Centre of Excellence for Nuclear Materials

Workshop

Materials Innovation for Nuclear Optimized Systems

December 5-7, 2012, CEA – INSTN Saclay, France

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Mechanical and Thermal Resistance of Multi-Material Components for ITER

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Mechanical and Thermal Resistance of Multi-Material Components for ITER

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The First Wall panels for ITER are complex parts composed of stainless steel, copper and beryllium [1]. These materials are joined using diffusion bonding technique. The stainless steel is a commonly used in nuclear reactors 316LN material and acts as a structural material. The copper alloy is a CuCrZr material which acts as a heat sink. The beryllium consisting in tiles and layer is used as the protective plasma facing material.

The fabrication of these panels is performed through 2 main steps. The first step consists in welding all together a bi-metallic support structure made from a thick CuCrZr plate embedded with 316LN tubes and bonded to a thick 316LN backing plate with cooling channels. The bonding is performed in a HIP (Hot Isostatic Pressure) facility. The second step is performed at a lower temperature and aims at simultaneously welding by HIP Be onto CuCrZr and ageing the CuCrZr heat sink to obtain the correct mechanical resistance of this alloy reinforced by precipitates.

The various joints 316LN/316LN, 316LN/CuCrZr, and CuCrZr/Be are then characterized [2] from a microstructural point of view and by mechanical tests. It is quite hard to characterize the strength of a diffusion bonded joints. Standard tests may be used for homogeneous joints whereas specific tests have been developed to characterize the heterogeneous bonds. To optimize the bond, we performed mainly impact and tensile bimaterial tests (Fig 1). Once the manufacture parameters have been optimized, advanced mechanical tests are performed based on Bimetallic CT specimens, axisymmetric notched specimens, 4P bending specimens. Numerical simulations are required to analyse the mechanical response. In order to characterize the fatigue resistance of the joints, specific mock-ups have been designed by the European Fusion Development Agreement – EFDA – team (Fig 2).

Results of heat flux testing will be reviewed for the various joints. The assembly of heterogeneous materials by HIPping is very complex. It may be used for various applications apart ITER FW panels such as test blanket module and divertor. It is also envisaged in PWR fission reactors, for instance to join 316 stainless steel onto 16MND5.

Fig. 1: Tensile tests specimens CuCrZr/316LN.

Fig. 2 : Mock-ups for high heat flux tests.

References

- [1] Boudot, C., Boireau, B., Cottin, A., Lorenzetto, P., Bucci, P., Gillia, O., Manufacture of a shield prototype for primary wall modules. Fusion Engineering and design, Volume 83, Issues 7-9, December 2008, pp. 1294-1299.
- [2] Gillia, O., Briottet, L., Chu, I., Lemoine, P., Rigal, E., Peacock, A., Characterization of CuCrZr and CuCrZr/SS joint strength for different blanket components manufacturing conditions. Journal of Nuclear Materials, Volumes 386-388, 30 April 2009, pp. 830-833.

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MECHANICAL AND THERMAL RESISTANCE OF MULTI-MATERIAL COMPONENTS FOR ITER

MINOS workshop : Materials innovation for Nuclear Optimized Systems - Helene Burlet

DECEMBER, 5-7, 2012

FIRST WALL PANELS

■ Complex components with multi materials :

Structure : stainless steel 316LN “Iter grade”

Heat sink : Copper alloy reinforced with precipitates

Aarmor : beryllium tiles

Initial design

New design

PROCESS ROUTES FOR THE FIRST WALL PANELS

HIPPED FIRST WALL PANELS

Hot Isostatic Pressing : reference route

- HIP : solid state bonding under high Temperature & high Pressure
- Multi steps route
 - SS/SS/Cu : one-step HIP cycle : 1040°C/2h – 140 MPa
 - Solutionning and heat treatment : 980°C/1h and 60°C/ min between 980°C and 480°C
 - HIP cycle applied for Be/CuCrZr : 580°C/2h – 140 MPa

SS/SS/CuCrZr bonding

- Development of specific non destructive US control on calibrated holes

- Ultrasonic Control of the FWP

- ➔ No defect has been detected in Cu/SS interfaces
- ➔ 6 little spots : modification in the properties of CuCrZr

Beryllium tiles bonding

- Need for interlayers
 - ✓ Between Cu and Be to prevent diffusion and precipitation of brittle phases
 - ✓ Between tiles to control the distance

Example of interlayers
between Cu and Be

Graphite interlayer

CHARACTERIZATION OF THE VARIOUS JOINTS AND MATERIALS

SS/SS/CuCrZr JOINT OBSERVATION

First tests :

- ✓ Tensile tests
- ✓ Impact Toughness tests with U shape notches

First criterion : the joint must not be the weakest zone

Further tests are requested to characterize the mechanical resistance of the joint

Notched specimens

Mechanical analysis of heterogeneous joints

- ✓ Tests
- ✓ Examinations
- ✓ Modelling

Plastic deformation map

Fracture surface

Determination of mechanical laws of the materials of the ZAD (Zone affected by the Diffusion)

Displacement measurement on a SEM platform

Comparison of the simulation results and the correlation maps

CT tests on bimaterial side grooves specimens

Stable crack propagation

CT tests give usefull indications on the influence of the process route

- US reveals no indications for this specimen
- No cracks nor residual porosities

Three different zones

- alignment of precipitates (initial interface)
- Much cleaner zone
- No diffusion observed

HEAT FLUX TESTING OF MOCK-UPS

MOCK-UPS : DIFFERENT DESIGN

Specific mock-ups have been designed to check some process parameters and tested under heat flux testing

Hot point detected after 267 cycles at 7MW/m^2

MOCK-UPS FOR THERMAL TESTS REQUIRED BY EFDA

1000 cycles 1.5MW/m^2

T surface Be $\sim 270^\circ\text{C}$

200 cycles 2.5MW/m^2

T surface Be $\sim 390^\circ\text{C}$

200 cycles 3MW/m^2

T surface Be $\sim 510^\circ\text{C}$

200 cycles 3.25MW/m^2

T surface Be $\sim 650^\circ\text{C}$

Best results

No failure of Be/Cu joint is observed but the test stop after 200 cycles at 3.25MW/m^2 because Be surface temperature reached 650°C

- ❖ HIP technique is well adapted to develop complex multimaterial parts
- ❖ HIP is foreseen for the Test Blanket Module TBM
- ❖ HIP is now well controlled

specific US controls have been developed

Hipped SS/SS developed for Cabri experimental reactor
have been accepted by BCCN

- ❖ Further applications

316LN/16MND5 joints for PWR

Acknowledgement

All this work has been done under the strong support of the European Community (EURATOM) and of EFDA association.

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