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Thermal fatigue damage and residual mechanical properties of W-Cu/Ag-Cu/1Cr18Ni9 brazed joint

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ABSTRACT

Thermal fatigue properties of W-Cu/1Cr18Ni9 steel brazed joint with Ag-Cu filler metal has been studied in this paper. With the increment of fatigue cycles, fatigue damage of the brazed joint became increasingly serious. There were micro holes and cracks appeared on the interface between brazing seam and base metals, and bending strength decreased from 690 MPa of the original joint to 380 MPa after 200 fatigue cycles. Fracture characteristic of W-Cu/Ag-Cu/1Cr18Ni9 joint changed from ductile fracture of the original joint to mixed ductile-brittle fracture after 200 fatigue cycles under external bending load and internal fatigue damage. The ductile fracture located on the Ag-based solid solution of brazing seam, and the brittle fracture occurred on the W-Cu composite.

1. Introduction

W-Cu/1Cr18Ni9 steel brazed joint is frequently applied to high temperature and complex environment. Therefore, thermal fatigue property of the joint is an important index to meet the severe requirements. Divertor is one of the most important components in nuclear fusion reactor test device. It is transition region between high temperature plasma and solid structure material [1–3]. At present, W and W alloy are considered as the most suitable plasma facing material, and stainless steel is the most popular structural material in divertor. However, there are great difference in physical properties between plasma materials and structural materials, brazing is considered as one of the most feasible methods to connect them [4–7]. Therefore, the brazed joint between W alloy and stainless steel has gradually become an important component of the divertor.

Because the designed joint need to work long time under thermodynamic load, it often require high thermal stress during service and the thermal expansion coefficient between W alloy and stainless steel is quite different [8]. Therefore, thermal fatigue failure has become one of the main failure forms of the brazed joint of W alloy and stainless steel in the divertor. In recent years, considerable interest has been generated in welding and thermal fatigue research of the W-alloy joint [9–12]. In this paper, thermal fatigue property of W-Cu/Ag-Cu/1Cr18Ni9 steel joint were investigated.

2. Materials and methods

Our research group have studied the microstructure and properties of vacuum brazed joint of W-Cu composite and 1Cr18Ni9 steel with Ag-Cu filler metal. Process parameters during the vacuum brazing were: brazing temperature $T = 855–865\,^{\circ}C$, holding time $t = 30$ min, vacuum level superior to 6×10^{-3} Pa (optimum technological parameters) [6]. Samples were machined by a linear cutting machine into blocks with sizes of 40 mm × 6 mm × 5 mm from the brazed joint. A circular hole with a diameter of 5 mm was drilled at the upper end of the 1Cr18Ni9 steel from the brazing seam 15 mm, as shown Fig. 1. The number of thermal fatigue cycles was 0, 100, 150 and 200 times. Thermal fatigue tests were carried out on the thermal fatigue test machine with special clamps. The parameters of thermal fatigue test were as follows: Upper limit temperature $\theta_{max} = 400\,^{\circ}C$ for 20 min followed by water and cooling for 2min.

After thermal fatigue test, the specimens were ground and polished by emery papers, cloths, and diamond grind paste and then etched to reveal microstructure of the brazing seam by mixture solution (HCl: HF: HNO_3 = 80 ml: 13 ml: 7 g) for 2–3s. Finally, microstructure feature and fracture morphology of the brazed joint with different cycle times were studied via scanning

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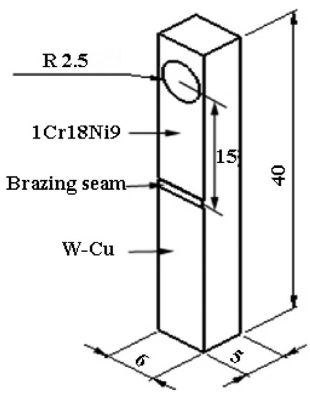

Fig. 1. Thermal fatigue specimen.

elector microscope (SEM) and energy dispersive spectrum (EDS), and four-point bending strength of the brazed joint after different cycle times were test using an electronic mechanical testing machine (CMT505).

3. Results and discussion

3.1. Thermal fatigue damage

3.1.1. Microstructure

Microstructure of W-Cu/Ag-Cu/1Cr18Ni9 steel brazed joint with difference fatigue cycles can be observed in Fig. 2. Previous studied [6] have demonstrated that both brazing seam and substrates of original joint (Fig. 2(a)) formed a good metallurgical bonding with a width about 60 μm. A slight diffusion layer existed in the interface, and no obvious micro cracks or hole defects were observed. A feature area was mainly Cu(Ag, Fe) solid solution and B feature area was mainly the eutectic Ag(Cu) solid solution. Thermal fatigue defects with difference cycles were listed in Table 1. The length of micro cracks and diameter of holes appeared in the processing of thermal fatigue were used as criterion to show the damage level of different cycles. Subsequently, microstructure of the brazed joints after 80 thermal fatigue cycles was investigated. Without micro cracks or hole defects were observed in the interface of this joint.

Compared with the original joint, the microstructure of W-Cu/Ag-Cu/1Cr18Ni9 steel brazed joint after 100 cycles changed from continuous and dense interface to discontinuous and uneven interface, and even some holes appeared (seen in Fig. 2(b)). Composition of interface between 1Cr18Ni9 steel and brazed seam(C) was analyzed by EDS with a chemical composition of Fe 69.64%, Cu 15.12%, Cr 6.75%, Ag 3.50%, Ni 2.99%. On the basis binary phase diagram of Fe-Cu, main phase in this region was Fe(Cu) solid solution. Therefore, it can be known that no more than 80 cycles of thermal fatigue could be expected in use of this joint.

The thermal expansion coefficient of W-Cu, Ag-Cu, and 1Cr18Ni9 steel was list in Table 2. Ag–Cu and 1Cr18Ni9 steel of the thermal expansion coefficient were taken from literature [13,14], W-Cu was test by thermal mechanical analyzer (TMA 402F3, NETZSCH). Table 2 indicated that the thermal expansion coefficient of all experimental materials increased gradually along with the increment of temperature. The expansion coefficient of 1Cr18Ni9 steel was bigger than that of W-Cu at every temperature value. The expansion coefficient of the Ag-Cu filler metal was between the base materials, which was benefit to relieve the interfacial stress. Distribution of X direction residual stress of the brazing joint was calculated by FEM as shown in Fig. 3, which played an important role in the fatigue defects occurred. It revealed that major tensile and compressive stress was distributed on the 1Cr18Ni9 steel side and W-Cu side, respectively. Fatigue defects was induced by the combined action of residual tensile stress and cyclic thermal fatigue load.

During the thermal fatigue test, the joints were subjected to

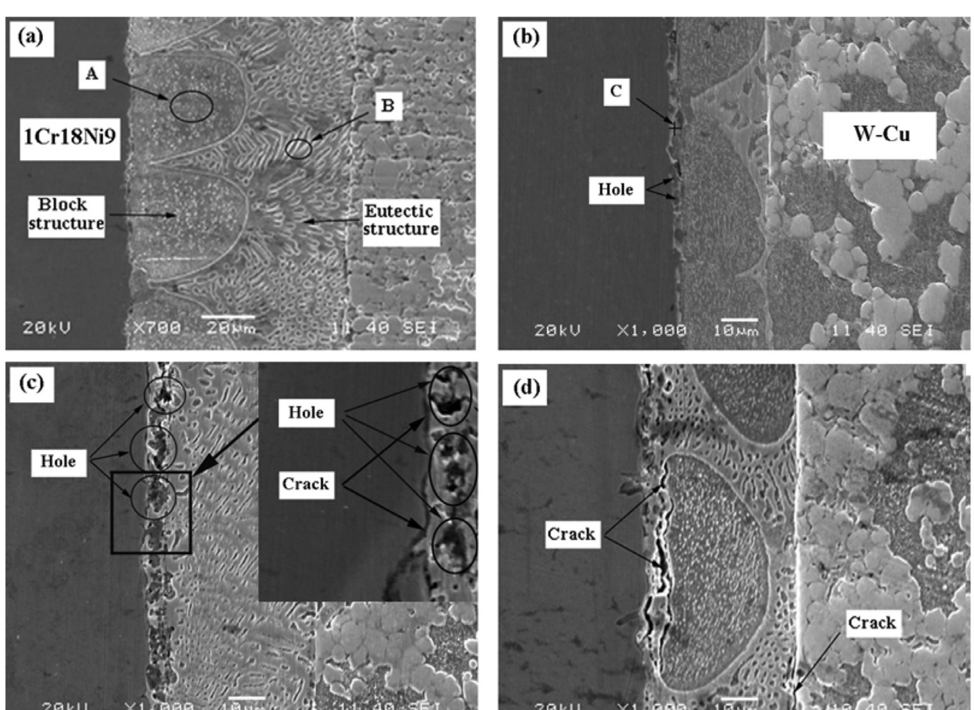

Fig. 2. Microstructure of the W-Cu/Ag-Cu/1Cr18Ni9 steel brazed joint with difference fatigue cycles; (a) Original joint, (b) 100 fatigue cycles, (c) 150 fatigue cycles and (d) 200 fatigue cycles.