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Effect of a brazing process on mechanical and fatigue behavior of alclad aluminum 3005 [†]

Hyun-Ho Kim and Soon-Bok Lee[*]
Department of Mechanical Engineering, KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon, 305-701, Korea

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Abstract

Alclad aluminum 3005, intended for use in a radiator tube, was evaluated to identify its tensile strength, fatigue behavior, and microstructure. The material consists of an AA3005 core, an AA4343 clad (outer side), and an AA7072 (inner side). To determine the effect of the brazing process, Al alloys before brazing and after brazing were examined with SEM, EDS and nanoindentation tests. Tensile tests were performed to estimate the fatigue behavior. And fatigue tests were performed under constant load amplitudes with mean loads. The mean stress effect on the fatigue behavior of the brazed aluminum was found to correlate well with the Smith-Watson-Topper relation.

Keywords: Alclad aluminum; AA3005; Brazing; Fatigue behavior; Mean stress effect

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1. Introduction

Aluminum alloys have suitable properties for heat exchanger applications. With the increasing demand for high performance and lightweight materials in the automobile industry, alclad aluminum alloys have been used for manufacturing automotive components such as outer panels and heat exchangers [1-4]. Using a brazing process, complex and multi-part assemblies of aluminum and alclad aluminum alloys are joined easily and cost-effectively [5]. Brazing is a method of permanently joining a wide range of materials and has wide applications in fabricating components [1].

For heat exchanger applications, alclad aluminum alloys (brazing sheets) consist of a core alloy that provides structural strength and a clad layer that has a low melting temperature for brazing process. During the brazing process the clad alloy melts and seals joints in the heat exchanger between the different components. The brazing sheet can be clad on one or both sides with the Al-Si alloy and in some cases one side is clad with a different alloy to provide corrosion protection on the inner clad (water-side) of a radiator [3].

Heat exchangers such as car radiators are subject to various loads such as pressure and its fluctuation, vibrations, and temperature fluctuations which induce isothermal and/or thermal fatigue. To avoid mechanical failure in heat exchangers from such loads, the mechanical and fatigue behavior of the alloy should be known prior to the design stage. Isothermal and thermal fatigue and/or low-cycle fatigue at service temperatures are considered important failure mechanisms of aluminum heat exchangers. The materials for heat exchangers must meet the special requirements of brazing to provide the highest possible combination of strength and corrosion resistance [1].

Table 1. Chemical compositions of the tested materials (wt.%).

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti
AA3005	0.06	0.21	0.30	1.18	0.22	< 0.01	0.03
AA4343	7.99	0.12	0.02	0.02	< 0.01	0.01	< 0.01
AA7072	0.53		< 0.01	0.07	< 0.01	0.97	< 0.01

In this study, tensile tests and fatigue tests were performed on alclad aluminum 3005 before brazing and after brazing at room temperature. With these tests we evaluated the changes of properties by brazing. The mean stress effects on fatigue behavior of alclad aluminum alloys were also examined.

2. Experiments

2.1 Materials and specimen

Two types of alclad aluminum alloys were tested in this study. A material that was not brazed (alloy before brazing) and a brazed material (alloy after brazing). The alclad aluminum alloy has a sandwich structure consisting of the core alloy AA3005, an outer clad (air side) of AA4343, and an inner clad (water side) of AA7072 with clad thickness of 8% on both sides. The chemical compositions of the alclad aluminum

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[*] Corresponding author. Tel.: +82 42 350 3029, Fax.: +82 42 350 5028
E-mail address: sblee@kaist.ac.kr

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alloys are given in Table 1.

Materials were obtained from the tube part of an aluminum radiator. Specimens were cut longitudinally to the rolling direction by a wire cutting method. The shape of the specimen was designed as a dog-bone-type thin plate with a thickness of 0.4 mm, a width of 5 mm and gauge length of 12 mm in the test section.

2.2 Microscopic examination

SEM, EDS and nanoindentation tests were performed on AA3005 alloy before and after brazing to find the effect of the brazing process. Using SEM, surface roughness and conditions of each type of specimen were observed. EDS test shows the surface composition change of the outer side clad and inner side clad, which is affected by the flux and core alloy. In addition, the surface hardness was evaluated by nanoindentation test.

2.3 Tensile and fatigue test

An Instron 8841, a hydraulic vertical axial-loading machine, was used for tensile and fatigue tests. The test machine has 1kN load capacity and a wedge type grip for a plate specimen. Before fatigue tests, tensile tests were performed for fatigue test design and life prediction using tensile strength. Tensile tests were performed 3 times on each type of specimen using a ramp and 100 N/min rate load. Fatigue tests were performed under constant load control. The test frequency was 7 Hz, the load ratio was over zero and the waveform was triangular. The load and displacement data were obtained using the DAX data acquisition program of the Instron 8841. Failure was defined as fracture of the specimen.

3. Test results

3.1 Changes in surface conditions and composition by a brazing process

Fig. 1 shows the surface of the alloy before brazing, while Fig. 2 presents the surface of the alloy after brazing. The surface of the alloy before brazing shows only stripes from the rolling process. The roughness of the surface is so small that it does not affect the tensile or fatigue strength. However the surface of the alloy after brazing is very rough. In addition, recrystallization on the brazed surface induced small surface cracks between grain boundaries. These surface conditions decrease the fatigue life and mechanical strength of the alloy after brazing.

From the EDS results shown in Figs. 3, we observed changes in the surface compositions of the inner and the outer clad aluminum. At the surface of the brazed alloy shown in Fig. 3, magnesium diffused from core alloy and reacted with the surface oxide. The Mg is harmful to the brazeability and wetting property [5].

Fig. 4 shows the change of the surface hardness by the brazing process. From these results, anticipate that the brazing

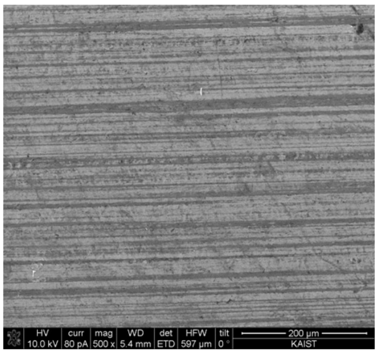

Fig. 1. Surface of alclad aluminum before brazing.

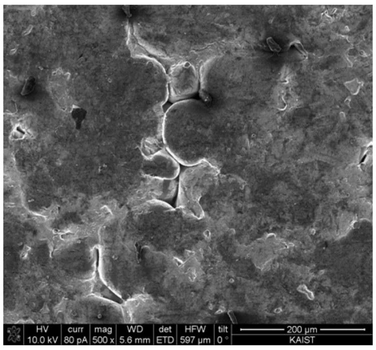

Fig. 2. Surface of alclad aluminum after brazing.

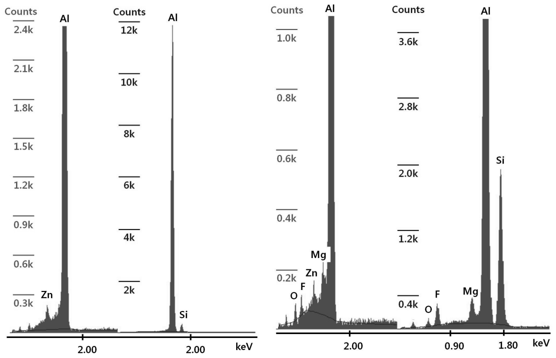

Fig. 3. Chemical composition of alloy before brazing (left) and after brazing (right), outer clad AA4343 (left) and inner clad AA7072 (right).

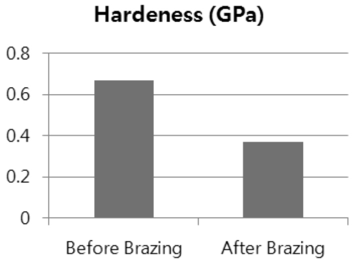

Fig. 4. Hardness of outer surface of alclad Al, AA3005 alloy before brazing (left) and after brazing (right).

Table 2. Tensile strength of AA3005 before and after brazing process.

Specimen No.	Tensile strength (MPa)	
	Before brazing	After brazing
1	168	145
2	168	150
3	169	146
Average	168	147

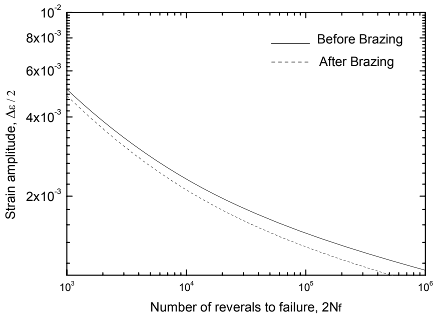

Fig. 5. Predicted total strain-life curves of AA3005 before brazing and after brazing.

process can decrease the fatigue properties of the alclad aluminum alloy.

3.2 Tensile tests of AA3005 before brazing and after brazing

Ultimate tensile strength can be used to construct a simplified total strain-life curve, which provides the proper amplitude for fatigue testing. Tensile tests were performed to obtain the tensile strength of AA3005 before and after brazing. Table 2 shows that the tensile strength of AA3005 after brazing degraded by almost 13% compared to AA3005 before brazing.

The degradation of strength after brazing was already predicted from the results of a microscopic examination. Tensile strength degradation can lead to a decrease of the fatigue strength, since the fatigue strength is related to the tensile strength and hardness of a material.

Fig. 5 shows the predicted total strain-life curves of AA3005 before and after brazing process. The curves were predicted with the medians method by Maggiolaro and Castro, expressed in Eq. (1). The medians method of prediction with a tensile strength was proposed for aluminum alloys [6].

$$\frac{\Delta\varepsilon}{2} = 1.9\frac{\sigma_B}{E}(2N_f)^{-0.11} + 0.28(2N_f)^{-0.66} \tag{1}$$

From the estimated fatigue life shown in Fig. 5, we found that the fatigue life of AA3005 after brazing was shortened. The predicted fatigue life difference becomes larger as the cycles to failure increases, which indicates that the degradation of mechanical properties heavily influences the fatigue properties.

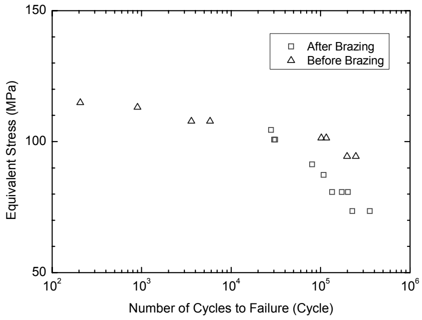

Fig. 6. Fatigue test results of AA3005 before brazing and after brazing.

3.3 Fatigue tests of AA3005 before and after brazing process

Fig. 6 shows the fatigue test results of AA3005 alloy before and after brazing using the SWT (Smith-Watson-Topper) method expressed in Eq. (2) [7].

$$\sigma_{eq} = \sqrt{(\sigma_a + \sigma_m)\sigma_a} \tag{2}$$

The maximum stress level of the fatigue testing load has been adjusted up to just below the tensile strength of each material. AA3005 alloy before brazing was tested at only one mean stress level. However, for the AA3005 alloy after brazing, fatigue tests were performed at three mean stress levels of 100, 87.5, and 75 MPa and three amplitude levels of 45, 57.5, and 70 MPa. Fatigue test results of AA3005 before and after brazing have different mechanical behavior. In the fatigue test of AA3005 alloy before brazing, we obtained the S-N relation at both the low cycle and high cycle fatigue regions. However, for the fatigue tests conducted after brazing, we obtained results only at the high cycle fatigue region.

To consider the effect of mean stress, we calculated the equivalent stress with several commonly used methods such as the Goodman method (Eq. (3)) [8], Gerber method (Eq. (4)) [9], and SWT method (Eq. (2)).

Eq. (3) and (4) are shown below:

$$\sigma_{eq} = \frac{\sigma_a}{1 - \dfrac{\sigma_m}{\sigma_{UTS}}} \tag{3}$$

$$\sigma_{eq} = \frac{\sigma_a}{1 - (\dfrac{\sigma_m}{\sigma_{UTS}})^2} . \tag{4}$$

Fig. 7 shows the fatigue test results of AA3005 after brazing. The equivalent stress was calculated with various methods to determine the mean stress effect. In Fig. 7, S-N relations using the Goodman method under a high mean stress condition (100 MPa) give unrealistically high equivalent stress. Meanwhile, the Gerber method estimated the equivalent more relevantly than the Goodman method. The equivalent stress amplitude obtained by the SWT method of the test loads with mean stress provided the proper S-N relations.

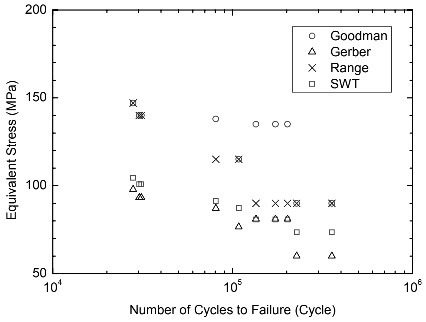

Fig. 7. Fatigue test results after brazing AA3005 using various methods to determine the mean stress effect.

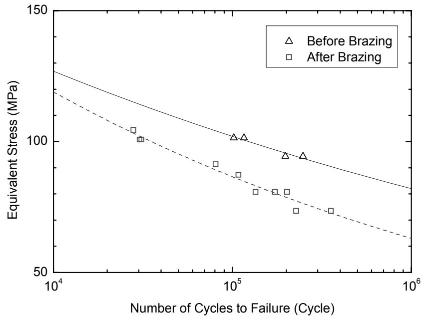

Fig. 8. Fitting curves of fatigue test results of AA3005 before and after brazing process.

Fig. 8 shows the fitting curves of fatigue test results of AA3005 before and after the brazing process. The fitting curves of fatigue test results in Basquin's equation form are Eq. (5) for the alloy before brazing and Eq. (6) for the alloy after the brazing process. The equivalent stress was obtained using the SWT method.

$$\sigma_{eq} = 304 \cdot (N_f)^{-0.09487} \quad (5)$$

$$\sigma_{eq} = 423 \cdot (N_f)^{-0.13791} \quad (6)$$

4. Results and discussion

From SEM, EDS and nanoindentation test results of AA3005 aluminum before and after the brazing process, degradation of tensile and fatigue strength, respectively, was anticipated. The fatigue life of AA3005 before and after the brazing process was estimated from the test results of the ultimate tensile strength of the materials. True S-N curves were also obtained from fatigue tests with mean stresses. Estimated fatigue life from the ultimate tensile strength shows that the difference in fatigue life before and after brazing AA3005 becomes larger as life goes high cycle fatigue. When AA3005 after brazing has 10000 cycle life, the predicted fatigue life of the alloy before brazing has 60% increased fatigue life. The difference in fatigue life before and after brazing in the actual fatigue test results becomes larger than the difference in the predicted S-N curves using tensile strength. For the case of AA3005 after brazing having 10000 cycle life, the fatigue life of the alloy before brazing is increased by 90%. The additional decrease in fatigue life of the alloy after brazing is due to the surface cracks and recrystallization occurred during the brazing process. The brazing process at high temperature induces further degradation of material properties and lowered fatigue strength as compared to the simply estimated fatigue strength using tensile strength or hardness.

5. Conclusions

The effects of a brazing process on the surface conditions and mechanical properties were evaluated by microscopic examinations, and tensile tests with the two types of alclad aluminum 3005 alloy, samples before brazing and samples after brazing. Fatigue tests of the alloy before and after brazing were also performed and the results were compared with the predicted fatigue life using the tensile strength.

(1) The brazing process induces surface cracks and degradation of tensile strength and hardness, which reduces the fatigue strength of AA3005.

(2) The SWT method is found to be suitable for analysis of mean stress effect after brazing alclad aluminum 3005.

(3) Fatigue life difference between before and after brazing AA3005 in fatigue testing is larger than the difference in the fatigue life predicted by medians methods suggested by Maggiolaro and Castro using the tensile strength.

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Soon-Bok Lee received his Ph.D. from Stanford University in 1980. He is currently a Professor in the Mechanical Engineering Department of KAIST. His research interests include reliability in electronics packaging and thin film, elevated temperature materials, fatigue and fracture. He is a member of KSME, KORAS, ASME, IEEE, and SEM.

Hyun-Ho Kim received his B.S. and M.S. degrees from KAIST. He is currently in the doctoral program in Mechanical Engineering Department of KAIST. His research interests include reliability, low and high cycle fatigue, fatigue crack growth and thermo-mechanical fatigue of structural materials.