Effect of the Heat treatment on the Mechanical Properties on the CuCrZr alloy and Ferritic-Martensitic Steel

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1. Introduction

The CuCrZr alloy and ferritic-martensitic steel (FMS) are being considered as the primary candidate for the heat sink material of the international thermonuclear experimental reactor (ITER) first wall and the structure material of the test blanket module (TBM) first wall, respectively [1-3]. For the fabrication of ITER and TBM first wall, we must carry out the HIP process at the high temperature. However, the mechanical properties of the CuCrZr alloy and FMS are known to be very sensitive to the thermal history [4]. Therefore, in this study, the effect of heat treatment on the mechanical properties of the CuCrZr alloy and FMS was investigated to optimize the HIP joining conditions for the fabrication of the ITER and TBM first wall.

2. Experimental procedure

2.1 Effects of the cooling rate and aging treatment on the mechanical properties of the CuCrZr alloy

The CuCrZr alloy used in this study was produced by the KM Europa Metal. The CuCrZr alloy block, 60(t) x 60 x 70 mm^3 in size, was machined from the as-received CuCrZr alloy, and canned with SS304 by a TIG welding. The canned CuCrZr alloy was solution-annealed at 980 ◦C for 30 min and cooled down by four different cooling methods as listed in Table 1. The gas cooling rate was controlled by changing the gas flow rate. During the cooling process, the temperature was recorded from 980 to 500˚C to determine the cooling rate by using two thermocouples inserted into the center and outer part of the canned CuCrZr alloy.

The microstructure of the aged CuCrZr alloy was observed by an optical microscopy (OM) and the grain size was determined by a line intersection method according to ASTM E112-96. The tensile tests for the CuCrZr alloy were performed at RT and 250˚C.

2.2 Effect of the post HIP heat treatment (PHHT) on the mechanical properties of the ferritic-martensitic steel

The FMS used in this study was produced by KOUFU Co., LTD., Japan. First, in order to get the optimum conditions of a PHHT, the material properties of FMS were investigated with a focus on the effect of a normalizing and tempering. The details of the heat treatment conditions are listed as follows: 1. After a normalizing at 850, 900, 950, 1000 and 1050˚C for 2h followed by a tempering at 750˚C for 2h (fixed tempering temperature); 2. After a normalizing at 950˚C for 2h followed by a tempering at 650, 700, 750 and 800˚C for 2h (fixed normalizing temperature).

For the joining of FMS to FMS, the FMS was machined in the form of blocks and channels and assembled as shown in Fig. 4, and then encapsulated with 2 mm SS304 plates. The canisters were out-gassed and HIPed at 1050˚C, 100MPa and 2h. The HIP joined specimens were normalized at 950˚C for 2h and tempered at 750˚C for 2h which were optimized in this study.

The mechanical properties and joining strength were examined by tensile and Charpy impact tests, and the microstructure evolution was observed by an OM.

Table 1. Variation of cooling rate with four different cooling conditions.

Cooling methods	**Cooling rate, ˚C/min**	
	center	**Outer part**
Water quenching (WQ)	458	467
Rapid gas cooling (RGC)	207	208
Slow gas cooling (SGC)	89	90
Air cooling (AC)	36	37

3. Results and discussion

3.1 Effects of the cooling rate and aging treatment on the mechanical properties of the CuCrZr alloy

The results of the measured cooling rate were listed in Table 1. The difference in the cooling rate between the center and the outer part was about 1˚C/min for GCA, GCB and AC whereas WQ was about 9˚C/min.

The microstructure of the aged CuCrZr alloy was not significantly different even though the aging temperature as well as the cooling rate was changed. The average grain size was ranged from 76 to 108㎛ for all the heat-treated CuCrZr alloys. However, the change of the average grain size did not correlate well with an aging temperature as well as a cooling rate since the grain morphology was not homogeneous.

Fig. 1 shows the result of tensile test with an aging temperature and a cooling rate at RT and 250˚C, respectively. The tensile strength showed the highest value at an aging temperature of 440˚C irrespective of the cooling rate and it was decreased gradually with an increase of the aging temperature. For the same aging temperature, tensile properties were increased with the cooling rate. The difference in the tensile strength with the cooling rate became smaller when the CuCrZr alloys were aged at above 600˚C. The tensile test result at 250˚C showed an almost similar behavior to the RT test result. The red lines are the minimum value recommended by ITER. Tensile strength was lower than the minimum requirement value when the aging temperature was higher than 600˚C which could be the upper limit of HIP temperature.

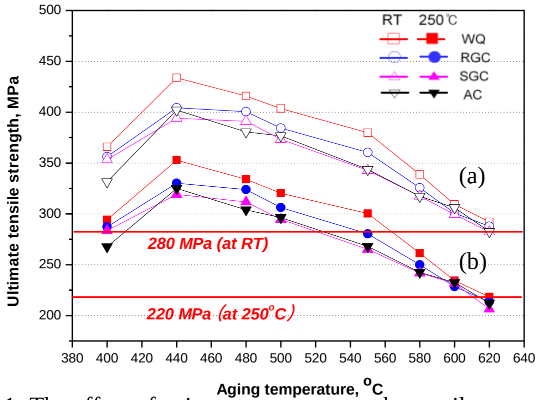

Fig. 1. The effect of aging temperature on the tensile strength of the CuCrZr alloy cooled with different cooling rates: tested at (a) room temperature and (b) 250˚C.

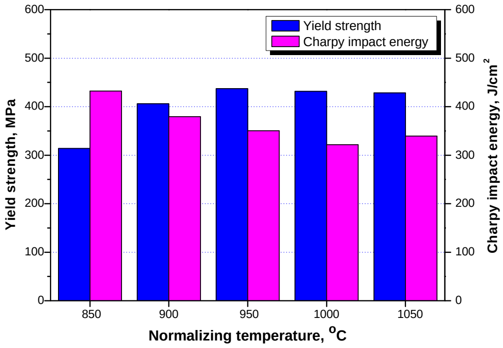

Fig. 2. The effect of the normalizing temperature on the yield strength and Charpy impact energy of FMS.

3.2 *Effect of the heat treatment on the mechanical properties of the ferritic-martensitic steel*

After a PHHT, the grain size was increased with an increasing normalizing temperature. The results of tensile and Charpy impact test on the normalized FMS are summarized in Fig. 2. After being heat treated at 1050˚C for 2h, HIP joining conditions, the mechanical properties were degraded, and it showed very brittle behavior. However, after PHHT, the yield strength was slowly increased with the normalizing temperature and showed similar strength values above 950˚C. The impact energy was gradually deceased with an increasing normalizing temperature. This means that the thermally reduced mechanical properties were recovered to the as-received state by the following a PHHT. The normalizing temperature could be employed in the range from 950 to 1050˚C based on only this result, however the excessive grain coarsening was observed at a normalizing temperature above 1000˚C. Normally, the coarsening of prior-austenite-grains of in FMS can cause a decrease of the fracture toughness and a shifting of the ductile to brittle transition temperature to a higher temperature [2]. In this study, the normalizing temperature is applied at 950˚C after the HIP treatments.

In the case of the tempering effect, the significant differences of the grain coarsening could hardly be confirmed by the OM observation. Fig. 3 shows the results of the tensile and Charpy impact tests on the tempered FMS. The yield strength was decreased with an increase of tempering temperature. On the other hand, Charpy impact energy was increased. The effective tempering temperature can be employed in the range around 750˚C based on the obtained as-received result.

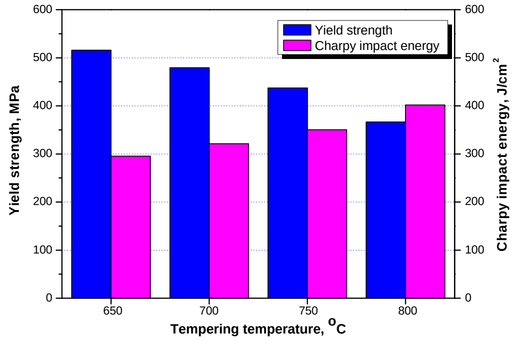

Fig. 3. The effect of the tempering temperature on the yield strength and Charpy impact energy of FMS.

The appearance of the HIP joined channel type FMS/FMS and the microstructure of the joint interface are shown in Fig. 4. We found some joined traces in the interface. However, in all the tensile tested specimens, a fracture never occurred at the joined interface, and the tensile properties of the HIP joined specimen were similar to that of the as-received FMS.

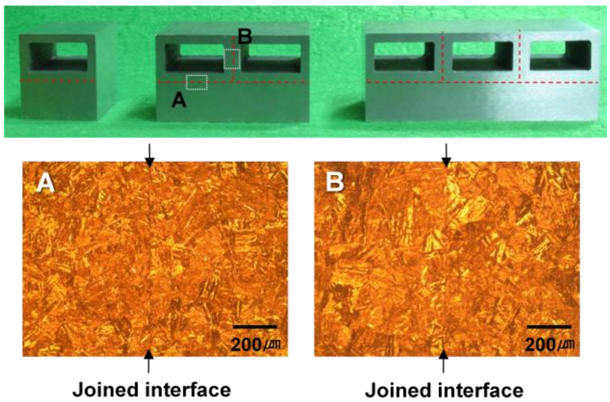

Fig. 4. Appearance of the HIP joined channel type FMS/FMS and the microstructure of the joint interface.

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