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Influence of aluminum solid fraction on property of steel-mushy aluminum bonding plate

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Abstract: The interfacial shear property of steel-mushy aluminum bonding plate was studied, and the relationship between aluminum solid fraction and the interfacial shear strength of bonding plate was determined. The results showed that when aluminum solid fraction is 34.3%, the maximum interfacial shear strength of bonding plate is 71.0 MPa.

Key words: steel-mushy aluminum bonding plate; solid fraction; interfacial shear strength

The steel-aluminum bonding plate which has excellent composite properties is needed in many aspects from aviation field to microscope field [1], but the defects which consist in the present pressing technologies of bonding plate make the properties of bonding plate can not satisfy the user's needs completely, thus limits the application range of bonding plate greatly. For steel-aluminum solid to solid bonding, the bonding forms of steel and aluminum are mechanical occlusion and only part physical bonding [2], so the interfacial mechanical properties of solid to liquid bonding plate are generally bad. For steel-aluminum solid to liquid bonding, the bonding form of steel and aluminum is metallurgic bonding which is the firmest one [3], however, the higher bonding temperature can result in steel-aluminum brittle compound (Fe_2Al_5 and $FeAl_3$) layer forming between steel plate and liquid aluminum very easily, and thus embrlttlement happens at the interface of solid to liquid bonding plate [4]. Therefore we must try hard to develop new technology and method to destroy the layer structure of the brittle compound and thus remove the embrittlement at the interface of bonding plate whose interfacial mechanical properties will be increased further.

This paper, for the first time, conducted the steel-mushy aluminum bonding in the study field of steel-aluminum bonding and determined the relationship between aluminum solid fraction and the interfacial shear strength of bonding plate.

1 Experimental

Processing such as defatting, descaling and so on to 1.2mm-thick 08Al steel plate was conducted. Industry pure aluminum (99.99%) mushy was prepared by means of mechanical stirring method. The steel-mushy aluminum bonding experiments were carried out by using draw cast bonding method on the bonding equipment shown in **figure 1**. The preheat temperature of

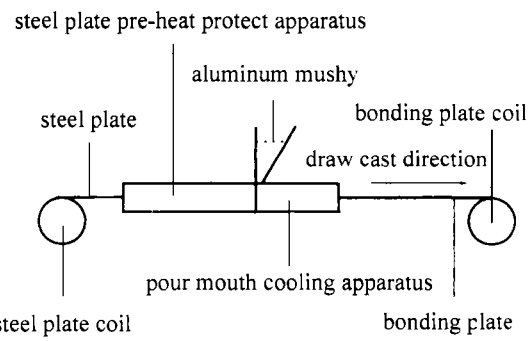

Figure 1 Steel-mushy aluminum draw cast bonding

steel plate was 450 ℃. The precision of the temperature was ±1 ℃. The speed of draw cast was 10 mm/s. The cooling way was water gas cooling whose cooling speed was 300 ℃/s. The solid aluminum layer thickness of bonding plate was 2.0 mm. After the bonding experiments, the testing samples of interfacial shear strength (shown in **figure 2**) were made from the bonding plate by using linear cutting method. The interfacial shear strength of the samples was measured on universal material testing machine. The testing data which were used to analyze by means of nonlinear theory were shown in **table1**.

2 Results and Discussions

According to the testing data shown in table 1, the

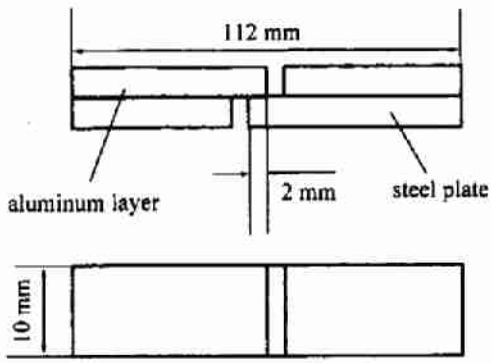

Figure 2 Testing sample of interfacial shear strength

Table 1 Aluminum solid fraction,interfacial shear strength and relative error

Aluminum solid fraction / %	Interfacial shear strength/MPa		Relative error / %
	Testing data	Regressive data	
0	63.3	62.8	0.8
5	64.2	65.1	1.4
10	67.4	66.9	0.7
15	68.7	68.4	0.4
20	69.0	69.6	0.9
25	69.8	70.4	0.9
30	70.4	70.9	0.7
35	70.6	71.0	0.6
40	70.5	70.8	0.4
45	69.2	70.2	1.4
50	68.3	69.3	1.5
55	67.2	68.0	1.2
60	64.1	66.4	3.5
65	62.3	64.4	3.4

relationship between the aluminum solid fraction (x) and the interfacial shear strength of bonding plate (y) in steel-mushy aluminum bonding (shown in **figure 3**)

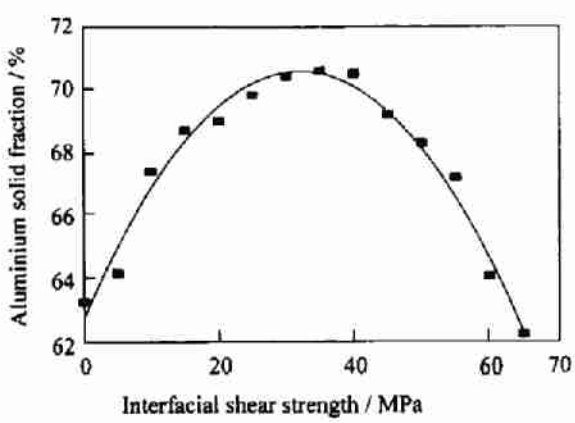

Figure 3 Relationship between aluminium solid fraction and interfacial shear strength.

was got. After regressive analysis by using nonlinear theory, the regressive equation was got

$$y = 62.8 + 0.48x - 0.007x^2 \quad \text{(MPa)} \qquad (1)$$

The regressive correlation coefficient R_1 was 0.987 76. The relative error values between the testing data and the regressive data were shown in table 1. From the table, it could be seen that the maximum value of relative error was no more than 3.5%, this illustrated that regressive equation (1) had reported the relationship between aluminum solid fraction and the interfacial shear strength of bonding plate in steel-mushy aluminum bonding correctly. Let the derivative of equation (1) equal to nought, the condition for the maximum interfacial shear strength of bonding plate was got: $x = 34.3\%$, $y = 71.0$ MPa, namely, when aluminum solid fraction was 34.3% in the bonding, the maximum interfacial shear strength 71.0 MPa of steel-mushy aluminum bonding plate was obtained.

For steel-mushy aluminum bonding, when aluminum mushy contacted with the surface of steel plate, solid aluminum and liquid aluminum contacted with steel in some proportion respectively on the interface. The liquid aluminum atom has higher energy, its spread reaction ability is bigger. The solid aluminum atom has lower energy, its spread reaction ability is smaller [5]. Steel-aluminum brittle compound could generate on the place where liquid aluminum contacted with steel because of the severe spread reaction of steel and aluminum, and steel-aluminum solid solution generated on the place where solid aluminum contacted with steel because of nearly no spread reaction of steel and aluminum. Thus the interface of steel-mushy aluminum bonding plate should be made up with steel-aluminum solid solution and steel-aluminum brittle compound. **Figure 4** was the electron probe micrograph of the interface of steel-mushy aluminum bonding plate. It showed that the interface of steel-mushy aluminum bonding plate was made up of the regions such as 1, 2, 3, 4 and so on. The result of the multiple-point composition analysis to region 1, 3 and so on was corresponding to that of the normal steel-aluminum solid to liquid bon-

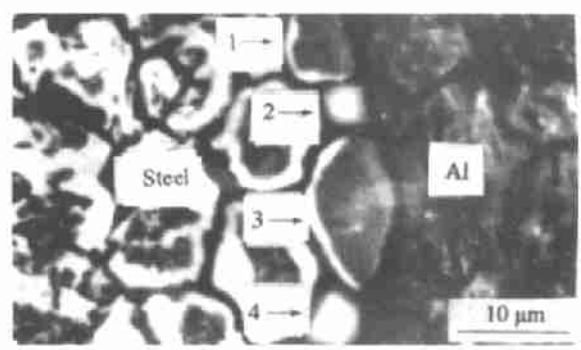

Figure 4 Interface of steel-mushy aluminum bonding plate

ding, that was, steel-aluminum brittle compound $FeAl_3$ and Fe_2Al_5. However, the result of the multiple-point composition analysis to region 2, 4 and so on was steel-aluminum solid solution whose aluminum content was less than 3%. So the interface of steel-mushy aluminum bonding plate was made up of steel-aluminum solid solution and steel-aluminum brittle compound alternatively. To the steel-aluminum bonding plate, the brittle compound formed much stronger metallurgic bonding, it was corresponding to a reinforcement muscle which had a pin role to the sliding between steel and aluminum at the interface, and the solid solution formed weaker bonding. However, it was the solid solution that destroyed the layer structure of steel-aluminum brittle compound at the interface and avoided the embrittlement of the entire interface of bonding plate, thus when aluminum solid fraction was at the range of 0–34.3%, shown as figure 3, with the increasing of aluminum solid fraction, the steel-aluminum brittle compound layer was gradually separated to net structure at the interface, and the brittle role of steel-aluminum brittle compound to the bonding interface gradually decreased, and thus the interfacial shear strength increased gradually.When aluminum solid fraction was at the range of larger than 34.3%, shown as figure 3, with the increasing of aluminum solid fraction, the solid solution at the interface was more and more, the area of weaker bonding between steel and aluminum was bigger and bigger, the pin role of brittle compound was smaller and smaller, and the interfacial bonding turned to be solid solution weaker bonding, and thus the interfacial shear strength decreased gradually.

3 Conclusions

For steel-mushy aluminum bonding, the existence of solid aluminum in aluminum mushy destroyed the slabby distributing of steel-aluminum brittle compound at the bonding interface, and thus prevented the embrittlement of the entire bonding interface from happening, so the interfacial shear strength of steel-mushy aluminum bonding plate was bigger than that of steel-aluminum solid to liquid bonding (the aluminum solid fraction was 0) plate. The relationship between aluminum solid fraction and the interfacial shear strength of bonding plate was:

$$y = 62.8 + 0.48x - 0.007x^2$$

The maximum interfacial shear strength (71.0 MPa) of steel-mushy aluminum bonding plate was obtained when aluminum solid fraction was 34.3% in the bonding.

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