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Demonstration of Diffusion Welding Performance of Alloy 617

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1. Introduction

One critical issue designing for an intermediate heat exchanger (IHX) in a very high temperature gas-cooled reactor is the need for efficient helium-to-helium heat exchangers. The components may be replaced during the design life of the reactors. However, IHXs must meet the requirements of ASME Code, since the components form the part of the pressure boundary in high temperature reactor systems.

Compared to the helical coil designs, several compact heat exchangers, such as brazed plate-fin heat exchanger, fusion bonded formed plate heat exchanger, fusion bonded unit cell heat exchanger, and fusion bonded printed circuit heat exchanger, are current candidates for the components. Plate-fin heat exchangers can handle high pressure/temperature and provide a low pressure drop with efficient thermal standpoint. However, brazing has its own limitation or vulnerability that is unsuitable for the nuclear safety class service [1,2]. On the contrary, diffusion welding (DFW) is added to the allowed Section IX welding processes in the 2011 Addenda. The Appendix basically specifies bonding procedures and performance testing, while design, fabrication, and inspection requirements are provided in 2009 in Code Case 2621-1 [3,4].

In this study, methodology development for diffusion-welded Alloy 617 following ASME Code Case is introduced. Brief outlines of the methodology, metallography, and tensile testing with further technical issues are covered.

2. Methods and Results

2.1 DFW Methodology in ASME Code

Procedures and performance qualification specimens for diffusion welding in ASME Code Section IX are as follows. The dimension of the welding shall be a minimum of 200×200 mm^2 having at least 50 interface planes. A minimum of three tensile testing shall be taken perpendicular and parallel to the interface, and the results should meet the requirements of SA-370. Finally, microstructural evaluation shall be performed with an optical microscope at 50× and 100× magnification.

As a preliminary testing for Code qualification, Alloy 617 plates having a dimension of 100×100 mm^2 are prepared. Three different hot pressing conditions are employed based on the experimental results [5,6], and the metallography and tensile testing perpendicular to the interface are carried out.

2.2. Metallographic Analysis

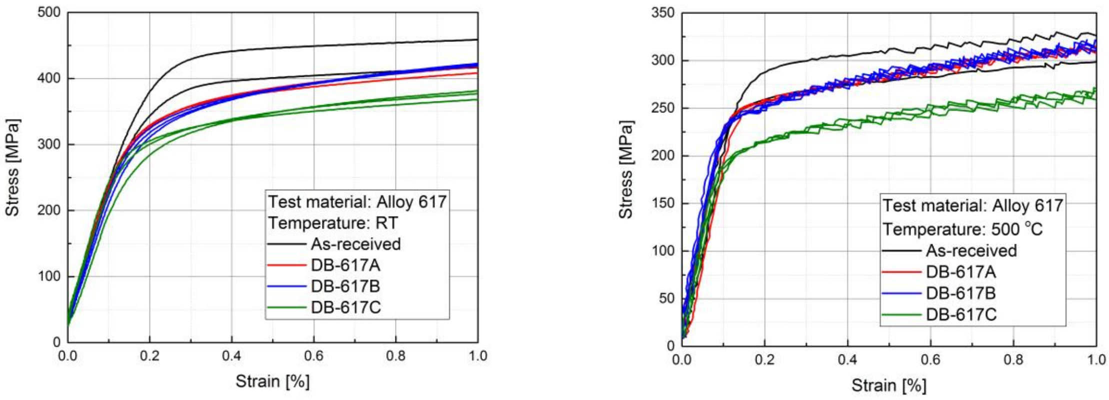
Metallography required in Section IX is performed by taking a section and slicing it longitudinally. Specimens are mounted and prepared for light optical and scanning electron microscopic (SEM) analysis using standard procedures, with the surface finish of 0.1 μm diamond paste. Of course, a chemical etching is employed to develop the grain boundary and the interface. SEM equipped with energy dispersive spectrometry (EDS) is expected to reveal the chemistry of the precipitates (oxide and/or carbides) formed at the interface.

Further analysis using transmission electron microscope (TEM) will be performed to identify fine-scale examination. While SEM/EDS is a common technique available in many electron microscopes for identifying the chemical compositions, TEM analysis equipped with electron energy loss spectroscopy (EELS) can work better for those low atomic numbers (carbon and oxygen). Auger electron spectroscopy (AES) is employed for evaluating the near-surface chemistry.

2.3. Mechanical Testing

A fundamental tensile testing is subjected for mechanical testing. Following the Code requirement, duplicate specimens designed on the basis of ASTM: E8/E8M-15a standards are used. Conventional mechanical characteristics of Young's modulus, yield strength, (ultimate) tensile strength, maximum elongation, reduction in area, and location of failure are directly obtained through the testing. Stress-strain curves of the diffusion-welded Alloy 617 are evaluated in comparison to the as-received and/or conventional fusion weldments. Code requires to prepare the tensile specimen in two directions (perpendicular and parallel to hot pressing), but the effect of loading directions on tensile property will be additionally covered.

Fig. 1 shows the stress-strain curves of the diffusion-welded Alloy 617 compared to the as-received specimens. In this case, the loading direction is perpendicular to the interface. As noted earlier, three different conditions are applied for the diffusion welding. Tensile behavior of the DB-617A is quite similar to that of DB-617B condition at both room temperature and 500 ^{o}C. Both are hot pressed below the



(a) (b)

Fig. 1 Stress-strain curves of the as-received and diffusion-welded Alloy 617 up to the strain range of 1 %: (a) room temperature and (b) 500 ^{o}C

annealing temperature of the alloy with relatively low compressive pressure. The total strain after hot pressing is less than 5 %. On the contrary, tensile curve for DB-617C shows that yielding starts earlier than the others and the strength is somewhat lower than that of the as-received.

There are limited characteristics of diffusion-welded Alloy 617. When the stacks with the gas passages are diffusion-welded, a large number of semi-circular flow passages are formed. As expected, the sharp corners where the flow passages meet flat plates are known to be the stress concentration. Thus, experimental testing is scheduled to reveal the creep and rupture properties of the notch specimens.

3. Summary

As an application of compact heat exchanger for high temperature reactor systems, joining methodology, performance and modeling of diffusion welding of Alloy 617 are investigated. One key outcome through this study is to understand DFW properties at elevated temperature in comparison with the conventional welding technology.

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