Microstructure and Tensile Performance of Diffusion-Welded Alloy 800H

Jong-Bae Hwang [a, b], Injin Sah [b*], Eung-Seon Kim [b]
[a]*Department of Materials Science & Engineering, Chungnam National University, Daejeon 34134, Republic of Korea*
[b]*Next-Generation Fuel Technology Development Division, Korea Atomic Energy Research Institute, Daejeon 34057, Republic of Korea*
**Corresponding author: injin@kaeri.re.kr*

1. Introduction

Diffusion welding of Ni-based alloys has been investigated for fabricating printed circuit heat exchangers [1–3]. However, secondary precipitates, such as Al-rich oxide or Ti-rich carbide, formed at interfaces of diffusion weldments severely deteriorate mechanical properties [1–3]. Several methods have been proposed to fix this intrinsic issue; post-weld heat treatment [1–3], insertion of interlayer [2,4], and surface modification [5]. Nevertheless, a decrease in mechanical properties has been consistently reported.

An innovative method is recently proposed by the authors, and in this study we applied the method to Alloy 800H (UNS N08810), which is a promising material for next-generation high temperature reactor systems. Microstructural feature was characterized. Tensile property of the diffusion weldment was evaluated and compared with that of base material.

2. Methods and Results

2.1 Experiments

Alloy 800H, one of well-known steam generator tube materials, was used. Table I describes the chemical compositions of the plate. Two plates having a dimension of 50 mm × 50 mm × 25 (T) mm were prepared for joining. Two plates in contact with each other were exposed at 1150 °C for an hour under uniaxial compression of 10 MPa. During this process, a high vacuum condition of ~10^{-5} Torr was maintained. No interlayer was employed.

We performed an electron backscattered diffraction analysis to reveal the extent of grain boundary migration. For evaluating mechanical property, tensile test was performed at a room temperature (25 ℃). The tensile specimens having a dimension of 4 mm diameter and 20 mm gauge length were prepared. The tensile specimens were extracted from the diffusion weldment perpendicular to the interface. We also prepared some tensile specimens from base material parallel to the rolling direction. Initial strain rate was 0.5 mm/min.

Table I: Chemical compositions of Alloy 800H plate (wt.%)

Fe	Cr	Ni	Mn	C	Al	Ti
Bal.	20.12	31.85	0.87	0.07	0.49	0.51

2.2 Microstructure

Fig. 1 is a micrograph from the electron backscattered diffraction analysis near the interface. Grain boundary migration across the interface was observed, while planar grain boundary remained in some places.

In previous studies for diffusion welding of this alloy, Hong et al. reported extensive formation of Ti-rich carbides along the interface, which resulted in two separate matrices [1]. In a study using Ni foil as an interlayer, An et al. also reported Ti-rich carbides at the interfaces between the interlayer and matrices [2]. They conducted post-weld heat treatment for additional movement of constituent elements across the interfaces; however, the effect was insignificant as the dissolution temperature of Ti-rich carbides is too high for their process. Transmission electron microscopy analysis is being carried out for the diffusion weldment to observe whether Ti-rich carbides is precipitated at the interface.

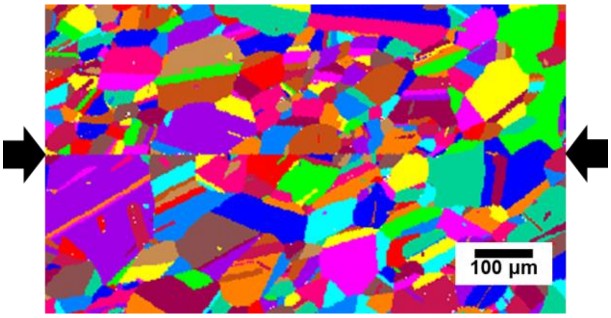


Fig. 1. Microstructure of the diffusion weldment near the interface (arrows indicate the interface)

2.3 Tensile property

Fig. 2 shows stress-strain curves of the diffusion weldment. Performance of the diffusion weldment is compared with the base material. As can be seen in Fig. 2, both materials behave quite similarly. The stress-strain curves are almost coincide up to strain of ~10%. Having sufficient ductility (~53%) and a gradual decrease in strength after ultimate tensile strength indicates remarkable integrity of the joint.

The minimum requirements for diffusion weldment are introduced in Section IX of American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME BPVC). At 25 ℃, yield strength of 170 MPa, ultimate tensile strength of 450 MPa, and strain at fracture of 30% are the minimum requirements for this alloy as per ASTM: B409-06 (2016) standard. As can be seen in Fig. 2, the diffusion weldment developed in this study satisfies the minimum requirements.

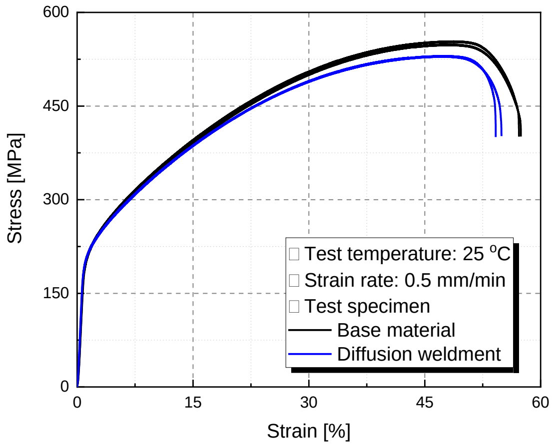
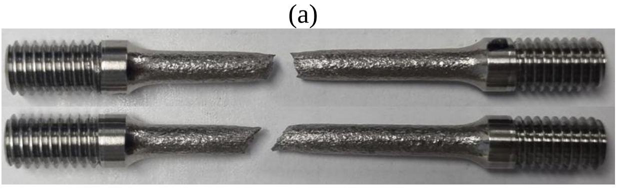


Fig. 2. Stress-strain curves of the diffusion weldment compared with the base material

Many researchers have understood that grain boundary migration across interfaces is an indication of sound joint. Xiong et al. pointed out that remnant planar grain boundary would be one of major factors that degrade mechanical property [6]. However, planar grain boundary is naturally created when matrices with different orientations come into contact. For example, planar grain boundary can be seen even in diffusion welding of stainless steels where no secondary precipitate is observed at interfaces [7–9]. Judging from the stress-strain curves in Fig. 2, it seems that the planar grain boundaries remained at the interface do not heavily affect the tensile behavior. To make this clear, tensile test at high temperature (up to 760 ℃) is in progress. The results are expected to provide allowance limit of the diffusion weldment described in Section III Division 5 of ASME BPVC.

Fig. 3 shows the tensile specimens fractured in a ductile manner. The location of the fracture of both materials was random in the gauge section. No evidence of a brittle fracture is observed.

(a)



(b)

Fig. 3. Photographs of the fractured specimens: (a) base material and (b) diffusion weldment (the interface is placed at middle of the gauge section)

3. Conclusions

Diffusion welding was performed for Alloy 800H with a process recently developed by the authors. The process seems to suppress formation of Ti-rich carbides at the interface, leading to extensive grain boundary migration across the interface. The stress-strain curves of the diffusion weldment were similar to those of the base material. Yield strength, ultimate tensile strength, and strain at fracture meet the minimum requirement presented in current ASME BPVC. The specimens were fractured away from the interface in a ductile manner.

Acknowledgement

This study was supported by Nuclear Research and Development Program of the National Research Foundation of Korea (NRF) grant funded by the Ministry of Science, ICT & Future Planning (2020M2D4A2068407).

REFERENCES

[1] S. Hong, S. H. Kim, C. Jang, and I. Sah, The Effect of Post-Bond Heat Treatment on Tensile Property of Diffusion Bonded Austenitic Alloys, Transactions of the Korean Society of Mechanical Engineers A, Vol. 39, No. 12, pp. 1221–1227, 2015.
[2] T. An, G. O. Subramanian, and C. Jang, Effect of Post-Bond Heat Treatment on the Diffusion Bonding Properties of Alloy 800H with Ni-foil Interlayer, Transactions of the Korean Nuclear Society Virtual Autumn Meeting, Oct. 21–22, 2021, Online.
[3] I. Sah, J. -B. Hwang, W. -G. Kim, E. -S. Kim, and M. -H. Kim, High-Temperature Mechanical Behaviors of Diffusion-Welded Alloy 617, Nuclear Engineering and Design, Vol. 364, 110617, 2020.
[4] R. E. Mizia, D. E. Clark, M. V. Glazoff, T. E. Lister, and T. L. Trowbridge, Optimizing the Diffusion Welding Process for Alloy 800H: Thermodynamic, Diffusion Modeling, and Experimental Work, Metallurgical and Materials Transactions A, Vol. 44A, pp. S154–S161, 2013.
[5] I. Sah and E. -S. Kim, Enhanced Joint Integrity of Diffusion-Welded Alloy 617 by Controlling the Micro-Chemistry near the Surface, Materials Today Communications, Vol. 29, 102770, 2021.
[6] J. Xiong, Y. Peng, M. Samiuddin, Lin Yuan, and J. Li, Common Mechanical Properties of Diffusion Bonded Joints and Their Corresponding Microstructure Features, Journal of Materials Engineering and Performance, Vol. 29, No. 5, pp. 3277–3286, 2020.
[7] S. -X. Lin, F. -Z. Xuan, and S. -T. Tu, In Situ Observation of Interfacial Fatigue Crack Growth in Diffusion Bonded Joints of Austenitic Stainless Steel, Journal of Nuclear Materials, Vol. 366, pp. 1–7, 2007.
[8] T. Gietzelt, V. Toth, and A. Huell, Challenges of Diffusion Classes of Stainless Steels, Advanced Engineering Materials, Vol. 20, 1700367, 2018.
[9] V. R. Saranam and B. K. Paul, Feasibility of Using Diffusion Bonding for Producing Hybrid Printed Circuit Heat Exchangers for Nuclear Energy Applications, Procedia Manufacturing, Vol. 26, pp. 560–569, 2018.