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Characteristics of deformation joining of aluminum-stainless steel composite sheet ①

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Abstract: In order to study the characteristics of deformation joining of aluminum-stainless steel composite sheet, an applied example of this composite sheet was given. The conditions of the composite sheet were discussed, the optical micrographs and scanning electron micrographs were examined by contrast ways of deformation joining and braze joining. Simultaneously the analysis of energy spectrum was also conducted. The results indicate that the deformation joining composite sheet possesses high bonding strength, good corrosion resistance, less inclusions and less microcracks.

Key words: deformation joining; braze joining; interface; bonding strength; composite sheet

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1 INTRODUCTION

As everyone knows, aluminum and stainless steel are difficult to weld together[1-6]. In the past, brazing, projection welding as well as aluminizing were used. Nowadays, a new method is put forward, in which the aluminum sheet and stainless steel sheet heated by induction heater are connected by pressure of a screw press. Not only can this method improve bonding behavior of the composite sheet, but also can it raise the productivity greatly. This technology is called deformation joining, i.e. press joining. In China, it has been successfully used to fabricate cookers with sandwich bottom, which have been well received by people. In order to meet the requirements of the market, the J54 series screw presses using deformation joining have been developed by Qingdao Metalforming Machinery Group Co., China. The deformation joining technology has opened many new fields of application, especially in the automotive and household appliances industry in the world[7].

2 CHARACTERISTICS OF DEFORMATION JOINING AND OUTLINE OF PROCESSES

2.1 Characteristics of deformation joining

Taking the fabrication of sandwich bottom cooker as an example, the illustration is as follows. For the deformation joining of sandwich bottom cooker, a screw press is a suitable machine because it possesses good forming characteristics. The screw press is an energy bound machine. The energy stored in its flywheel will be completely released when it compacts a workpiece. According to the theory of force-energy of screw presses[8-10] (as shown in Eqn. 1 and Fig. 1), in the same energy level (E/E_n), the less the deformation energy of a workpiece, the more the compaction force, and vice versa. In Fig. 1[9], it is quite clear that $A_b < A_a$ and $F_b > F_a$. Furthermore, the force—energy curves vary with the energy level. The greater the energy level, the higher the force—energy curves. The highest curve represents the force—energy curve at the nominal energy of the press.

$$F = \sqrt{\frac{E}{E_n} F_1^2 - 2CA} \qquad (1)$$

where F —compaction force; F_1 —limited hard compaction force; E —selected energy of the press; E_n —nominal energy of the press; C —stiffness of the press; A —deformation energy of a workpiece.

In the deformation joining, it does not need large energy, but large force is required because its deformation is very small. Generally, the impact time of pressing sandwich bottom cooker at a screw press is about 0.02 - 0.1 s[11]. The energy of a screw press has to be released completely in the very short time. Therefore, a huge force is generated, under the action of which, in the interfacial metal at the thermal state plastic flow occurs and the metal embeds each other. As a result, the aluminum and stainless steel sheets are securely connected together.

2.2 Outline of processes

Taking the fabrication of a sandwich bottom

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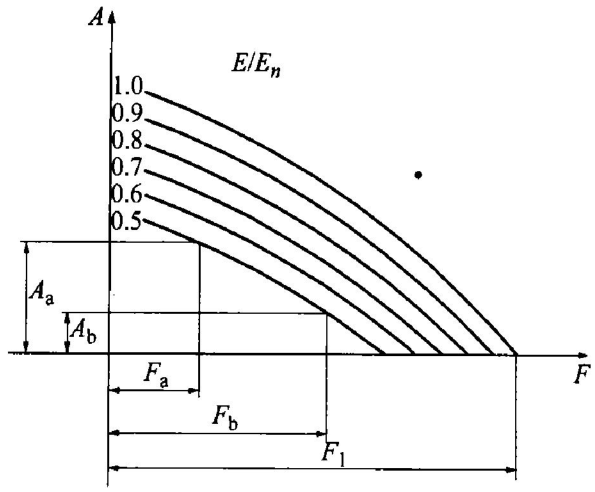

Fig. 1 Typical force—energy relationship curves of screw press

cooker as an example, the deformation joining process can be finished in 4 steps:

1) Washing and drying the stainless steel bottom sheet, aluminum sheet and stainless steel cooker body;

2) Positioning the stainless steel bottom sheet, aluminum sheet and stainless steel cooker body together in a spot-welder;

3) Heating the positioned assembly in an induction heater to 400 ℃ or so generally;

4) Pressing the spot welding assemble in a screw press with a die.

In the past, a sandwich bottom cooker was usually fabricated by the braze joining process. Its different points with the deformation joining process are as follows:

1) The braze joining is performed in a braze machine;

2) The brazing filter metal must be put between aluminum and stainless steel sheets;

3) The heated temperature is near 680 ℃.

The sketches of the deformation joining and braze joining processes are respectively shown in Fig. 2(a) and (b). The sectional photos of the sandwich bottom cookers fabricated by the deformation joining and braze joining are respectively shown in Figs. 3(a) and (b). The sandwich bottom cookers fabricated by deformation joining possess good quality and long service life; and they obtain favorable comments at domestic and overseas. Using 6 300 – 16 000 kN screw presses, the sandwich bottom cookers from 130 mm to 300 mm in diameter can be produced.

3 CHARACTERISTICS OF DEFORMATION JOINING AND BRAZE JOINING COMPOSITE SHEET

3.1 Preparation of samples

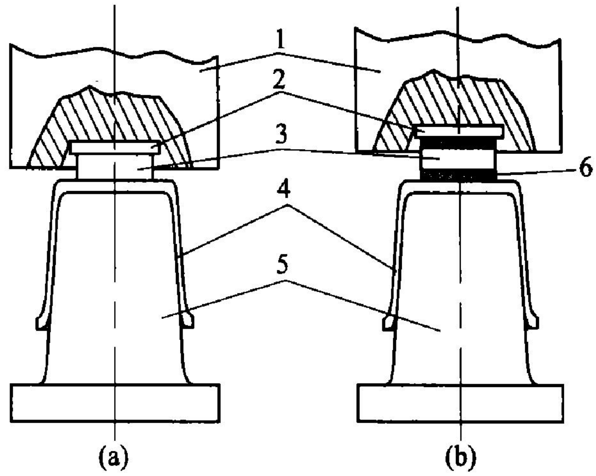

Fig. 2 Process sketch of composite sheets
(a) —Deformation joining; (b) —Braze joining
1 —Upper die; 2 —Stainless steel bottom sheet;
3 —Aluminum sheet; 4 —Stainless steel cooker body;
5 —Lower die; 6 —Brazing filler metal

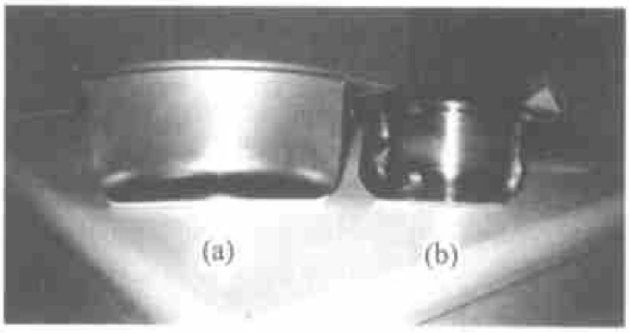

Fig. 3 Sectional photos of sandwich bottom cookers
(a) —Deformation joining; (b) —Braze joining.

The sample, as shown in Fig. 4, was taken perpendicular to the bottom of the cooker. The cross section surface of the sample was polished by metallographic sandpaper. After abrasive finishing, the electrical corrosion was continued, using 10% oxalic-acid aqueous solution. For the sample of deformation joining, the corrosion time was 3 min; for braze joining, 1.45 min. In Fig. 4, the positions of the measured points are respectively 1, 2, 3, 4, and 5. Measured point 5 is within interface layer.

3.2 Contents and results of measurement

In order to comprehend the composition distribution of the composite sheets, the analysis of energy spectrum was conducted. The measured results are listed in Table 1.

In order to study the influences of different processes on the microstructure and performance of the composite sheets, the optical micrographs of the samples, as shown in Fig. 5, were observed by metallographic microscope.

For further researching the connecting condition and the micro - characteristic of the interface of

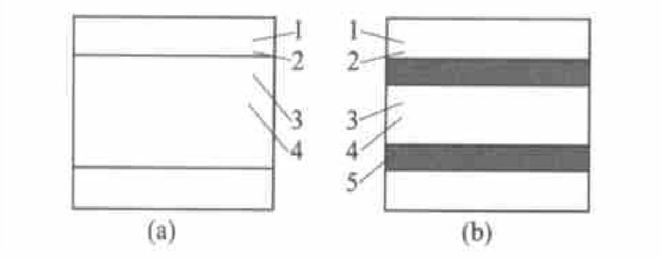

Fig. 4 Position of measured points of composite sheet samples
(a) —Deformation joining; (b) —Braze joining

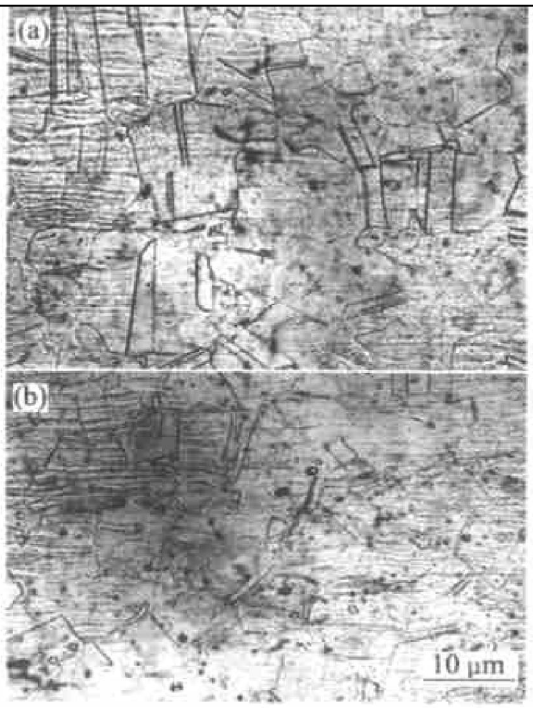

Fig. 5 Optical micrographs of composite sheets
(a) —Deformation joining; (b) —Braze joining

Table 1 Composition distribution of composite plates (mole fraction, %)

Process	Measure point	Composition				
		Si	Cr	Fe	Ni	Al
Formation joining	1	1.65	20.13	70.61	7.61	0.00
	2	1.64	20.22	70.73	7.41	0.00
	3	1.05	0.45	1.00	0.03	97.47
	4	0.68	0.56	0.94	0.00	97.81
Braze joining	1	1.14	17.46	81.25	0.15	0.00
	2	1.27	17.28	81.31	0.14	0.00
	3	2.95	1.84	6.52	0.00	88.67
	4	0.26	0.56	0.16	0.02	99.00
	5	10.22	3.78	15.91	0.04	70.05

the composite sheet, the scanning electron micrographs of the samples, as shown in Fig. 6, were investigated by scanning electron microscope.

In addition, for analyzing the condition of aluminum in the middle of deformation joining sample, the scanning electron micrograph of measured point 4, as shown in Fig. 7, was taken.

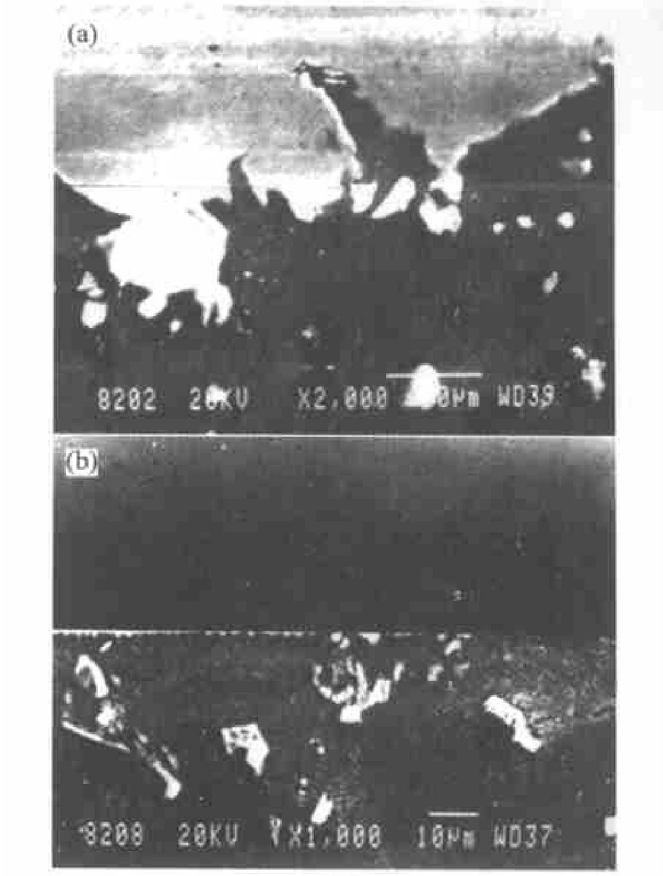

Fig. 6 Scanning electron micrographs at interface of composite sheets
(a) —Deformation joining; (b) —Braze joining

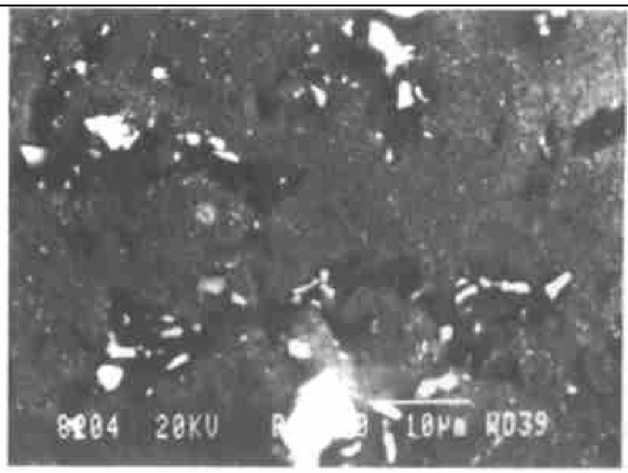

Fig. 7 Scanning electron micrograph in middle of aluminum of deformation joining sample

3.3 Analysis of measured results

3.3.1 Characteristics of interface between aluminum and stainless steel sheet

From Fig. 6(b), we can see clearly an interface layer with smooth edge. The interface layer is generated by mutual fusion of materials by means of braze welding. As we know, not only the chemical compatibility of aluminum and stainless steel, but also the physical compatibility is worse owing to the large difference in elastic modulus and thermal expansion coefficient. Therefore, the bonding strength of braze joining is weak.

In Fig. 6(a), there is no smooth layer, but instead, jigsaw-like interface formed because of plastic flow of materials. Under tremendous compaction force, the aluminum and stainless steel in the interface have embedded each other. The connecting way is similar to cold welding. The bonding strength of deformation joining is better than that of braze joining.

Using in practice indicates that for the cooker made by braze joining, sometime a crevice occurs in a cooker bottom along the interface and the deformation appears in the cooker bottom when the cooker falls down on the ground in case. But for the cooker made by deformation joining, the above problems have not come out yet.

3.3.2 Characteristics of base metals —aluminum and stainless steel sheet

1) Corrosion resistance

Analyzing Fig. 5, we can see that in the two kinds of samples, the crystallite size is all about 20 μm, and twin crystal and rolling fiber structures exist. It follows that the two kinds of processes do not have large influence upon crystallite size and microstructure. However, as shown in Table 1, the composition of braze joining sample has greater change due to diffusion of elements. It leads to a reduction in the corrosion resistance of stainless steel. From Fig. 5(b) we can see many corrosion-pits in stainless steel base of braze joining sample, for which the corrosion time is just 87 s. However, in Fig. 5(a) only a few corrosion-pits in stainless steel base of deformation joining sample, for which the corrosion time was 3 min.

2) Inclusions and microcracks

As shown in Table 1, the material composition diffusion is distinct for the braze joining sample. From Fig. 6(b), we can see that inclusions and microcracks evidently exist in the aluminum of the braze joining sample. But as shown in Fig. 7, inclusions and microcracks are indistinct in the aluminum of the deformation joining sample. It is conceivable that micro defects get to a certain extent closing under the enormous compaction force in deformation joining process.

4 CONCLUSIONS

1) The braze joining depends upon interface layer with smooth edge. The interface layer is generated by mutual fusion of materials by means of braze welding. Its bonding strength is weak. But the deformation joining depends upon a jigsaw-like edge generated by mutual embedment of material due to plastic flow under tremendous compaction force. The bonding strength is strong.

2) In the two kinds of processes, the crystallite size and microstructure of base metals are the same, but the corrosion resistance is different. The corrosion resistance for deformation joining is better than that for braze joining. In addition, inclusions and microcracks in the base metal are less for deformation joining than that for braze joining.

3) The technological process of braze joining is more complex and pollutes environment. Moreover its productivity is low. But the technological process of the deformation joining is simple and no pollution. At the same time, it possesses high productivity.

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