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Effects of processing parameters on Be/CuCrZr joining

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1. Introduction

A joining of Be/CuCrZr has been considered as the key technology for the fabrication of the ITER first wall. Among the joining methods, Hot isostatic pressing (HIP), which is one of the diffusion bonding methods, is the most feasible method to join the Be and CuCrZr alloy. In the HIP joining of Be and CuCrZr, the interlayer was used to prevent the formation of brittle intermetallic compounds in the interface. Therefore, it is crucial to select a suitable interlayer for a joining of Be and CuCrZr. On the other hand, the diffusion between Be and CuCrZr would be enhanced with an increase of the HIP joining temperature, thereby increasing the joint strength. However, the HIP joining temperature is limited by the mechanical properties of CuCrZr. During the fabrication process of the ITER first wall, CuCrZr is subjected to several thermal cycles including a solution annealing, a cooling and an aging. The HIP joining of Be and CuCrZr corresponds to the aging of CuCrZr. The HIP joining at a higher temperature would cause a degradation of the mechanical properties of CuCrZr by an overaging effect although it is preferable for an improvement of the joint strength. In this study, the effect of the cooling rate on the mechanical properties of aged CuCrZr was investigated to find the maximum HIP temperature without a degradation of the mechanical properties of CuCrZr.

2. Experimental procedure

For investigating the effect of the cooling rate on the aged CuCrZr, the canned CuCrZr was solution-annealed at 980^{o}C for 0.5h and cooled down by four different cooling methods which were a water quenching, a rapid gas cooling, a slow gas cooling and an air cooling. After the completion of the cooling process, the CuCrZr alloys were subjected to an aging at 400^{o}C to 620^{o}C for 2h.

The microstructure of the aged CuCrZr was observed by an optical microscopy (OM) and the grain size was determined. For the selected alloys, the precipitation characteristics were examined by a transmission electron microscopy (TEM). The samples for TEM were prepared by a mechanical thinning to 70 μm followed by a twin jet polishing at 10V, 0.5A and -20^{o}C in a solution of 30vol.% HNO_3 and 70vol.% ethanol.

The tensile test of the CuCrZr alloys were performed at RT and 250^{o}C using the button headed cylindrical specimens with a gauge length of 30 mm and a diameter of 3 mm at a cross head speed of 5mm/min. The fracture surface after a tensile test was observed by a scanning electron microscopy (SEM).

3. Results and discussion

The change of the yield and tensile strength of the CuCrZr alloys with an aging temperature and a cooling rate were examined at RT. The yield strength showed the highest valve at the aging temperature of 440^{o}C irrespective of the cooling rate and it was decreased gradually with an increase of the aging temperature from 440^{o}C to 620^{o}C. For the same aging temperature, the yield strength was increased with a cooling rate. The difference of the yield strength with the cooling rate became smaller when the CuCrZr alloys were aged at above 580^{o}C. The change of the tensile strength showed almost the same behavior to that of the yield strength.

The tensile test result at 250^{o}C showed an almost similar behavior to the RT test result except that the highest strength was decreased by approximately 20% at 250^{o}C. Like the RT test, the yield and tensile strength exhibited the highest value at the aging temperature of 440^{o}C regardless of the cooling rate, and it was higher for the faster cooling rate. The elongation was changed from 19% to 30%, but its change is not likely to be influenced by an aging temperature and a cooling rate.

The strength of the CuCrZr alloy was significantly dependant on the aging temperature and the cooling rate. However, the change of the strength was not correlated with the microstructure observed by OM. This implies that the strength of the CuCrZr alloy is controlled more by the precipitation behavior than the grain size. It was reported that a bimodal distribution of coarse and tiny precipitates was observed in CuCrZr and the tiny precipitates contributed to the mechanical strength by an Orowan mechanism [1,2].

Fig. 1 shows the precipitation characteristics observed by TEM for the selected alloys in this study. In the alloys showing the highest yield and tensile strength by a water quenching and aging at 440^{o}C, precipitates were not observed in the bright field image but a number of unidentified contrasts was observed in the dark field image which is thought to be the Guinier-Preston (G-P) zones. When the aging temperature was increased to 580°C, precipitates are observed in the bright field image. Edwards et al. also observed fine G-P zones in CuCrZr alloy which was solution-annealed at 960°C for 3 h, water quenched and aged at 500oC for 3h [3]. However, the G-P zones were replaced with precipitates which were thought to be predominantly incoherent Cr-rich particles when the aging temperature was increased [3].

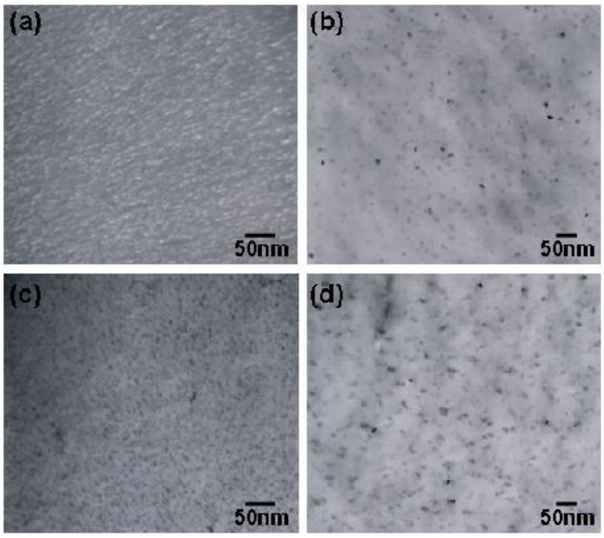

Figure 1. TEM (a) dark and (b, c, d) bright field images of the CuCrZr alloys which were cooled by (a, b) the water quenching and (c, d) the rapid gas cooling after solution annealing at 980°C for 0.5h and then aged at (a, c) 440°C and (b, d) 580°C for 2h.

On the other hand, the CuCrZr alloy cooled by a rapid gas cooling showed a fine distribution of the precipitates when aged at 440°C. As the aging temperature was increased to 580°C, the precipitate size was increased along with a decrease of the density. It was also found that the precipitate size was bigger at a higher cooling rate in the CuCrZr aged at 580°C. This demonstrates that the strength of CuCrZr was highly dependant on the distribution of the precipitates. Though the precipitation in CuCrZr was promoted more when the aging temperature was higher, the highest strength was obtained in the CuCrZr having a number of G-P zones.

It was reported that the strength of CuCrZr was decreased when an additional annealing was performed after an aging at 500°C for 3h [3]. Such a behavior became prominent when the annealing time was increased, which was correlated well with an increase of the precipitate size and a decrease of the density [3]. Holzwarth et al. also reported that the highest strength observed in CuCrZr was related with a fine distribution of the precipitates with a mean size of 2.3nm and a density of $3.3 \times 10^{22} m^{-3}$ which was only obtainable when the cooling rate was higher than 60°C/min. [1,2]. This implies that a fast cooling is crucial to make the CuCrZr alloys have fine distribution of the precipitates, thereby maintaining a higher strength. On the basis of the results obtained, the strength of the CuCrZr alloy was higher than the minimum value required in the design of the ITER first wall up to the aging temperature of the 600°C even though the gas cooling methods were applied after a solution annealing.

4. Conclusion

The effects of the cooling rate on the microstructure and the mechanical properties of aged CuCrZr alloys were examined. The strength showed the highest valve at the aging temperature of 440°C irrespective of the cooling rate and it was decreased gradually with an increase of the aging temperature up to 620°C. The strength of CuCrZr was highly dependant on the distribution of the precipitates and the highest strength was obtained in the CuCrZr having a number of G-P zones. The strength of the CuCrZr alloy was higher than the minimum value required in the design of the ITER first wall up to the aging temperature of 600°C when gas cooling after a solution annealing was performed.

Acknowledgements

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