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Heat treatment effects on the microstructure and properties of Cu–Cr–Zr alloy used for the ITER blanket components

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Cu–Cr–Zr bronze is used as a heat sink for enhanced heat flux first wall components and structural material for blanket module connectors of ITER. The solution annealing at 980 °C for 0.5 h, water quench and ageing at 475 °C for 3 h is specified as a reference heat treatment for ITER. The proper heat treatment is provided the better performance taking into account for various structural elements operating under different conditions. However, the actual manufacturing cycle might be different from the recommended one. As the result, heat treatment effects on the properties of Cu–Cr–Zr bronze might be different from that one specified in the ITER documentation. Thus, the effect of various types of heat treatment (in particular the parameters of aging) on the Cu–Cr–Zr alloy's properties is a very important. This paper deals with the investigation of heat treatment effects during aging at a temperature range of 350–750 °C and aging time from 5 to 180 min on the structure and physical-mechanical properties of Cu–Cr–Zr bronze.

1. Introduction

Cu–Cr–Zr alloy is proposed as a heat sink material for various components of ITER (blanket first wall, divertor, electrical straps and others). Blanket Module Connectors are mechanical fastening and electrical connection system of the blanket vacuum vessel of ITER. There are an electrical straps that provide blanket modules and vacuum vessel electrical coupling in the Blanket Module Connectors [1,2] and First Wall Panels [1]. An electrical strap consists of a central and lateral flanges connected by a group of current-carrying wave-like lamellas (Fig. 1) [3].

The operating temperatures of structural components, including electrical straps, are 250–350 °C [2–4]. The Cu–Cr–Zr alloy is chosen as a material that ensures an application under operating conditions.

Bronze interchangeability with another material unfeasible in most cases, as an except the necessary level of tensile properties, the main requirement for hardware is high thermal and electrical conductivity. A combination of high strength and electrical conductivity is one of the advantages offered by Cu–Cr–Zr in comparison with another copper-based alloy.

An electrical conductivity and tensile properties depend on both alloy's chemical composition and heat treatment [5,6]. Properties of precipitation hardened alloys depend in a great extent by the heat treatment and thermal-mechanical treatment. So, precipitates that are result in anneal play a key role in an alloy's strength — its high electrical conductivity.

The heat treatment for the manufacturing of the ITER structural components due to their specific geometry and use of different manufacturing for the connection of blanket module components differ from that one described in the ITER specification [7].

Data variations of such properties as tensile, electrical conductivity, hardness at different ageing hold time and ageing temperatures are very important. They allow to optimize the required properties and to predict a material behavior at various heat treatment.

The study of structural changes in the pre-deformed and aged Cu–Cr–Zr specimens is valuable since the obtained structure after heat treatment provides the maximum strength in combination with high electrical conductivity.

2. Material and test procedures

Cu–Cr–Zr plate 305 × 90 × 30 mm produced by JSC “Chepetsk Mechanical Plant” was used for investigation. The actual chemical composition and the ITER specification are presented in Table 1. The NIKIET data show that the main alloying elements are within the ITER specification [7].

The specimens were solution annealed at 980 °C for 30 min and water quenched. The ageing temperature varied from 350 °C to 750 °C with a step of 50 °C and the holding time from 5 to 180 min with subsequent cooling in air. The aging temperature was determined with

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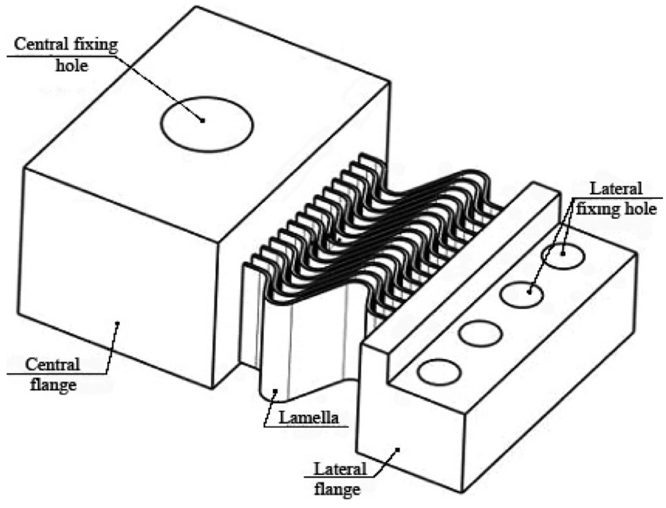

Fig. 1. Electrical strap.

an accuracy of ± 5 °C.

An oxidiesed layer with a depth of about $200 \times 10^{(-6)}$ m [200 microns] was mechanically removed from the surface of the tested specimens to avoid the oxide layer effect on the bronze properties. Physical-mechanical properties of bronze were measured to study the variations caused by heat treatment effects in accordance with different aging conditions.

Brinell hardness (HB) tests were performed in accordance with the current ISO standards. Wilson Hardness Reicherter UH 751 hardness has been used with the following test conditions - loading 125 MPa, ball diameter 5 mm, loading time 10 s. The equipment has been fitted out with a software for automatic measurements.

Electrical conductivity was measured by multifunctional eddy current device MVED-2M.

The measured quantities of hardness and electrical conductivity were statistically processed for getting the correlation between properties (electrical conductivity and hardness) and heat treatment conditions (ageing temperature and holding time).

To reveal the microstructure metallographic specimens were eached in a reagent with the following composition: 8 g $FeCl_3$; 25 ml HCl; 100 ml H_2O. This microstructure was analyzed by optical microscope Zeiss Axio Observer and Thixomet software.

The X-ray microanalysis were performed using scanning electron microscope (SEM) CamScan with software «INCA» (Acc. Voltage 15 kV. Beam current: 2nA.) and by the transmission electron microscope (TEM) Libra 120 Carl Zeiss.

3. Test results and discussion

As a result of measurements the hardness (HB) and electrical conductivity (MS/m) versus ageing time and temperature were obtained. The statistically processed data are presented in Figs. 2 and 3.

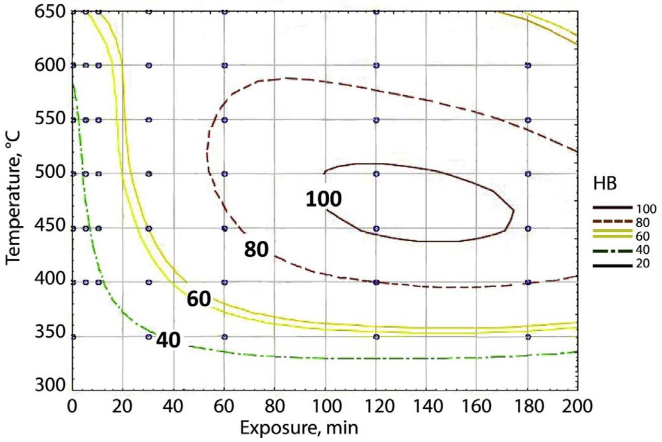

Fig. 2. Hardness (HB) versus aging time and temperature of Cu–Cr–Zr alloy after exposure for 30 min and water quench for 980 °C.

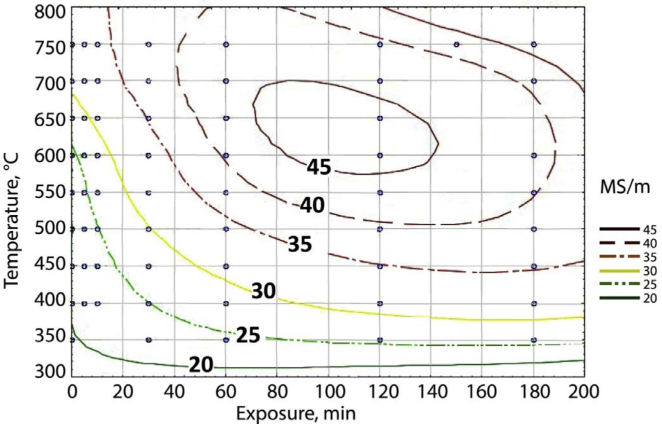

Fig. 3. Electrical conductivity versus aging time and temperature of Cu–Cr–Zr alloy after exposure for 30 min and water quench for 980 °C.

3.1. Hardness

The Fig. 2 shows that at low temperature (350 °C) the investigated Cu–Cr–Zr alloy doesn't strengthened. Hardening take place after aging temperatures at 400 °C and above. The maximum possible hardness can be reached HB 120 after hold time at 140 min and ageing temperature at 475 °C. Ageing at 500 °C reduces time of maximum hardness achievement, and hardness value decreases as compare with maximum possible one for this alloy. Hardness practically doesn't increases during the hold time because of an over-aging at 550 °C.

The measured hardness values at ageing temperatures range of 350–750 °C are given in the Fig. 4. It should be noted that with increase in temperature of aging from 350 °C to 450–500 °C and hold time from 100 to 140 min the hardness of Cu–Cr–Zr alloy increases, reaching the maximum value at aging temperatures of 450–475 °C. At further increasing exposure the hardness practically doesn't change. This result is well agreed with the data provided in papers [8,9] where influence of

Table 1
Chemical composition of Cu–Cr–Zr.

	Basic elements, mass. %			Impurities*,%.								
	Cu	Cr	Zr	Fe	P	S	Si	Pb	Co	Al	Zn	O
ITER specification [7]	Basic	0.6–0.9	0.07–0.15	0.009	0.0069	0.002	–	0.0017	0.06	0.0016	0.0069	< 0.008
NIKIET measurements	basic	0.81	0.11	0.021	0.0026	0.002	0.0063	–	–	–	–	< 0.001

* Total quantity of impurities < 0.15%.