2010, p. 213. doi:10.1179/136217110X12665048207610
[5] Kawano, T., Inoue, Y., Matsui, M., Nishio, K.: Welding in the World, *41*, 1998, p. 88.
[6] Suganuma, K., Kawakami, N.: Material Science and Technology, *9*, 1993, p. 349. doi:10.1179/026708393790172024
[7] Li, Y.: Welding and Joining, *7*, 1992, p. 5.
[8] Roulin, M., Laster, J. W., Aradeniz, G. K., Mortensen, A.: Welding Journal, *78*, 1999, p. 151s.