Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Tensile Property of the Diffusion-Welded Alloy 617 at Elevated Temperatures

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1. Introduction

Manufacturing a compact type heat exchanger is one critical issue for an efficient gas-to-gas heat exchanging system. Compared to the helical coil designs, several compact heat exchangers, such as brazed plate-fin heat exchanger (PFHE), fusion bonded formed plate heat exchanger (FPHE), fusion bonded unit cell heat exchanger (UCHE), and fusion bonded printed circuit heat exchanger (PCHE), are current candidates for the components [1]. Traditional brazing has a definite advantage in high pressure/temperature with a relatively low pressure drop, but structural integrity is not reliable for the nuclear safety class service.

In this study, mechanical properties of the solid state diffusion-welded Alloy 617 are presented. Based on the parametric study on the diffusion welding procedure, a stack is prepared following the standard ASME Code Section IX procedures. Microstructural analysis and tensile testing at elevated temperatures are conducted to characterize the interface properties.

2. Methods and Results

2.1 Diffusion Welding Parameters

Test material used in this study is Ni-base superalloy Alloy 617 (UNS N06617, Heat No. XX4516UK). Sixty plates having the dimension of 200×200 mm^2 are prepared for diffusion welding following the procedures and performance qualification in ASME Code Section IX. Based on the literature survey on diffusion welding of Ni-base alloys [2-4], diffusion welding is performed by a contractor (TNP Co.) following the parameters suggested by the authors.

Temperature of 1150 ^{o}C is applied for diffusion welding with the compressive pressure of 14.7 MPa and duration time of 2.0 h. After hot pressing, the diffusion weldment shows about -3.3 % of reduction in total thickness. Post-weld heat treatment is employed in a high vacuum furnace at annealing temperature for 8 h to enhance the further atomic diffusion across the interface.

2.2. Metallographic Analysis

Metallography required in Section IX is basically performed by taking a section and slicing it longitudinally. Furthermore, specimens are prepared for transmission electron microscope (TEM) equipped with electron energy loss spectroscopy (EELS) using a focused ion beam (FIB) technique to identify the fine-scale examination at the interface.

Fig. 1 shows the cross-sectional micrographs near the interface. There are many secondary precipitates without large voids. EELS analysis reveals that fine scale precipitates at/near the interface are Al-rich oxides (black dots) and Cr-rich carbides (grey dots), which would be agglomerated and remained during the exposure at diffusion welding process and cooling to room temperature. Strong peaks are observed at 574.0 eV for Cr $L_{2,3}$ and 532.0 eV for O K, but there is no evidence for Ti $L_{2,3}$ at 455.5 eV, even if the alloy contains 1.23 % of Al and 0.35 % of Ti to improve oxidation/corrosion resistance.

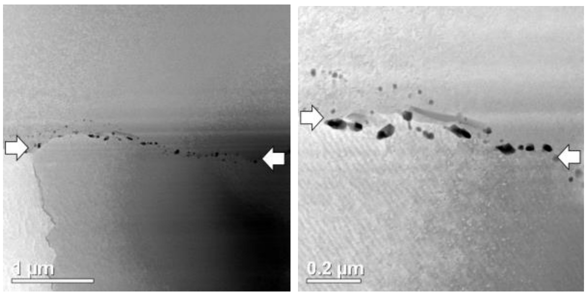


Fig. 1 TEM micrographs of the diffusion weldment near the interface. Arrows indicate the bond-line.

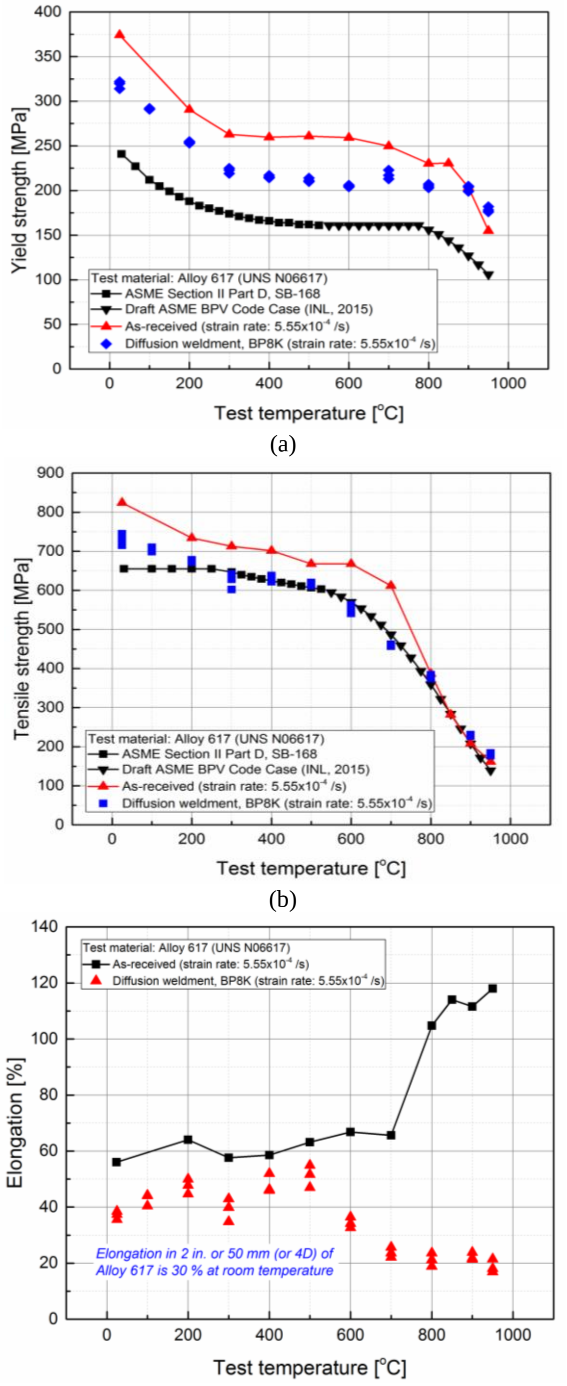
2.3. Mechanical Testing

A fundamental tensile testing is subjected for the diffusion weldment. Three duplicate specimens following ASTM: E8/E8M and E21 standards are prepared from the diffusion weldment. Round bar type having 6.0 mm in diameter and 30.0 mm in gauge length is employed. An MTS-810 universal material testing machine is used at a rate of 1.0 mm/min (strain rate: 5.55×10^{-4} /s). All specimens are loaded perpendicularly to the interface. As noted earlier, the tensile testing is carried out at room and elevated temperatures (up to 950 ^{o}C).

The tensile test results of diffusion weldment are shown in Fig. 2. For comparison, data for the as-received alloy (Code and experimental results) is also drawn. Mechanical requirements for nickel-chromium-cobalt-molybdenum alloy (UNS N06617) in ASTM: B168 are 240 MPa of yield strength, 655 MPa of tensile strength, and 30 % of elongation at room temperature.

For the diffusion weldment, 318±4 MPa of yield strength, 730±15 MPa of tensile strength, and 37.1±1.4 % of elongation are achieved.

In all testing temperature, the superior yield strengths of the diffusion weldment over the Code requirement are obvious (Fig. 2(a)). However, the tensile strength drops rapidly at elevated temperatures, so it could be said that the mechanical properties of the diffusion weldment does not meet the Code requirement (Fig. 2(b)). Relatively high ductility (> 30 %) is maintained up to 600 ^{o}C for the diffusion weldment, but poor elongation is appeared above 700 ^{o}C (Fig. 2(c)). It is believed that the presence of the secondary precipitates (e.g., Al-rich oxides) at/near the interface results in the insufficient mechanical properties at high temperatures, so a surface treatment is necessary to reduce the formation of the oxides.



(a)

(b)

(c)

Fig. 2 Tensile test results of diffusion-welded Alloy 617 at elevated temperatures. Strengths are compared with the as-received specimens: (a) yield strength, (b) ultimate tensile strength, and (c) elongation.

3. Summary

As an application of compact heat exchanger for high temperature reactor systems, diffusion welding of Alloy 617 is investigated in this study. One key outcome through this study is that strength and elongation of diffusion weldment are high enough for Code requirement at room temperature. However, lack of the mechanical properties is observed at elevated temperatures.

ACKNOWLEDGEMENT

This research was supported by the Nuclear Research and Development Program of the National Research Foundation of Korea (NRF) grant funded by the Ministry of Science, ICT & Future Planning (2016M2A8A1952772 and 2017M2A8A1014758).

REFERENCES

[1] J. Nestell, and T. -L. Sham, ASME Code Consideration for the Compact Heat Exchanger, ORNL/TM-2015/401, 2015.

[2] T. Totemeier, H. Tian, D. Clark, and J. Simpson, Microstructure and Strength Characteristics of Alloy 617 Welds, INL/EXT-05-00488, 2005.

[3] I. Sah, D. Kim, H. J. Lee, and C. Jang, The Recovery of Tensile Ductility in Diffusion-Bonded Ni-Base Alloys by Post-Bond Heat Treatments, Materials & Design, Vol. 47, p. 581, 2013.

[4] I. Sah, J. -B. Hwang, E. -S. Kim, and M. -H. Kim, Demonstration of Diffusion Welding Performance of Alloy 617, Transactions of the Korean Nuclear Society Spring Meeting, May 18-19, Jeju, Korea, 2017 (in Korean).