Tensile Properties of CuCrZr Tube during Mass Production for the ITER Divertor Outer Vertical Target*)

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The mass production of CuCrZr alloy - ITER Grade tubes for the ITER divertor outer vertical target (OVT) prototype and series production is now in progress as well as other material. It is required to manufacture the CuCrZr tube with the mechanical properties required by the design and with the grain growth suppressed in terms of prevention of water leakage and durability of electromagnetic load even after the completion of the OVT. Therefore, the mechanical properties are tested prior to a use for the OVT to confirm the mechanical properties and the quality during mass production of the CuCrZr tube. This paper reports the tensile properties, which are one of important mechanical properties required for the CuCrZr tubes used in the prototype and series production of the OVT. As the results of sampling inspection during the mass production, the CuCrZr tube was capable of meeting required values of the tensile properties even after the heat treatment simulated the solution annealing and aging in the PFU manufacturing.

Keywords: ITER, divertor, outer vertical target, plasma facing component, CuCrZr

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1. Introduction

The mass production of CuCrZr alloy - ITER Grade tubes for the ITER divertor outer vertical target (OVT) prototype and series production is now in progress as well as other material [1]. One CuCrZr tubes are used per one plasma-facing unit (PFU) as shown in Figs. 1 (a) and (b). One OVT is comprised of 22 PFUs as seen in Fig. 1 (c). The total number of CuCrZr tubes used in the 58 OVTs, including the four spares, is 1800 CuCrZr tubes including the test specimens as shown in Fig. 1. In the mass production of CuCrZr tubes, one of the more important points is to make sure that the quality is maintained.

In the manufacturing process of the OVT, the CuCrZr tube is subjected to several heat treatments. For example, in the manufacturing process of the PFUs of the OVT, heat treatment of brazing and solution annealing with gas quenching and aging are performed. It is necessary to prevent the mechanical properties of the CuCrZr tube from deteriorating and its crystal grains from growing due to the heat treatment in the manufacturing process of the OVT. In other words, it is required to manufacture the CuCrZr tube with the mechanical properties required by the design and with the grain growth suppressed in terms of prevention of water leakage and durability of electromagnetic load even after the completion of the OVT. Therefore, the mechanical properties are tested prior to a use for the OVT to confirm the mechanical properties and the quality during mass production of the CuCrZr tube. This paper reports the tensile properties, which are one of important mechanical properties required for the CuCrZr tubes used in the prototype and actual series of the OVT.

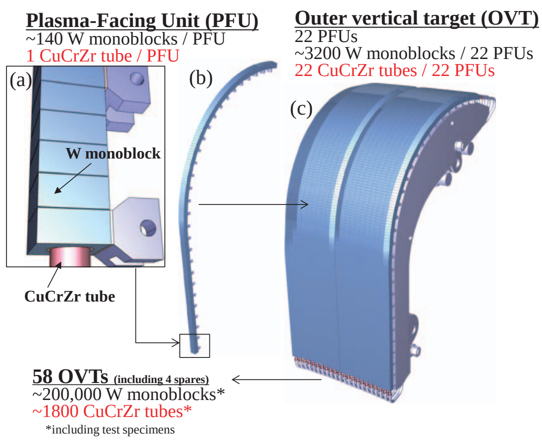

Fig. 1 CuCrZr tube in ITER divertor OVT. (a) enlarged view of a PFU, (b) the PFU, (c) birds-eye view of the OVT.

2. Procedure

A scope of tensile test for mechanical properties is to inspect tensile strength, 0.2% yield strength and total elongation at room temperature and 250°C. As applicable standards, the test method at room temperature was conducted in accordance with ASTM E8/8M-16, and the test method at 250°C was conducted in accordance with ASTM E21-09. For the calibration of the equipment, JIS B 7721-2018 and JIS B 7741-2016 were applied for testing at the room

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temperature, and ASTM E4 was used for testing at 250°C. The shape of the specimen was kept as a tube, with an outer diameter of 15 mm, an inner diameter of 12 mm, and a length of 200 mm. As for equipment, Maekawa Universal Testing Machine MRA-30-F2 for tensile test at room temperature and AG-x plus for tensile test at 250°C.

Figure 2 shows a manufacturing process of CuCrZr tubes and the timing of testing for confirmation of mechanical properties. The tensile properties of CuCrZr tubes prior to the use of the OVT were tested on specimens after the heat treatment in a vacuum furnace at 980°C for 30 minutes followed by gas quenching at 1°C/sec and aging at 475°C for 3 hr as shown in Figs. 3 (a) and 3 (b), considering a simulation of heat treatment during the manufacturing process of the OVT. The frequency of the tensile test was defined as a maximum 150 CuCrZr tubes per a lot, and tensile tests were conducted on three specimens per lot and per test temperature. So far, 300 of 1800 CuCrZr tubes required during all the OVTs have been manufactured, and the tensile test were performed for 7 lots, that is, a total of 42 specimens, including both room temperature and 250°C.

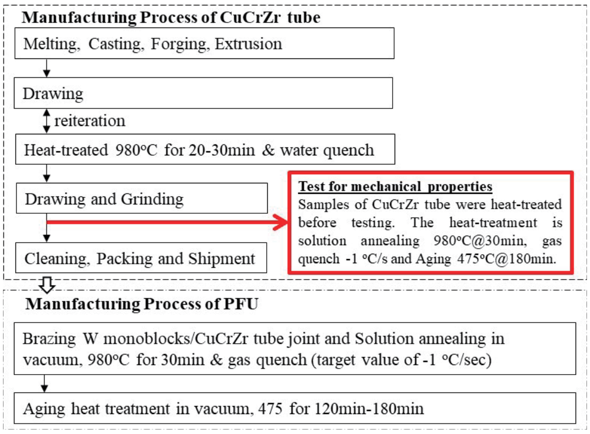

Fig. 2 Sampling process during manufacturing of CuCrZr tubes.

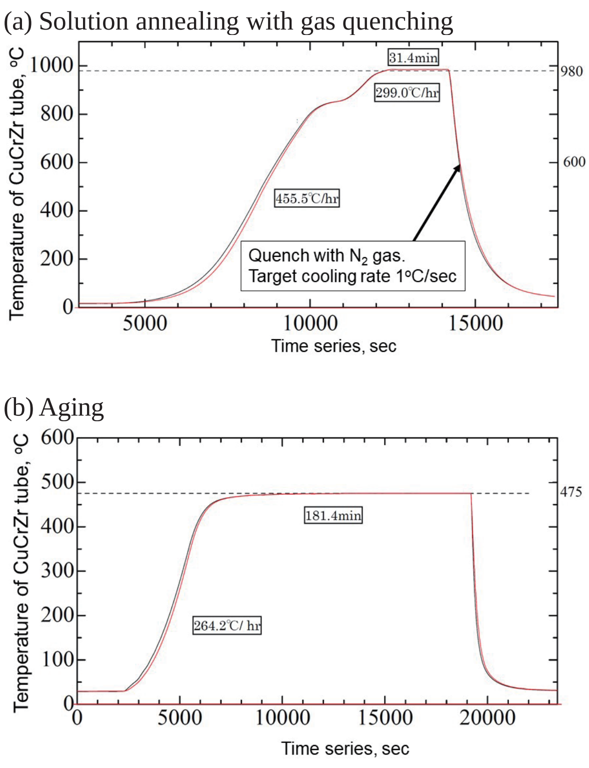

Fig. 3 Temperature profiles of heat treatment (a) solution annealing with gas quenching and (b) aging for tensile test specimens (Lot No. X0610-7619&7620).

3. Results and Discussion

The specimens after the tensile tests at room temperature and 250°C are shown in Fig. 4. Fracture position defined as per ASTM E8 as follows:

Fracture position A - a fracture inside the gauge marks which is located more than 25% of the elongated gauge length from either gauge mark;

Fracture position B - a fracture inside the gauge marks which is located less than 25% of the elongated gauge length from either gauge mark;

Fracture position C - a fracture outside the gauge marks.

In all 42 specimens, fracture position A occurred in 39 specimens as shown in Fig. 4, fracture position B occurred in 3 specimens, including 2 specimens at 250°C, and fracture position C occurred in zero. The fracture positions indicate that all tensile tests were properly performed.

The minimum value of the three tensile test results per a lot and per temperature is shown as the minimum tensile properties in Table 1. The required values were met all the tested 7 lots. It has been confirmed that the quality of the CuCrZr tube was maintained on a continuous basis during the mass production. In the mass production, the CuCrZr tube was capable of meeting required values of the tensile properties even after the heat treatment sim-

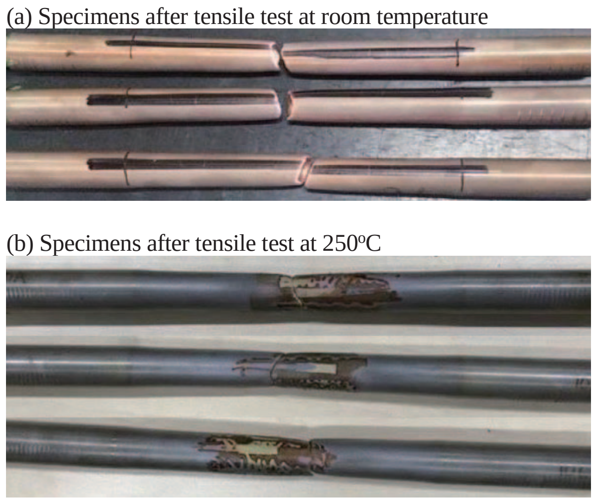

Fig. 4 Specimens of a CuCrZr tube (lot No. X0610-7619, Fracture position A) after the tensile test.

Table 1 Tensile properties of CuCrZr tube after solution annealing and aging.

Lot No.	Cooling rage[°C/s] during 980-600°C	Room temperature			250 °C		
		TS [MPa], min	YS [MPa], min	EL [%], min	TS [MPa], min	YS [MPa], min	EL [%], min
Required value for OVT	1.00	280	175	15	220	150	14
X0610-3949	0.99	371	231	30	284	182	27
X0610-3951	0.99	376	235	25	276	178	26
X0610-7619	1.07	372	224	30	298	196	30
X0610-7620	1.07	372	230	30	298	200	26
X0610-3950	1.17	362	220	31	266	164	29
X0610-3952	1.17	352	212	30	276	175	27
X0610-2718	1.19	391	276	26	304	224	24

Note: TS, YS and EL indicates a tensile strength, a 0.2% yield stress and a total elongation, respectively.

ulated the solution annealing and aging in the PFU manufacturing. The process of manufacturing the CuCrZr tube involves repeated the cold drawing and the heat treatment as shown in Fig. 2. It is known that the strength of CuCrZr tube depends on temperature and time duration of solution heat treatment, its cooling rate and those of aging. The results of the present tensile test indicate that the above factor values, which depend on the strength of the CuCrZr tube, were within the range of the required strength of the CuCrZr tube after PFU manufacturing even during mass production.

4. Summary and Conclusions

This paper reports the tensile properties, which are one of important mechanical properties required for the CuCrZr tubes used in the prototype and series production of the OVT.

It has been confirmed that the quality of the CuCrZr tube was maintained on a continuous basis during the mass production. As the results of sampling inspection during the mass production, the CuCrZr tube was capable of meeting required values of the tensile properties even after the heat treatment simulated the solution annealing and aging in the PFU manufacturing.

[1] M. Fukuda *et al.*, Fusion Eng. Des. **106**, 112283 (2021).