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Development of joining technology for ITER first wall by mock-up fabrication

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1. Introduction

The joining of different materials is considered as one of the key technologies that need to be developed for the fabrication of the ITER first wall consisting of Be, CuCrZr and stainless steels (SS). Among the many possible joining methods for Be, CuCrZr and SS, a hot isostatic pressing (HIP) is considered to be the most probable joining method for the fabrication of the ITER first wall [1-3]. The HIP joining technology for Be, CuCrZr and SS has been developed in the authors' previous researches [4,5]. However, the fabricability of the ITER first wall needs to be demonstrated by fabricating many types of mock-ups which can simulate the characteristics of the ITER first wall more than the joint samples do. In this investigation, three different types of mock-ups were fabricated with different number and size of Be tiles. For each type of a mock-up, three different types of interlayers were applied. The joining strength of Be/CuCrZr interface was evaluated to investigate the effect of an interlayer on the joining strength of Be/CuCrZr.

2. Experimental methods

The materials used in the fabrication of the mock-ups were Be tiles with a grade of S-65C VHP (Vacuum hot pressed), CuCrZr with a grade of Elbrodur G by KME and stainless steels (SS) with a grade of SS316L in the form of plates and pipes. The chemical compositions of the Be and CuCrZr were within the designated composition range in the specification for manufacturing of first wall qualification mock-ups [6].

The three types of mock-ups were fabricated with different number and size of Be tiles. First, a CuCrZr block with two SS316L coolant tubes was fabricated by a HIP joining at 1050^{o}C, 100MPa for 2h followed by a solution-annealing at 980^{o}C for 0.5h and a rapid cooling using water or gas. Such a post HIP heat treatment is required to place the CuCrZr in the solution-annealed state following the overaging and associated degradation of strength due to the CuCrZr/SS HIP process. A solution-annealed state allows the recovery of an acceptable strength level during the subsequent Be/CuCrZr HIP process. Before the HIP joining of Be/CuCrZr, the interlayers were coated onto the surface of the Be tiles. The types of interlayers applied to the mock-ups are Cr/Cu, Ti/Cu and Ti/Cr/Cu in [5]. Be tiles were joined to CuCrZr by a HIP at 580-620^{o}C, 100MPa for 2h.

Fig. 1 shows the large mock-up from the three types of the mock-ups fabricated in this work. The joining strength of the Be/CuCrZr interface was evaluated by a shear test at a cross-head speed of 0.5mm/min.

3. Results and discussion

The joining strength of the Be/CuCrZr joint specimens was determined at the shear strength at which the joint specimen fractured. Fig. 2 shows the effect of the interlayer type on the shear strength of Be/CuCrZr interface of the large mock-ups. The shear strength of the Be/CuCrZr joint specimens obtained from the three kinds of mock-ups was summarized in regard to the interlayer type. The shear strength of the Be/CuCrZr joint specimens with Cr/Cu interlayers was found to range from 157MPa to 204MPa depending on the number and the size of the Be tiles used in the mock-up. The highest shear strength with the Cr/Cu interlayer was obtained in the mock-up where three Be tiles with 80x80x10mm^3 were joined to CuCrZr.

From the shear strength of the Be/CuCrZr joint specimens with Ti/Cu interlayers, it was found that the shear strength was remarkably changed especially with the thickness of the Ti interlayer. When the thickness of the Ti interlayer was decreased from 10 μm to 5 μm with the thickness of the Cu interlayer being maintained at 10 μm, the shear strength was increased from 84MPa to 166MPa on average.

The shear strength of the Be/CuCrZr with a Ti/Cr/Cu interlayer was almost similar to each other regardless of the type of mock-ups. The variation of the shear strength was smallest among the three kinds of mock-ups when Ti/Cr/Cu interlayers were used for the HIP joining of Be and CuCrZr.

In this investigation, it was found that the joining strength of the Be/CuCrZr can be changed depending on the interlayer types and the mock-up design. The highest shear strength was obtained from the Be/CuCrZr joint specimens which were taken from the Be/CuCrZr/SS mockups with three 80x80x10mm^3 Be tiles and a Cr/Cu interlayer while the lowest shear strength was obtained for the Be/CuCrZr mock-up with a Ti/Cu interlayer. However, the shear strength of the

Be/CuCrZr joint specimen with a Ti/Cu interlayer was increased when the thickness of the Ti interlayer was decreased from 10 μm to 5 μm.

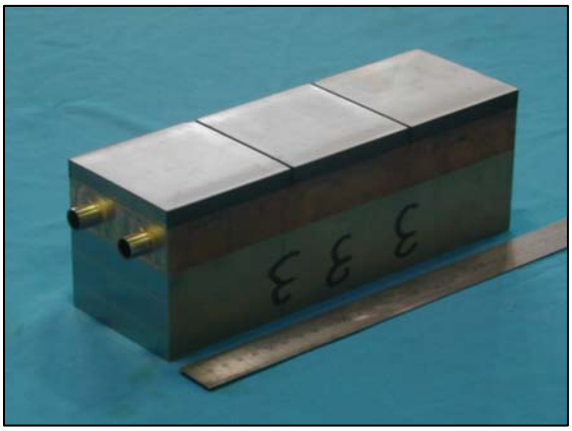
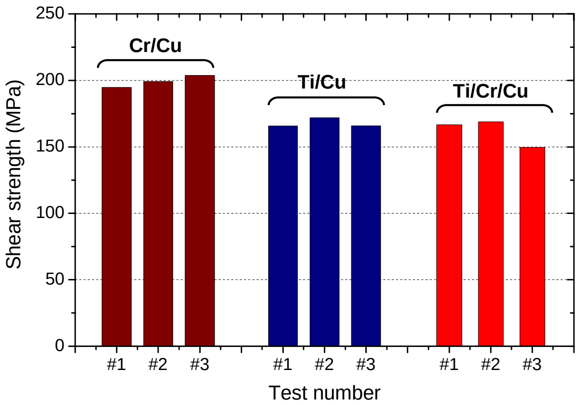


Fig. 1. Large mock-up with three $80x80x10mm^3$ Be tiles.

Fig. 2. Effect of the interlayer type on the shear strength of



Be/CuCrZr interface of the large mock-ups

In the authors' previous research [5], the effect of an interlayer type on the HIP joining of Be/CuCrZr was investigated by using Be/CuCrZr joint specimens with Cr/Cu and Ti/Cu interlayers. The Be/CuCrZr joint specimen with a Ti/Cu interlayer showed a higher shear strength than that with a Cr/Cu interlayer, which is not consistent with the current result. Although the interlayer type plays an important role in obtaining a Be/CuCrZr joint with a higher strength, the HIP joining strength of Be/CuCrZr could be influenced significantly by the other parameters during the fabrication process. This implies that another parameter other than the interlayer type should be controlled precisely to obtain a Be/CuCrZr joint with a higher strength.

In this investigation, the effect of the HIP joining temperature on the shear strength of a Be/CuCrZr joint was also investigated, only for the mock-up with one $50x50x10mm^3$ Be tile. The shear strength was increased with an increase of the HIP joining temperature from 580^{o}C to 620^{o}C for both the Ti/Cu and Cr/Cu interlayers. This is consistent with our previous result [5]. However, the increase of the shear strength by the increase of the HIP temperature from 580^{o}C to 620^{o}C is not as significant as the change of the shear strength due to the change of the interlayer type. Moreover, the mechanical properties of CuCrZr were found to be decreased due to the overaging effect when the aging temperature was increased from 580^{o}C to 620^{o}C [5]. It is suggested that 580^{o}C could be more relevant compared to 620^{o}C for the fabrication of the ITER first wall.

4. Conclusions

Three types of the mock-ups consisting of Be, CuCrZr and stainless steel (SS) were fabricated by a HIP joining method to demonstrate the fabricability of the ITER first wall. The effects of the mock-up design and the interlayer type on the joining strength of the Be/CuCrZr joint were investigated on the basis of the shear test results for the Be/CuCrZr joint specimens. The effect of the size and the number of Be tiles used in the mock-ups was not as significant as the interlayer selection. Even though the shear test is considered to be very useful to elucidate which interlayer is the most applicable for the joining of Be and CuCrZr, the final interlayer selection should be based on the results obtained from the high heat flux test for the mock-ups fabricated in this work.

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