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Control of Erosion in Brazing Sheet Produced by Continuous Annealing Process

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Abstract

The effect of annealing conditions on erosion during brazing of brazing sheets used for automotive heat exchangers was investigated. The erosion may occur when the deformed structure (sub-grain structure) of the core alloy remains unrecrystallized or a fine-grained structure is obtained even at the melting temperature of the filler alloy. The density of fine precipitates that retard the recrystallization of the core alloy is decreased after the CAL-type annealing. As a result, the deformation level required to inhibit the erosion is decreased, thus improving the formability of brazing sheets.

1. Introduction

Aluminum brazing sheet is used for automotive heat exchangers. The brazing sheet usually consists of Al-Mn series core alloy with Al-Si filler alloy cladding. In general, automotive heat exchangers are manufactured by applying various forming processes, followed by heating to about 873 K in a nitrogen atmosphere. In drawn-cup type evaporators, used as heat exchangers in automobile air conditioners, the brazing sheet must be highly formable due to the level of forming required. Consequently, the brazing sheet is often supplied in an O-temper condition (full annealed condition). Also, erosion may occur in lightly deformed areas during brazing [1]. Erosion is a phenomenon in which the core alloy is partially or almost completely penetrated by molten filler alloy. When erosion occurs, the mechanical properties, corrosion resistance, and brazeability of the material is degraded. In addition, there is a possibility that it can degrade the performance of the heat exchangers. Therefore, there is strong demand for materials research to reduce the level of erosion.

The erosion is considered to be closely related to the recrystallization behavior of the core alloy during brazing. Erosion may occur when the deformed structure of the core alloy remains unrecrystallized or the grain structure is refined even at the melting temperature of the filler alloy [2-4]. These structures are often produced, the former in lightly deformed, and the latter in highly deformed materials. The deformation level has a strong influence on the recrystallizaition behavior of the core alloy.

With a high deformation level, erosion does not occur because the sub-grain structure does not remain by being fully applied the driving force of the crystallization of the core alloy. However, the formability of the brazing sheet is degraded concomitantly with the inhibition of erosion.

In this paper, we focus on the annealing conditions of the brazing sheet, which were used to control the metallographic structure of the material. These conditions are discussed in terms of inhibiting erosion and the degradation of formability.

2. Experimental Procedure

AA3003 core alloy clad with AA4343 filler alloy was used. The chemical composition of the core and filler alloy is shown in Table 1. Homogenizing treatment was applied to the core alloy, and the filler alloy cladding was applied to both sides of the core alloy at a cladding ratio of 10% on each side. The cladded sheet was then hot and cold rolled to a thickness of 0.43 mm and finally annealed. Batch-type annealing and salt-bath annealing were used. Batch-type annealing is conventionally used to anneal aluminum alloy. Salt-bath annealing is characterized by a high heating rate, a high cooling rate and short holding time at high temperature. In this study, salt-bath annealing was used to simulate CAL (Continuous Annealing Line) type annealing. Batch-type annealing was performed at 643 K for 2 hours and salt-bath annealing at 793 K for 10 seconds. The cooling rate after annealing was 40 K / min for batch-type annealing, and 50 K / sec for salt-bath annealing. Strain was then imposed on the brazing sheets and the deformation level was varied from 0 to 20%. Finally, the specimens were heated in a high-purity nitrogen atmosphere at 878 K for 3 minutes, to simulate brazing treatment.

After brazing, the microstructure of the specimens was observed using an optical microscope. A transmission electron microscope (TEM) was used to characterize the microstructures. Tensile tests were performed using a JIS No.5 specimen.

Table 1: Chemical composition of core and filler alloy (mass%).

	Si	Fe	Cu	Mn	Al
Core alloy:AA3003	0.25	0.65	0.15	1.15	bal.
Filler alloy:AA4343	7.5	0.4	0.1	-	bal.

3. Results and Discussion

3.1. Occurrence of Erosion

Figure 1 shows the optical microstructure of a L-ST section after brazing at 878 K. When the deformation level was 3%, erosion occurred in specimens where batch-type annealing (referred to as batch specimens) was used, while it did not occur in specimens where CAL-type annealing (CAL specimens) was used. Both batch and CAL specimens did not show erosion at a deformation level of 5%. This indicates that annealing conditions affect the relationship between the occurrence of erosion and the deformation level.

3.2. Effect of Annealing Condition

Figure 2 shows the relationship between the deformation level before brazing and erosion depth. Erosion depth is defined here as the distance from the surface of the residual filler alloy to the point at which the molten filler alloy was diffused. Erosion depth was evaluated by optical micrographic observation of a L-ST section. In each specimen, there were regions in which erosion depth was greater at a low deformation level. However, when the deformation level was 10% or more, the erosion depth was slight, or there was no erosion. At a low deformation level, the reduction in erosion depth varied with annealing condition. For CAL specimens, erosion did not occur when the deformation level was more than 3%. For batch specimens, however, the erosion depth was still greater than that of CAL specimens at a deformation level of 5%.

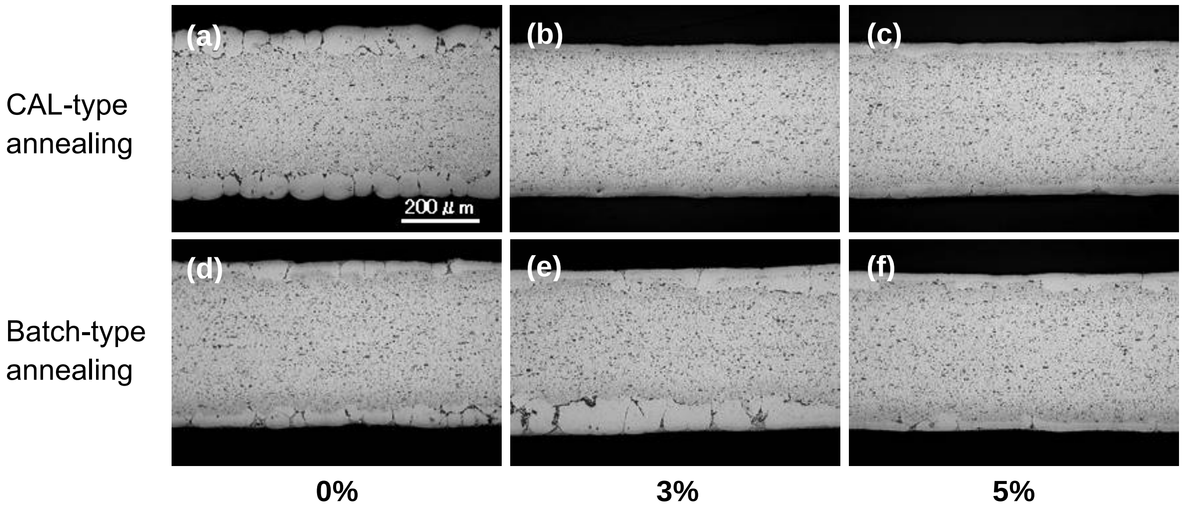

Figure 1: Optical microstructures of a L-ST section after brazing at 878 K for 3 minutes. The deformation level is (a) 0%, (b) 3%, (c) 5% with the use of CAL-type annealing, and (d) 0%, (e) 3% (f) 5% with the use of batch-type annealing.

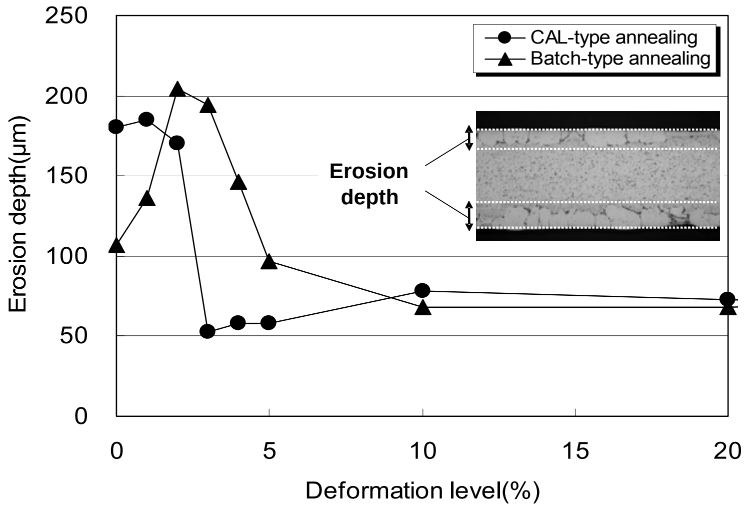

Figure 2: Relation between deformation level varied from 0 to 20% before brazing and erosion depth.

When the deformation level was 0%, that is, the O-temper condition, the erosion depth of CAL specimens was greater than that of batch specimens. This difference seemed to be due to differences in the grain size of the core alloys. The grain boundary in the core alloy is one of the diffusion paths for the molten filler alloy. The grain structure of the core alloy is shown in Figure 3. The heating rate for CAL-type annealing is extremely high compared to batch-type annealing. Therefore, in CAL specimens, erosion occurs in the O-temper condition because a fine-grained structure is obtained. The deformation level required for inhibition of erosion is 3% in CAL specimens and is more than 5% in batch specimens. It is therefore possible to reduce the deformation level required for inhibition of erosion by using CAL-type annealing.

The erosion is closely related to the recrystallization behavior of the core alloy during brazing. Erosion is a phenomenon that occurs when molten filler alloy diffuses into the core alloy. It can occur when the deformed structure of the core alloy remains unrecrystallized even at the melting temperature of the filler alloy. The grain structure of a L-ST section after brazing is shown in Figure 4. The CAL specimens recrystallized at a deformation level of 3%, while the batch specimens did not recrystallize completely at a deformation level of 5%. This result agrees well with the erosion depth shown in Figure 2.

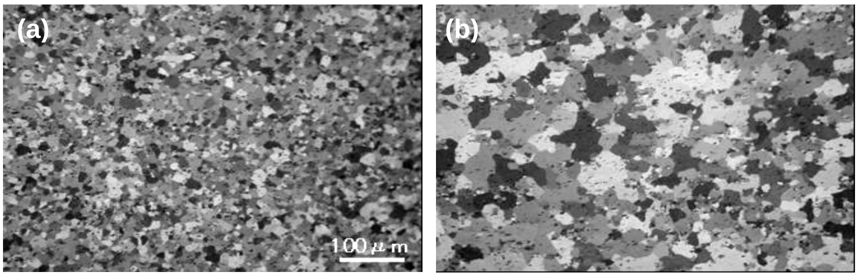

Figure 3: Grain structures of a core alloy after annealing (L-LT section). (a) CAL-type annealing (b) Batch-type annealing.

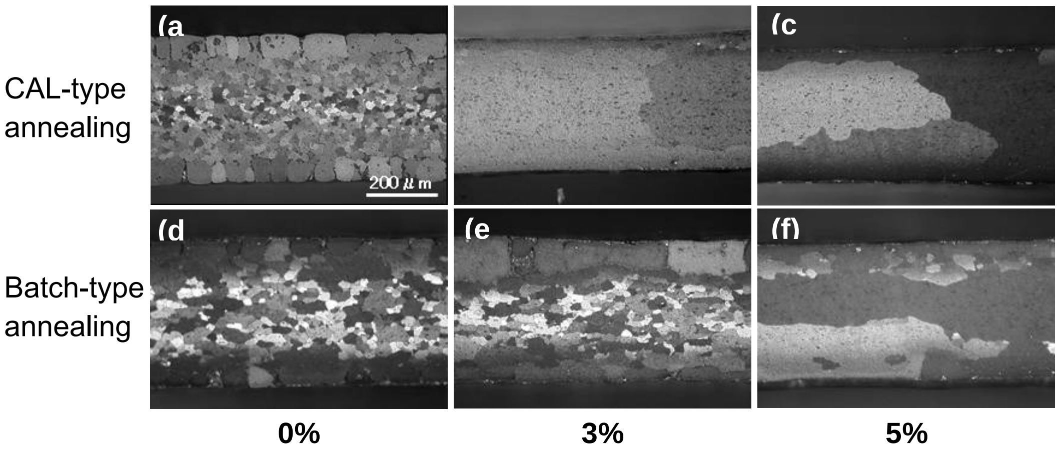

Figure 4: Grain structures of a L-ST section after brazing at 878 K for 3 minutes. The deformation level is (a) 0%, (b) 3%, (c) 5% with the use of CAL-type annealing, and (d) 0%, (e) 3% (f) 5% with the use of batch-type annealing.

3.3. Recrystallization behavior of the core alloy

Figure 5 shows the optical microstructure of the core alloy before brazing. The dispersion particles are several micrometers in size, and appear to have been formed during casting. Depending on the deformation level, it is possible that these particles are generated by nucleation site of the recrystallization of 1 micrometer or more in size [5-6]. The particle distribution remains much the same, and the number of the nucleation site of the recrystallization is comparable for each specimen. Nevertheless, recrystallization behavior changes with annealing conditions.

Figure 6 shows the precipitate dispersion of a core alloy in the O-temper condition. Numerous fine precipitates can be observed only in the batch specimens (indicated by arrow). Figure 7 shows the specific resistance of brazing sheet. The specific resistance is proportional to the amount of solid solubility. The specific resistance of the batch specimens is much lower than that of the CAL specimens. This indicates that large amounts of precipitation result from batch-type annealing. However, fine particle hardly precipitates during CAL-type annealing, with its high cooling rate and short holding time at high temperatures.

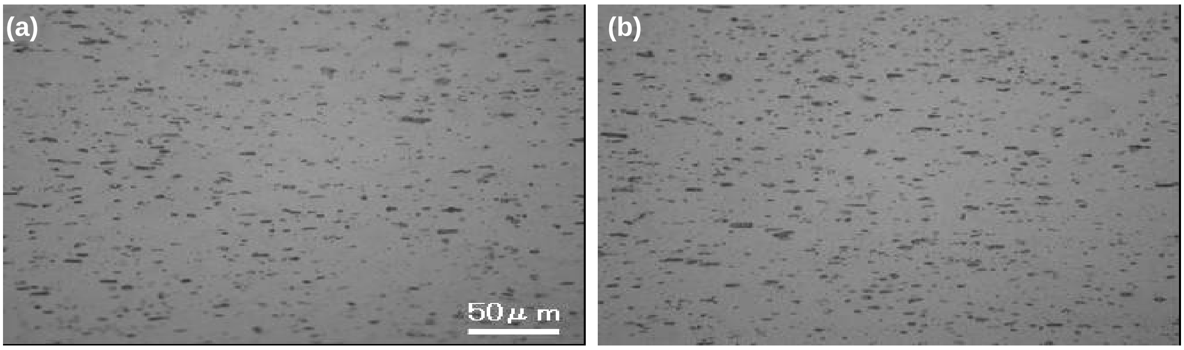

Figure 5: Microstructures of a core alloy (L-LT section). (a) CAL-type annealing (b) Batch-type annealing.

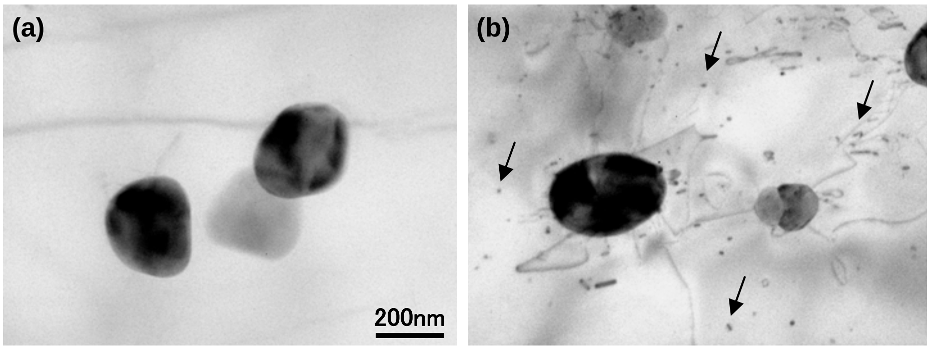

Figure 6: TEM micrographs of a core alloy after annealing. (a) CAL-type annealing (b) Batch-type annealing.

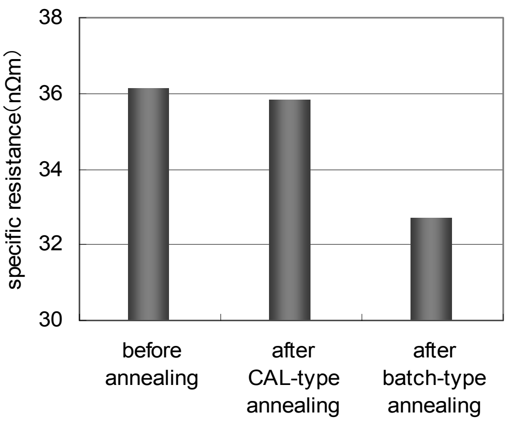

Figure 7: Specific resistance of brazing sheets.

Fine precipitates of about 0.1 micrometer or less retard the recrystallization of the core alloy because they prevent dislocations or sub-grain boundaries from recovering. The precipitation of fine particle which retard recrystallization of the core alloy can inhibit with the use of CAL-type annealing. As a result of controlling precipitate dispersion, the deformation level required to inhibit erosion can be lowered.

3.4. Enhancement of Formability

The formability of a brazing sheet is predominantly influenced by mechanical properties and grain size. Erosion occurs in lightly deformed areas because recrystallization of the core alloy is not completed before melting of the filler alloy. Then, before press forming, when strain is applied beforehand, erosion can be inhibited. The deformation level required for erosion control was 3% for CAL-type annealing, and 5% for batch-type annealing. Table 2 shows the mechanical properties of the brazing sheet at these deformation levels. The yield strength is decreased by about 12 MPa. Furthermore, the elongation of 5% or more increases by using CAL-type annealing. In addition, a fine grain is obtained, and `orange peel' and cracking of deformed areas during forming are suppressed. Therefore, erosion control and improve formability can be achieved by inhibiting precipitate dispersion.

Table 2: Mechanical properties of brazing sheet.

	Deformation level (%)	UTS (MPa)	YTS (MPa)	Elong (%)
CAL-type annealing	3%	132	97	32
Batch-type annealing	5%	131	109	27

4. Conclusion

In relation to the brazing sheet used for heat exchangers, we investigated the effect of annealing conditions on erosion during brazing. In this paper, we used CAL-type annealing which is characterized by a high heating rate, a high cooling rate, and short holding time at high temperatures. As a result of using the CAL-type annealing, the precipitation of fine particles, which retard recrystallization of the core alloy, can be inhibited. Therefore, the deformation level required to inhibit the erosion can be lowered from 5% for batch-type annealing to 3% for CAL-type annealing.

The yield strength decreases by about 12 MPa, and the elongation increases by 5% or more with a decrease in the deformation level. Furthermore, a fine-grained structure is obtained, which improves the formability of the brazing sheet.

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