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Influence of diffusion time on steel-mushy Al-7graphite bonding①

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[Abstract] The bonding of steel plate to Al-7graphite slurry was conducted using casting rolling technique. The influence of diffusion time on interfacial mechanical property and structure of bonding plate was studied. The results show that: under the condition of 510 ℃ for preheat temperature of steel plate and 32% of solid fraction of Al-7graphite slurry, the relationship between interfacial shear strength S and diffusion time t is $S = 25.3 + 4.47t - 0.133t^2 + 0.001t^3$. When diffusion time is 22.5 s, the largest interfacial shear strength 69.9 MPa is got, and the corresponding interface is made up of Fe-Al compound and Fe-Al solid solution alternatively and in a right proportion.

[Key words] diffusion time; interfacial shear strength; interfacial structure
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1 INTRODUCTION

The common steel-backed Al base bonding plate includes steel-backed Al-Sn bonding plate[1, 2] and steel-backed Al-Pb bonding plate[3, 4] mainly. Steel back has high strength, Al base has perfect thermal conductivity and lubricating property, thus this bonding plate is used for bearing[5]. At low temperature, this bearing performance is very good. However, at high temperature, the lubricant Sn or Pb in Al base will melt and run off, thus the lubricating property deteriorates rapidly[6]. This limits the application of steel-backed Al base bearing greatly.

Graphite has excellent lubricating property especially at high temperatures[7], and Al-graphite is a very ideal solid lubricant[8]. If steel-backed Al-graphite bonding plate can be prepared, the application of steel-backed Al base bearing will enlarge ulteriorly.

For steel-backed Al base bonding plate, interfacial mechanical property is very important. It dominates the usage of bonding plate. Generally, interfacial mechanical property is determined by interfacial structure. It is well known that the formation of interface is the result of diffusion of Al atoms to steel substrate and reaction with Fe atoms[9]. Therefore, diffusion time has a crucial influence on steel-backed Al base bonding plate.

The authors have successfully realized the even-distribution of graphite particles in Al-graphite composite by using semi-solid processing technique[10]. In this work, the bonding of steel plate to Al-7graphite slurry is conducted using casting rolling technique, and the influence of diffusion time on interfacial shear strength and interfacial structure of bonding plate is studied.

2 EXPERIMENTAL

The experimental materials were 1.2 mm thick 08Al steel plate, Al and 230 mesh graphite particles (about 60 μm). Al contains 1.5% Si (mass fraction), its freezing range is from 580 ℃ to 660 ℃.

The experimental procedures were as:

1) Treat steel plate surface. Firstly defat and descale the surface to get fresh surface. Secondly immerse the surface in flux (K_2ZrF_6) aqueous solution, the concentration of the solution is 7%, the temperature of the solution is 90 ℃, immersing time is 1 min, these conditions could form a 10 μm thick flux layer on the steel plate surface, this flux layer could prevent the fresh surface from oxidizing. Thirdly stove the steel plate for 1 min at 200 ℃ in order to remove the water in flux layer.

2) Prepare Al-7graphite slurry using electromagnetic mechanical stirring method[8]. The solid fraction of slurry is 32%, the precision of solid fraction is ±0.1% (controlled by the temperature of Al-7graphite slurry).

3) Conduct the bonding of steel plate to Al-7graphite slurry. Fig. 1 is the experimental equipment of steel-mushy Al-7graphite bonding. The rolling speed is

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10 mm/s and the preheat temperature of steel plate is 510 ℃, these two bonding parameters are the reasonable ones which were optimized with a genetic algorithm. The precision of speed is ±0.1 mm/s, the precision of temperature is ±1 ℃, the diameter of roller is 320 mm, the thickness of bonding plate is 2.5 mm. The diffusion of Al atoms to steel substrate happened in the pour mouth, the diffusion time is the quotient of length of pour mouth(200 mm) divided by rolling speed.

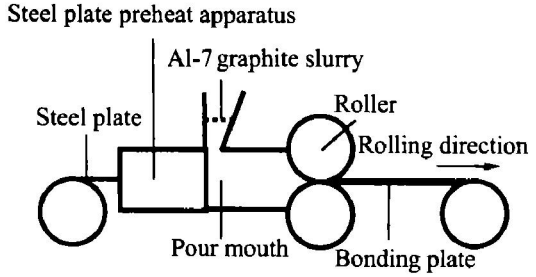

Fig. 1 Sketch of steel-mushy Al-7 graphite bonding

4) Cut up the bonding plate into testing samples for mechanical experiment and SEM experiment using linear cutting method. Testing sample for mechanical experiment is shown in Fig. 2. Testing sample for SEM experiment is block of 10 mm × 10 mm × 2.5mm, one side of this sample must be carefully ground, polished, eroded, cleaned and dried, the etching reagent is 0.5%HF, 1.5%HCl, 2.5%HNO_3 and 95.5%H_2O.

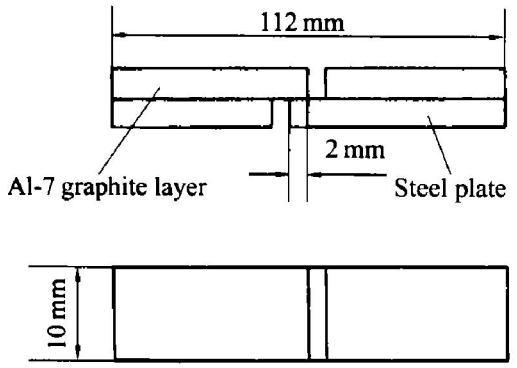

Fig. 2 Testing sample for interfacial shear strength

5) Conduct mechanical experiment to measure interfacial shear strength on universal material testing machine, and conduct SEM experiment to determine interfacial structure of bonding plate.

3 RESULTS AND DISCUSSION

3.1 Relationship between diffusion time and interfacial shear strength

According to experimental data, the relationship between diffusion time and interfacial shear strength of steel-mushy Al-7graphite bonding plate is got(as shown in Fig. 3). After regressive analysis using nonlinear theory, the regressive equation is

$$S = 25.3 + 4.47t - 0.133t^2 + 0.001t^3 \quad (1)$$

where S is interfacial shear strength, t is diffusion time. The regression coefficient R_1 is 0.989 05. This proves that Eqn. (1) builds a correct relationship between diffusion time and interfacial shear strength. Let the derivative of Eqn. (1) equal to nought, the condition for the largest is t = 22.5 s, and the corresponding largest interfacial shear strength is 69.9 MPa.

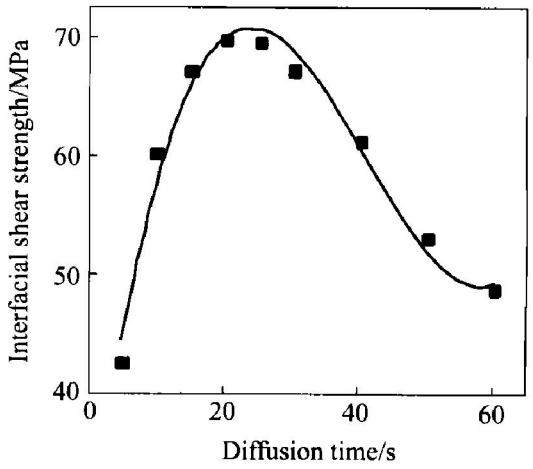

Fig. 3 Diffusion time and interfacial shear strength

3.2 Interfacial structure of bonding plate

The typical SEM micrographs of interface are shown in Fig. 4. Fig. 4(b) (t = 22.5 s) is the interface corresponding to the largest interfacial shear strength. For each micrograph in Fig. 4, the right side is 08Al steel substrate, the left side is Al-7graphite layer(the white round parts are primary solid particles and the dark round parts are graphite particles), and the juncture of steel substrate and Al-7graphite layer is the interface. It can be seen that the structures of interface are different. In Figs. 4(a) and (b), the interface is made up of the regions such as 1, 2 and 3. The results of composition analysis show that region 2 is made up of Fe-Al solid solution whose aluminum content is less than 3.5% and regions 1 and 3 are made up of Fe-Al compound. It can be seen that much more Fe-Al compounds generate in Fig. 4(b) than in Fig. 4(a). In Fig. 4(c), the results of composition analysis show that the interface is made up of Fe-Al compound completely. From Fig. 4(a) to (b) and (c), it can be summarized that the proportion of Fe-Al compound increases gradually with diffusion time, and the ideal interface should be made up of Fe-Al compound and Fe-Al solid solution alternatively and

in a right proportion(as shown in Fig. 4(b)) .

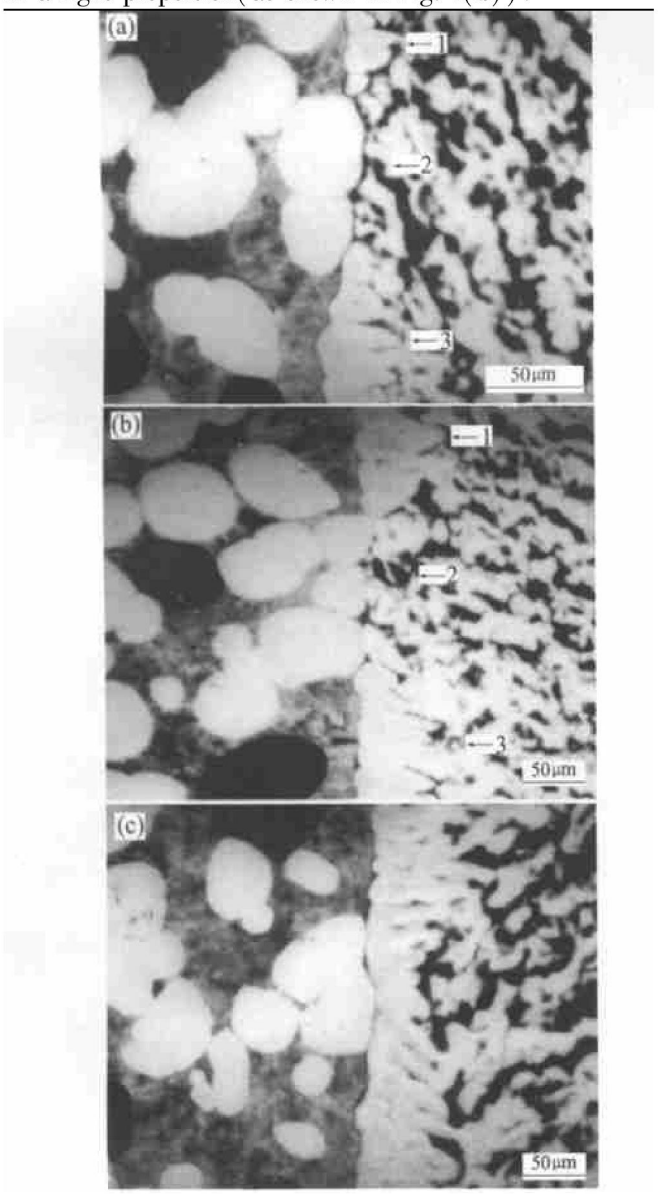

Fig. 4 Interfacial structure of bonding plate at different diffusion times
(a) —t = 10 s; (b) —t = 22. 5 s; (c) —t = 50 s

3. 3 Discussion

For steel-mushy Al-7graphite bonding, when Al-7graphite slurry contacts with the surface of steel plate, the primary solid particles and liquid in the slurry contact with steel substrate in some proportion respectively. The liquid Al atom has higher energy, and its diffusion and reaction capability is bigger[11]. So there exists severe diffusion and reaction at the place where liquid contacts with steel substrate. Here only the Fe-Al compound is generated, and the interfacial structure is just the same as that of solid to liquid bonding. However, the solid Al atom has lower energy, and its diffusion and reaction capability is smaller. Furthermore, the contact of primary solid particles with steel plate is not as close as that of liquid with steel plate. So there exists little diffusion at the place where primary solid particles contact with steel substrate. Here only the Fe-Al solid solution is generated(as shown in Fig. 4(a)) . With the increasing diffusion time, the diffusion of Al atoms increases gradually. The longer the diffusion time, the more the diffusion of Al atoms, and the more the reaction of Al atoms with Fe atoms. So the quantity of Fe-Al compound increases gradually(as shown in Fig. 4(b)) . When diffusion time is long enough, the reaction happens at the whole interface, and thus the interface is made up of a continuous Fe-Al compound layer (as shown in Fig. 4(c)) .

For steel-mushy Al-7graphite bonding, Fe-Al solid solution forms weak combination, and Fe-Al compound forms strong metallurgic combination. When diffusion time is shorter than 22. 5 s, with the increasing diffusion time, Fe-Al compound at the interface increases gradually, namely, strong combination increases gradually. Therefore, the interfacial shear strength increases with time(as shown in Fig. 3) . However, when diffusion time is longer than 22. 5 s, too many Fe-Al compounds generate at the interface, which may result in embrittlement[12]. So interfacial embrittlement happens under this condition. Furthermore, The longer the diffusion time, the more the Fe-Al compound, and the more grievous the embrittlement. Therefore, the interfacial shear strength decreases with diffusion time(as shown in Fig. 3) . Only when diffusion time is about 22. 5 s, the interface can be made up of Fe-Al compound and Fe-Al solid solution in moderate proportion. In this structure, the embrittlement does not happen, and Fe-Al compound plays its role of strong combination adequately. Therefore the interfacial shear strength reaches to the largest value.

4 CONCLUSIONS

1) For steel-mushy Al-7graphite bonding, with the increasing of diffusion time, the quantity of Fe-Al compound at the interface increases gradually. The interface corresponding to the largest interfacial mechanical property is made up of Fe-Al compound and Fe-Al solid solution alternatively and in a right proportion.

2) Under the condition of 510 ℃ for preheat temperature of steel plate and 32% of solid fraction of slurry, the relationship between diffusion time and interfacial shear strength of steel-mushy Al-7graphite bonding plate is

$$S = 25.3 + 4.47t - 0.133t^2 + 0.001t^3$$

where S is interfacial shear strength, t is diffusion time. When diffusion time is 22. 5 s, the largest interfacial shear strength is 69. 9 MPa. Therefore, the reason-

able diffusion time is 22.5 s.

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