ARTICLE IN PRESS

Fusion Engineering and Design xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

High heat flux test and cooling effect of tungsten brazed mockups with swirl tube

K.M. Kim[a,*], H.T. Kim[a], H.C. Kim[a], S.H. Park[a], S.H. Hong[a], H.K. Park[a], H.J. Ahn[a], Y.S. Kim[a], S.K. Kim[b], D.W. Lee[b]

[a] *National Fusion Research Institute, Daejeon, Republic of Korea*
[b] *Korea Atomic Energy Research Institute, Daejeon, Republic of Korea*

A R T I C L E I N F O

Keywords:
KSTAR
Tungsten
CuCrZr
Brazing
High heat flux test
Swirl tube

A B S T R A C T

It is so important that the bonding technology between tungsten and dissimilar metals for the PFC of ITER and DEMO, KSTAR. The development of tungsten brazing technology was first launched for the KSTAR PFC.

Flat type tungsten block was brazed on CuCrZr in vacuum at a temperature of 980 °C for 30 min using silver free brazing alloy. The brazing filler is a 0.05 mm thick-plate made of a Ni-Cu-Mn alloy.

Tungsten brazed mock-ups with a swirl and smooth tube were tested at an electron beam facility, KoHLT-EB (Korea heat load test facility-Electron Beam) in KAERI. The high heat flux test was performed for tungsten brazed mock-ups with a swirl and smooth tube under the heat flux of about 5.4–8 MW/m^2. The test results show there are no delamination or failures at the bonding joints during and after all the heat flux test.

According to the thermal hydraulic analysis and results of heat flux test, the cooling effect of the smooth tube was better than one of the swirl tube at the conditions of the coolant of about 0.35 MPa and the heat flux of over about 5 MW/m^2.

1. Introduction

Graphite tiles that are bolted on the heat sink plate has been used as a plasma facing material in KSTAR PFC. The cooling efficiency between the wall material and the heat sink plate is too low because all graphite tiles are bolted on the heat sink plate within the cooling channels [1]. The wall material needs to be bonded on the heat sink plate to improve the heat transfer rate between the wall material and the heat sink plate.

Tungsten is one of the most promising divertor materials and CuCrZr alloy is considered as material of heat sink in the upgraded KSTAR PFC. There are many types and methods to bond the wall material on the heat sink plate such as the flat type brazing bonding and the flat type HIP(hot isostatic pressing) bonding, monoblock type brazing bonding, monoblock type HIP bonding. We have first started the development of the brazing bonding technology between flat type tungsten and CuCrZr block with smooth and swirl tube. We need to confirm which kind of tube types is better for the upgraded KSTAR PFC.

In this study, we present the manufacturing process of tungsten brazed mock-ups with a swirl tube and the results of the high heat flux test and thermal hydraulic analyses.

2. Flat-brazed mockups

The flat type brazed tungsten mockups with a smooth and swirl tube had been fabricated for the high heat flux test. Table 1 shows the kinds and specifications of the materials used in the fabrication of the mockups including tungsten.

The size of the flat type brazed mockup was 50 mm in length, 28 mm in width, and mm in height (tungsten was 5 mm in height, OFHC-Cu as interlayer was 2 mm, and CuCrZr block was 33 mm). The cooling tube of the mockup was 12 mm in inner diameter, 15 mm in outer diameter, and 200 mm in length.

The brazing process was performed two times to manufacture the flat type brazed mockups. The 1st brazing was to bond tungsten block on OFHC-Cu and CuCrZr block at a time using a 0.05 mm thick-plate made of a Ni-Cu-Mn alloy. The baking step at the temperature of about 850 °C for 30 min was carried out to finally remove the impurities and to equally raise the temperature of the mockup.

The brazing conditions were to be kept at the temperature of about 980 °C for 30 min in vacuum while applying a pressure of about 20 kPa on top of the mockup that is to be obtained the maximum strength at the joint. These conditions had been confirmed in previous studies for the flat type brazing bonding [2].

* Corresponding author.
E-mail address: kyungmin@nfri.re.kr (K.M. Kim).

https://doi.org/10.1016/j.fusengdes.2018.01.055
Received 3 October 2016; Received in revised form 3 January 2018; Accepted 23 January 2018
0920-3796/

Table 1
Specification and material of flat-brazed mockup.

Part	Material	Specification
Plasma facing material	Tungsten	W > 99.94%, > 19.0 g/cm^3, ASTM B760-86 (1999), hot rolled plate
Heat sink plate	CuCrZr	ASTM C18150: Cu(bal) Cr(0.6–0.9) Zr (0.07–0.15)
Interlayer	OFHC-Cu	O < 10 ppm, ASTM B170, C10200
Tube	CuCrZr	ASTM C18150: Cu(bal) Cr(0.6–0.9) Zr (0.07–0.15), ID12-OD15-200L
Swirl tape	STS304L	W12.2-1t-200L, twist ration = 2
Filler alloy #1 (W-OFC-CuCrZr)	Brazing filler alloy	Nicuman37, Cu(52.5) Ni(9.5) Mn(38), 0.05 mm thick-plate, liquidus = 925 °C
Filler alloy #2 (CuCrZr block-tube)	Brazing filler alloy	BAg-8, Ag(72) Cu(28), 0.1 mm thick-plate, liquidus = 780 °C

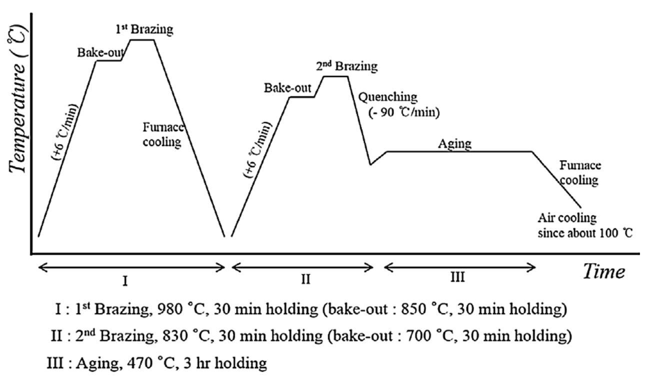

Fig. 1. Time-temperature graph for the brazing bonding of flat-tungsten mockup.

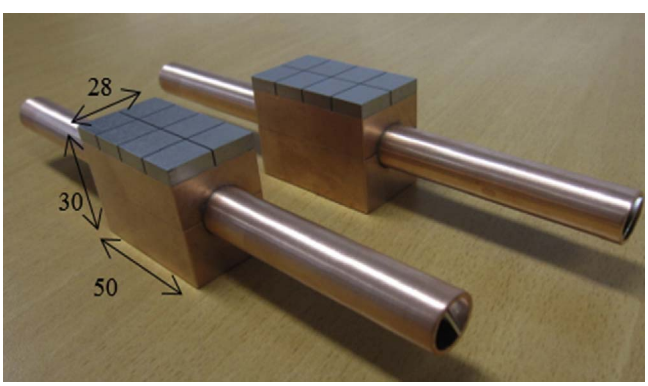

Fig. 2. Flat-tungsten brazed mockups with cooling tube for high heat flux test.

The 2nd brazing was to bond between CuCrZr block and tube with the brazing filler alloy of the Bag-8 at the brazing temperature of about 830 °C for about 30 min after the baking step at the temperature of about 700 °C.

Once all the brazing process was complete, Ar gas was injected to quench the mockups in vacuum furnace. The aging treatment for CuCrZr was carried out for about 180 min at about 470 °C after the quenching process [3]. A swirl tape with about 0.8 mm thick and twist ratio of 2 was inserted into the CuCrZr tube before the brazing. Fig. 1 is the time-temperature graph for the brazing bonding of flat-tungsten mockup.

3. High heat flux test

The KoHLT-EB in KAERI (Korea Atomic Energy Research Institute) was used to heat flux test on the tungsten-brazed mockups. It has an 800 kW electron gun (from Von Ardenne, Germany) with a maximum beam power of 300 kW, maximum accelerating voltage of 60 kV [4] (Fig. 2).

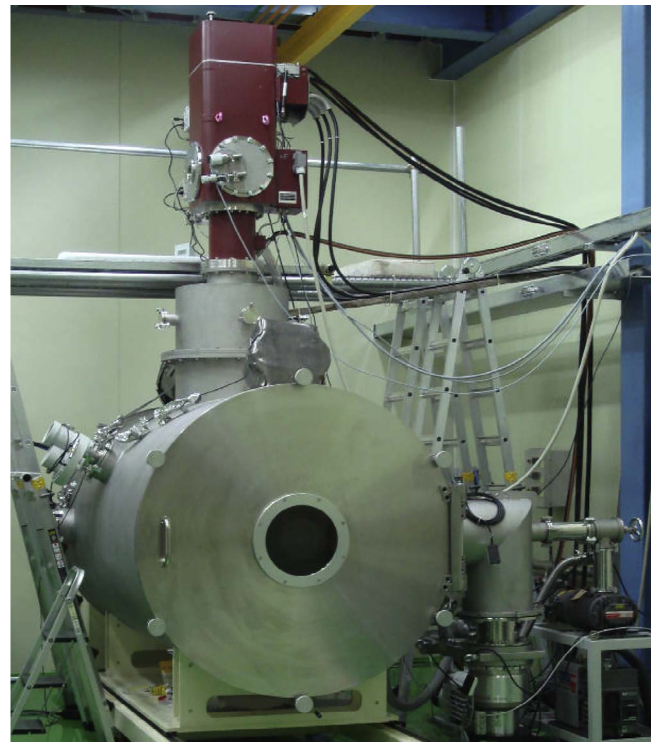

Fig. 3. High heat flux tester, KoHLT-EB in KAERI.

The surface temperature of the mockup was monitored by a pyrometer and the local temperature of one was measured using two K-type thermocouples which were inserted into 3 mm below tungsten and 2 mm below Cu/CuCrZr joint. There was the calorimetry to measure the temperature of water as a coolant. Fig. 3 shows the high heat flux tester, KoHLT-EB in KAERI.

The high heat flux tests were carried out under the water-cooled conditions with a water flow rate of about 0.5 kg/sec, a pressure of about 0.35 MPa, and an inlet temperature of about 17 °C which was same conditions of the KSTAR PFC. Two tungsten-brazed mockups with a smooth and swirl tube were tested with a heat flux of 5.4–8 MW/m^2 up to 220 cycles at a time.

4. Thermal hydraulic analysis

The transient thermal hydraulic analysis was performed on flat type tungsten mockup with a smooth and swirl tubes under the heat flux of 8 MW/m^2 using Ansys-CFX. The finite element mesh was composed of tetra- and hexa-hedral elements with about 950,000 nodes and 1,480,000 elements as shown in Fig. 4.

The boundary conditions for the thermal hydraulic analysis were as shown in Table 2. The water flow rate in the analysis was 0.5 kg/sec that was equal condition with the heat flux test, the pressure of the coolant was 0.3 MPa, and the temperature of water at inlet was 16.7 °C.

For turbulence modeling and shear stress transport(SST) viscosity model was used to analyze. The heat transfer coefficient was assumed for forced convection regime. The Nusselt number and the friction factor were evaluated by Dittus-Boelter equation and Blasius equation for turbulent flow in the smooth tube [5]. A swirl tape in the tube of the mockup was assumed using modified the empirical correlations of the heat transfer coefficient evaluated by Gambill et al. [6].

An Eulerian dispersed two-phase flow model was selected for a nucleate boiling model, where the interphase transfer models assumed that the vapour phase was dispersed in a continuous liquid phase. Ansys