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Research of Diffusion Bonding of Tungsten/Copper and Their Properties under High Heat Flux

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W (tungsten)-alloys will be the most promising plasma facing armor materials in highly loaded plasma interactive components of the next step fusion reactors due to its high melting point, high sputtering resistance and low deuterium/tritium retention. The bonding technology of tungsten to Cu alloy was one of the key issues. In this paper, W/CuCrZr diffusion bonding has been performed successfully by inserting pure metal interlay. The joint microstructure, interfacial elements migration and phase composition were analyzed by SEM, EDS, XRD, and the joint shear strength and micro-hardness were investigated. The mock-ups were fabricated successfully with diffusion bonding and the cladding technology respectively, and the high heat flux test and thermal fatigue test were carried out under actively cooling condition. When Ni foil was used for the bonding of tungsten to CuCrZr, two reaction layers, Ni4W and Ni(W) layer, appeared between the tungsten and Ni interlayer with the optimized condition. Even though Ni4W is hard and brittle, and the strength of the joint was oppositely increased (217 MPa) due primarily to extremely small thicknesses (2～3 μm). When Ti foil was selected as the interlayer, the Ti foil diffused quickly with Cu and was transformed into liquid phase at 1,000^{o}C. Almost all of the liquid was extruded out of the interface zone under bonding pressure, and an extremely thin residual layer (1～2 μm) of the liquid phase was retained between the tungsten and CuCrZr, which shear strength exceeded 160 MPa. When Ni/Ti/Ni multiple interlayers were used for bonding of tungsten to CuCrZr, a large number of intermetallic compound (Ni_4W/$NiTi_2$/NiTi/Ni_3T) were formed for the interdiffusion among W, Ni and Ti. Therefore, the shear strength of the joint was low and just about 85 MPa. The residual stresses in the clad samples with flat, arc, rectangle and trapezoid interface were estimated by Finite Element Analysis. The simulation results show that the flat clad sample was subjected maximum residual stress at the edge of the interface, which could be cracked at the edge and propagated along the interface. As for the rectangle and trapezoid interface, the residual stresses of the interface were lower than that of the flat interface, and the interface of the arc clad sample have lowest residual stress and all of the residual stress with arc interface were divided into different grooved zones, so the probabilities of cracking and propagation were lower than other interfaces. The residual stresses of the mock-ups under high heat flux of 10 MW/m^2 were estimated by Finite Element Analysis. The tungsten of the flat interfaces was subjected to tensile stresses (positive S_x), and the CuCrZr was subjected to compressive stresses (negative S_x). If the interface have a little microcrack, the tungsten of joint was more liable to propagate than the CuCrZr due to the brittle of the tungsten. However, when the flat interface was substituted by arc interfaces, the periodical residual stresses in the joining region were either released or formed a stress field prohibiting the growth or nucleation of the interfacial cracks. Thermal fatigue tests were performed on the mock-ups of flat and arc interface under the heat flux of 10 MW/m^2 with the cooling water velocity of 10 m/s. After thermal cycle experiments, a large number of microcracks appeared at the tungsten substrate due to large radial tensile stress on the flat mock-up. The defects would largely affect the heat transfer capability and the structure reliability of the mock-up. As for the arc mock-up, even though some microcracks were found at the interface of the regions, all microcracks with arc interface were divided into different arc-grooved zones, so the propagation of microcracks is difficult.

Keywords: Tungsten-alloys, Interdiffusion, Thermal fatigue tests