Journal of Nuclear Materials 386–388 (2009) 437–440

Contents lists available at ScienceDirect

Journal of Nuclear Materials

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

Mockups of blanket cooling plates manufactured in different diffusion welding setups

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ARTICLE INFO

PACS:
28.52.Lf

ABSTRACT

The high amount of energy applied to the structural elements of a future fusion power plant results in the need of using plates with meandering cooling channels. Of the different proposals [J.-F. Salavy, G. Aiello, P. Aubert, L.V. Boccaccini, M. Daichendt, G. De Dinechin, E. Diegele, L.M. Giancarli, R. Lässer, H. Neuberger, Y. Poitevin, Y. Stephan, G. Rampal, E. Rigal, J. Nucl. Mater., 386–388 (2009) 922. [1]]. made to manufacture such plates, a diffusion welding process of two symmetric halves is a promising candidate. This paper will focus on the recent industrial manufacturing series conducted to increase the dimensions of the workpiece. In this case, the diffusion welding process was performed in a hot isostatic pressing setup. In a former attempt, a uniaxial diffusion welding setup had been applied.

1. Introduction

Fusion power plants are presently being discussed for future electrical energy supply. A central component of a future fusion power plant [2] will be the breeding blanket (BB) with its breeder units (BU) [3] manufactured of EUROFER structural material [4]. An advantage of the deuterium–tritium nuclear fusion reaction is the large amount of specific energy released. On the other hand, a huge amount of energy acts on the breeding blanket, as a result of which nearly all parts of it have to be cooled down. A well working high-performance cooling system will prevent overheating. Such a system can be achieved when all components are made of plates with curved cooling channels inside. A promising attempt to manufacture such a cooling plate (CP) is the production of symmetric half plates that are provided with cooling channels milled at half depth. These half plates are then connected by a diffusion welding (DW) process. The resulting welding pressure distribution is influenced the least by the dimensions of the ribs between adjacent cooling channels [5]. Other advantages of this welding technique are the perfect welds generated inside the workpiece and the possibility of producing a cooling channel system of any shape.

Any DW process will warm up the workpiece and apply a high pressure for a certain time. A DW process can be performed in two different kinds of setups. The first one is called uniaxial diffusion welding (U-DW) setup where bonding pressure is generated mechanically, for instance, by a tensile testing machine or a hydraulic press. Using this method, the bonding pressure results from a uniaxial force applied to two opposite sides of the workpiece. U-DW requires a furnace and a vacuum system, as was described in [6]. The U-DW-based manufacturing experiment performed had failed due to a crack in a high-temperature thermocouple vacuum lead.

The second type of DW setup is called hot isostatic pressing (HIP) setup. A HIP setup is similar to an autoclave. It is a tank with a hot gas (mostly argon, up to 1200 °C) and high pressure of typically up to 1300 bars. The workpiece has to be protected against the gas by a canister, since the hot gas may contain some residual oxygen or nitrogen which may cause oxidation and nitration and, thus, embrittlement of the workpiece. The canister has to be evacuated prior to the HIP cycle and to be removed afterwards. The gas applies a force to each side of the workpiece in contrast to the U-DW process, where a uniaxial force is applied perpendicular to two opposite sides. The workpieces used were flat CPs, see chapter on mockups below. As regards the product of gas pressure and area of each side, the biggest influence acts on the largest surface area of the workpiece, which is parallel to the welding area. A DW process performed in a HIP setup may therefore generate a pressure distribution in the welding area that is comparable to that of a U-DW process with a grain of salt.

The present paper will report the results of an attempt to manufacture CPs by using a HIP setup.

2. Mockups

Three different types of mockups shall be discussed.

The first mockup (Fig. 1) is called compact mockup (CMU) [6,7]. It is similar to a CP with outer dimensions of 68 mm × 72 mm × 50 mm. It consists of two gas chambers. This allows for

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doi:10.1016/j.jnucmat.2008.12.154

checking the leak tightness and pressure resistance to the environment as well as for the execution of the same tests for a rib separating adjacent cooling channels. The test parameters correspond to the later operation conditions of 80 bars and 500 °C for the helium coolant. Through a leak in a first-wall plate, helium may enter the plasma – see below – or possibly the BB. This has to be prevented. A leak between adjacent cooling channels can lower the cooling power. This will happen in CPs with adjacent cooling channels and opposite gas flow direction. The CMU is manufactured from EUROFER 97 (batch 83697).

The second mockup is a modified CP of a BU, see Fig. 2, and hereinafter referred to as CP mockup. A former investigation [5,7] revealed a non-homogeneous weld pressure distribution in the different ribs of a CP. This will decrease the weld quality in the outer ribs and may generate leaks from the cooling channel system into the environment. This problem is mitigated by broadening the outer weld areas. Such a CP consists of two manifolds which are connected by a cooling channel system. Consequently, the CP mockup cannot be tested for leak tightness of adjacent cooling channels.

The third mockup is an approximately quarter-sized first-wall (FW) plate, Fig 3. The FW is the best known CP. It covers the blanket on the plasma side and has a structural, a safety, and a cooling function. The FW mockup contains eight independent cooling channels. Hence, seven inner ribs can be tested for leak tightness. The CP and FW mockups are manufactured from the EUROFER 97/2 batch 393402 [5]. The differences between the two EUROFER batches with respect to the DW process are discussed in [6,8].

The half pieces of each mockup are adjusted by dowel pins.

2.1. Preparation of half plates

All mockups are manufactured from EUROFER rolled plate material. Firstly, two pieces sawn out of the delivered material are flattened by milling due to a small curvature of the original plate material. The cooling channels are milled into the plates at half depth. As a last step, the weld surface is prepared by a dry milling process [9]. This surface is easier to weld and the DW pressure is reduced. It takes about one day to prepare the weld surface of one FW mockup half. Finally, the weld surface has to be degreased. The former laboratory DW specimen and the CMU had been degreased using hot acetone in an ultrasonic bath. However, the large CP and FW mockup dimensions require other cleaning techniques. The well-known dry ice cleaning procedures is used for this purpose. The parameters were also determined by former

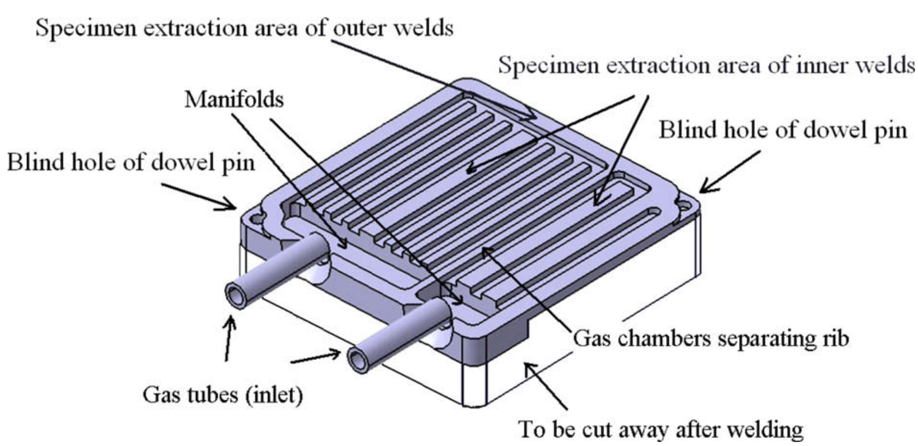

Fig. 1. Sketch of a CMU.

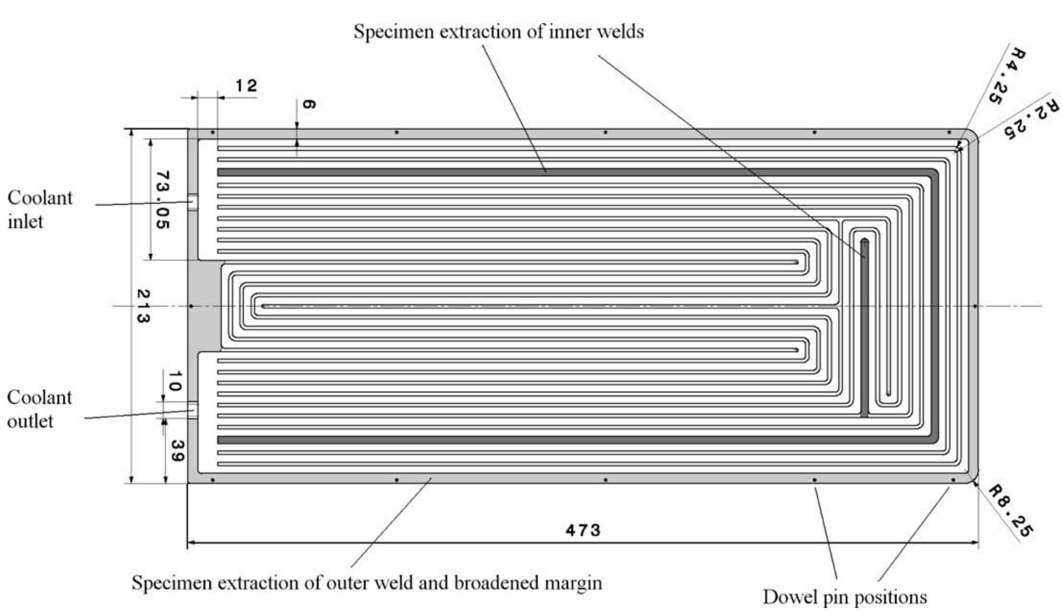

Fig. 2. Sketch of the CP mockup half plate, all dimensions in mm, note: only two of all dowel pins are marked.

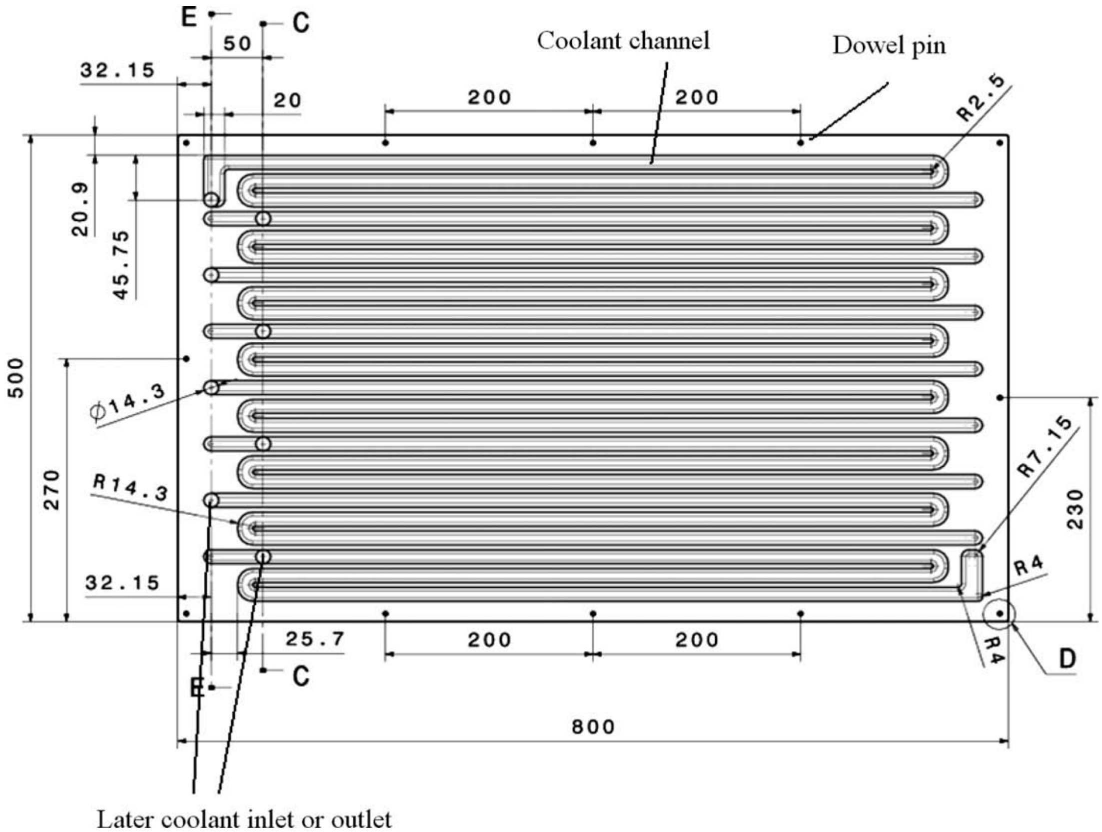

Fig. 3. Sketch of an FW mockup half plate, all dimensions in mm. Only one dowel pin, one coolant channel, one inlet, and one gas outlet are marked.

investigations [5]. An additional CMU cleaned with dry ice shall not be treated by this paper.

2.2. DW process

Work started with a U-DW process for laboratory-scaled specimens of 25 mm × 30 mm × 40 mm in dimension. It is a three-step 24 MPa process. Compression creep specimens taken from the margin and center of the original EUROFER 97/2 plate indicate [8] that the plastic creep speed varies locally under DW process conditions. These variations can be reduced by a heat treatment (1050 °C) in the first step. The second step [8,9] results in the halves being pressed plastically onto each other (1010 °C) with a high pressure of 25 MPa. Creep deformation reduction and improvement of the weld quality are achieved in the third step at 1050 °C and a pressure of 15 MPa. In U-DW setup at the FZK laboratory, a computer with an appropriate controlling program provides for an ideal heating behavior and the thermal gradient is nearly negligible in laboratory-scaled workpieces. Thermocouples are welded directly to the mockups. This cannot be done in an industrial HIP setup. The temperatures cannot be changed, if grain coarsening shall be avoided or the weld quality shall be maintained. Hence, the process times are increased and thermal gradients are avoided during the active steps according to results of a former U-DW experiment [6] and semi-empirical numerical estimations, see Table 1 process times. The pressure is increased (20%) to balance the expected inhomogeneous pressure distribution in the weld surface [6] and the deformation of the coolant channels.

TZM (titanium zirconium molybdenum alloys produced by powder metallurgy) plates with a lubricant are placed on the opposite surfaces – parallel to the weld area – of the mockups. Doing this, a collapse of the cooling channels has to be avoided. This package is boxed and evacuated for three days to about 10^{-5} mbar.

The whole HIP process (FW and CP) lasts about 9 h, including heating and cooling (about 17 °C/min).

For pressure and leak tightness tests, small EUROFER tubes are welded to all mockups after the HIP process. A prolonged post-weld heat treatment (PWHT) [6] is applied to the CP and FW mockup in a vacuum furnace. The CMU is subjected to the usual PWHT (980 °C 30 min and 3 h 730 °C) in the IMF-II U-DW setup.

2.3. Pressure and leak tightness tests

The pressure test is carried out with argon at room temperature and 145 bars for 60 min according to later operation conditions. A pressure drop by less than a quarter of a bar is used as criterion for pressure resistance. All mockups passed the test successfully. The CP mockup is welded in the inlet and outlet region. In the true CP, however, these regions are milled away.

The leak tightness test is performed with helium at 130 bars and a maximum leakage rate of about $5 \cdot 10^{-10}$ mbar l/s. All outer and inner welds tested were found to be leak-tight.

Table 1
Process times, including recovery times and excluding the heating time prior to the first step.

Mockup	First step (min)	Second step (min)	Third step (min)
Laboratory DW specimen	45	60	80
CMU	120	70	115
CP mockup	120	95	130
FW mockup	120	95	130

3. Conclusions

The results reported confirm that the 24 MPa laboratory DW process has been adapted successfully to a HIP setup. A ''quarter''-sized FW (50 cm × 80 cm × 5 cm), a CP mockup, and a CMU were manufactured. The DW welds were pressure-resistant and helium leak-tight.

Some other necessary tests of the FW mockup could not be performed due to the lack of time. Micrographs are supposed to show grain coarsening. The influence of the heat treatment during the HIP process and PWHT will have to be investigated by Charpy impact and tensile tests. The specimens will have to be taken from different positions of the mockup. Specimens of the base material will yield first indications as regards the influence of the heat treatment. Comparison of weld and base material specimens will reveal the weld quality. This work is now being prepared.

Comparison of the different DW setups shows that it may be reasonable to repeat the former U-DW experiment. The number of HIP setups by far exceeds that of U-DW setups. A fitting U-DW setup would allow for a better temperature control.

The CP mockup will be tested for pressure drop of the cooling medium. These experiments will have to be discussed in the future. After this, a mechanical destructive examination, as that done for the FW mockup, will have to be performed.

Acknowledgements

This work, supported by the European Communities under the contract of Association between EURATOM and Forschungszentrum Karlsruhe, was carried out within the framework of the European Fusion Development Agreement (EFDA). The views and opinions expressed herein do not necessarily reflect those of the European Commission. The authors thank EURATOM and the Forschungszentrum Karlsruhe for the financial support. The authors additionally thank Mr Spiess (IHM) for applying the PWHT, Mr Fuhrmann (ITP) for performing the leak tightness test, Mr Wagner (BTI) for the pressure test. Thanks also go to all colleagues not mentioned here for their help and discussion.

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