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Effect of heat treatments on the properties of CuCrZr alloys

A.D. Ivanov [a,*], A.K. Nikolaev [b], G.M. Kalinin [c], M.E. Rodin [a]

[a] *Engineering Center of Nuclear Equipment Strength, Reliability and Lifetime (ENES) P.O. Box 788, 101000 Moscow, Russia*
[b] *Tsvetmetobrabotka Institute, Pyzhevskiy pereulok, 7, 109017 Moscow, Russia*
[c] *ITER Garching Joint Work Site, Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching bei München, Germany*

Abstract

CuCrZr alloys are proposed as a main option for the high heat flux components of ITER. Heat treatments applied during components manufacturing may result in property changes of the CuCrZr alloys. This paper deals with the detailed investigation of heat treatment effects on the properties of the CuCrZr alloys.

1. Introduction

CuCrZr alloys can be subjected to thermal cycles typical for high isostatic pressure and brazing techniques during manufacturing of ITER components. The properties of CuCrZr alloys are known to be sensitive to heat treatments [1]. Rather restricted data are available on the behaviour of this material in conditions of simulated cycles for ITER components manufacturing [2]. The objective of the present study was to quantify the variation in hardness, electrical conductivity and tensile properties of a CuCrZr alloy under some heat treatment conditions.

2. Experimental

The studied material was a 5-mm thick sheet of a CuCrZr alloy produced by the Tsvetmetobrabotka Institute according to Standard TU 48-21-5050-82. The CuCrZr alloy has the following chemical composition (wt%): 0.96% Cr, 0.067% Zr, 0.002 Ni, <0.003 Bi, $\leqslant$0.01 As, $\leqslant$0.003 Pb, $\leqslant$0.01 Zn and Cu balance. The solution annealing of the CuCrZr specimens has been performed at 950 °C for 30 min. The accuracy of the temperature measurement was +10 °C. Four various cooling modes have being realized (Fig. 1): water quenching, air cooling, fast furnace cooling and furnace cooling. The average cooling rates determined in the temperature range of 950–500 °C were as follows: 90 °C/s at water quenching, 3 °C/s at air cooling, 14.5 °C/min at fast furnace cooling and 1.3 °C/min at furnace cooling. After solution annealing, the specimens have been aged at temperatures of 450, 480, 520, 550, 650, 750, 850 and 950 °C for 10, 30, 60, 120, 180, 240, 300 and 600 min.

The Vickers hardness (98 N force) has been determined. The experimental uncertainty in the hardness measurement was ±(2–7) HV. The electrical conductivity has been determined by the Eddy current method. The measuring error was ±0.3 MS/m. The microstructure has been studied by an 'Axiophot' microscope equipped by a 'Mop-Videoplan' attachment for computer processing of the grain size measurements. The grain size has been investigated in two orthogonal directions. The measurements of about 170 grains have been performed on one specimen for each heat treatment mode. The tensile tests have been performed at room temperature and 300 °C. The velocity of active gripper movements at testing was 1 mm/min. The following tensile properties have been determined: ultimate tensile strength (UTS), yield strength (YS), total elongation (TE) and reduction in area (RA).

* Corresponding author. Tel.: +7-095 268 9207/9471; fax: +7-095 264 7934.
E-mail address: ivanov@entek.ru (A.D. Ivanov).

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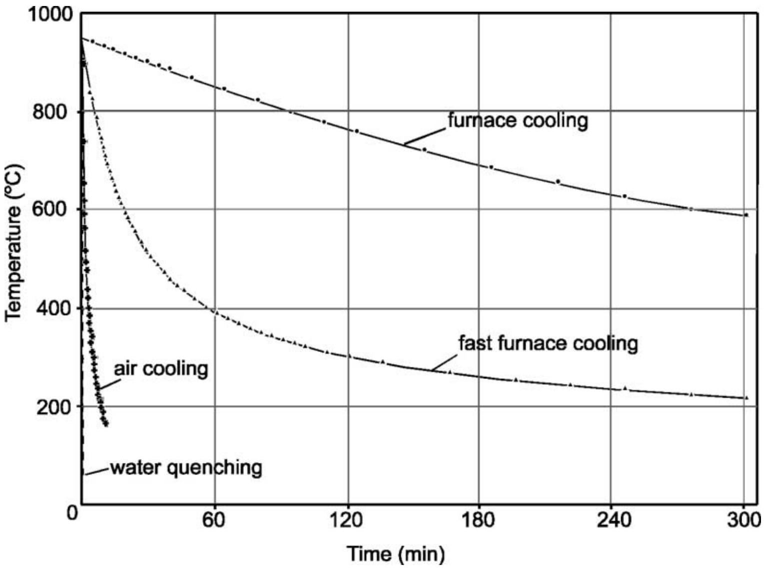

Fig. 1. Cooling of CuCrZr alloy solution annealed at 950 °C for 30 min.

3. Results

The analysis of the properties of the CuCrZr alloy solid solution annealed at 950 °C and cooled with various rates (Table 1) shows considerable changes of the electrical conductivity and hardness.

The changes of these properties testify that the investigated material changes from the supersaturated solid solution (water quenching) to various degrees of its decay form. This degree increases with decreasing cooling rate. The CuCrZr alloy water quenched has the lowest values of hardness and electrical conductivity. The highest values of electrical conductivity have been observed after the slowest cooling (furnace cooling). This indicates the complete decay of the supersaturated solid solution. However, the low hardness of these specimens testifies that the phases form the coagulated particles and do not provide the hardening. The tensile properties and grain sizes practically do not depend upon the cooling method.

The effect of aging at 450–950 °C on the tensile properties of the CuCrZr alloy solution annealed and cooled with different rates is shown in Figs. 2 and 3. After water quenching the supersaturated CuCrZr solid solution is exposed to the decay in the temperature range of 450–550 °C. This fact is verified by the changes of hardness, electrical conductivity and mechanical properties (Fig. 2). The kinetic dependence of hardness and strength variation is similar. The electrical conductivity is most sensitive to the solid solution ordering that is accompanied by extraction of the hardening phase.

The partial decay of the CuCrZr solid solution takes place during air cooling with the rate of about 3 °C/s in the temperature range of 950–500 °C. This decay continues during the isothermal exposure in the temperature range of 450–550 °C, and the corresponding changes of electrical conductivity, hardness and mechanical properties (Fig. 3) testify this change. However, the intensity of the process is in this case lower than that of the CuCrZr alloy in the water quenched state analogous conditions.

The investigated alloy water quenched and aged at 480 °C for 2–3 h has the following tensile properties at room temperature: UTS $\approx$ 380 MPa, YS $\approx$ 240 MPa,

Table 1
CuCrZr alloy properties after solution annealing at 950 °C for 30 min and various cooling rates

Cooling mode	Average cooling rate[a]	Hardness (HV)	Electrical conductivity (MS/m)	Grain size (μm)	UTS (MPa)	YS (MPa)	TE (%)	RA (%)
Water quenching	90 °C/s	68	24	22	258	109	42	78
Air cooling	3 °C/s	74	28	27	250	94	43	81
Fast furnace cooling	14.5 °C/min	93	38	26	258	106	46	78.5
Furnace cooling	1.3 °C/min	85	45	25	250	101.5	41	81

[a] Temperature range of 950–500 °C.

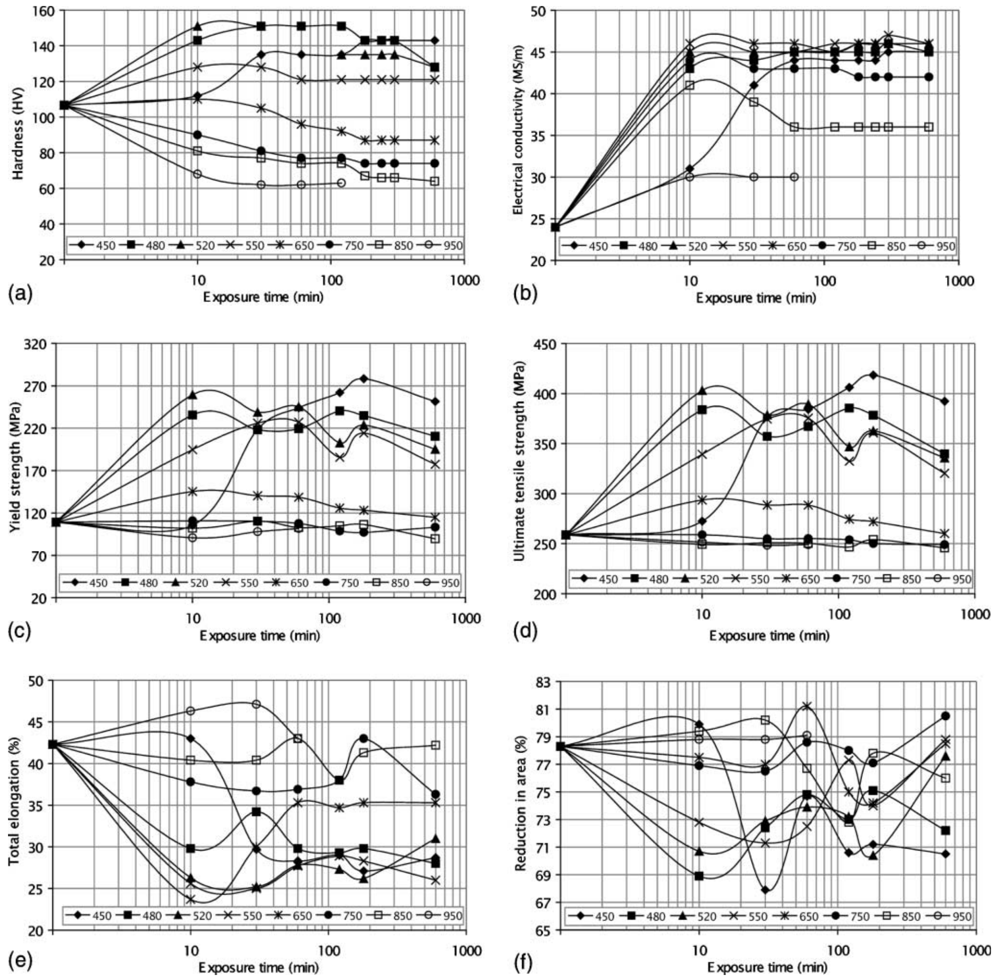

Fig. 2. Influence of aging on the properties of CuCrZr alloy water quenched: hardness (a), electrical conductivity (b), YS (c), UTS (d), TE (e) and RA (f).

TE ≈ 29% and RA ≈ 73%. The strength of this material after air cooling and the same aging is about 80% of the strength of the alloy in the above-mentioned state. So, in case of cooling rates not lower than 3 °C/s in the temperature range of 950–500 °C realizing the manufacturing of ITER multi-layer components, the strength of the CuCrZr alloy could be considerably increased by the additional aging at temperatures of 480–520 °C.

The cooling rates lower than 14.5 °C/min at 950–500 °C (fast furnace cooling) after solution annealing cause practically a complete decay of the solid solution of the investigated alloy. The residual processes of structure changes taking place in the investigated material after isothermal exposures at 450–600 °C do not cause a considerable influence on the property changes.

The tensile tests of the CuCrZr alloy were performed at 300 °C after water quenching and aging. The UTS and TE at 300 °C decrease for age temperatures of 450–650 °C in comparison with the testing temperature of 20 °C. The YS varies ambiguously for any age conditions: 450, 550 and 650 °C for 10 min and 480 °C for 30 min. Specimens air cooled and aged at 480 °C have been tested at 300 °C. The UTS, YS and TE decrease and the RA does practically not change in comparison with the test at 20 °C.

4. Conclusions

Experimental data have been obtained on physical–mechanical properties (electrical conductivity, hardness, strength and ductility) of the CuCrZr alloy. Hardness and electrical conductivity of the CuCrZr alloy depend on the cooling rate after solution annealing and are determined by the degree of decay of the solid solution versus the cooling rate. Water quenching and air cooling

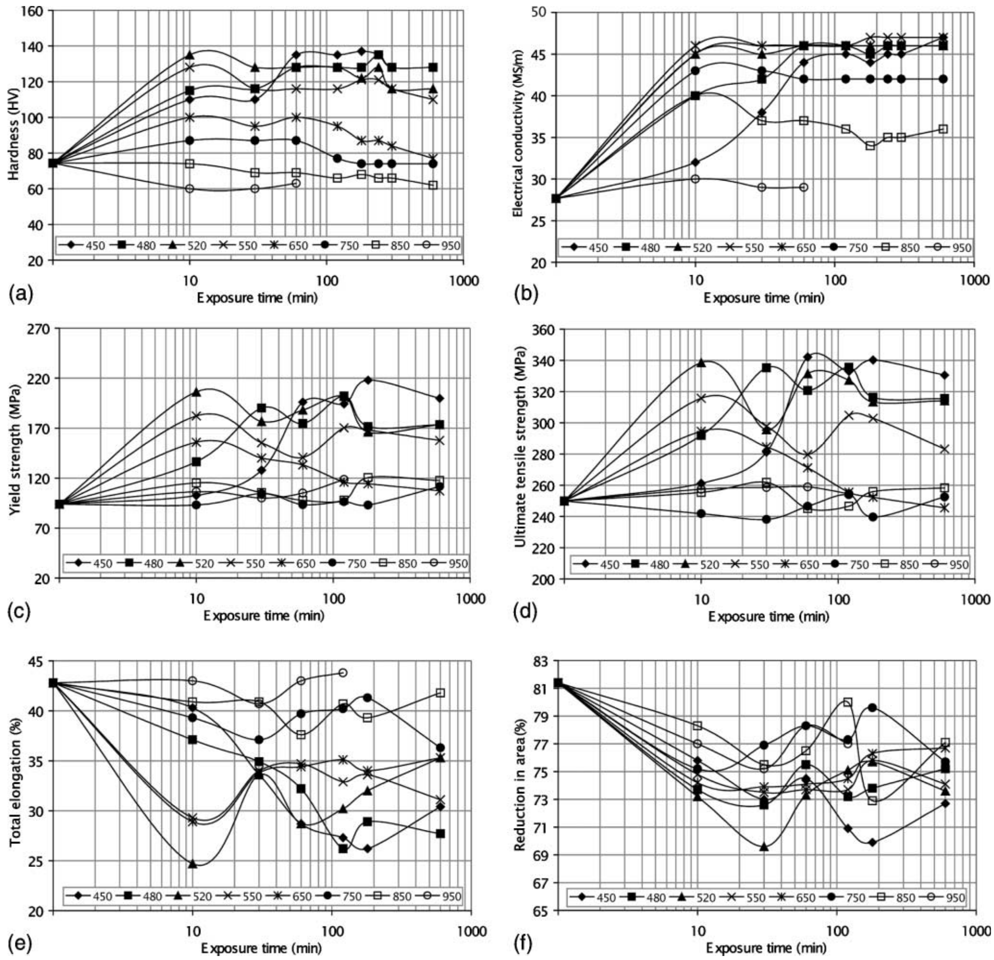

Fig. 3. Influence of aging on the properties of CuCrZr alloy air cooled: hardness (a), electrical conductivity (b), YS (c), UTS (d) TE (e) and RA (f).

are only able to keep the solid solution and to provide hardening during aging. The investigated cooling conditions of the CuCrZr alloy practically do not affect on the tensile properties and grain size after solution annealing.

The most reasonable variations of the age temperature for providing a high strength of the material are in the range 480–550 °C. Higher temperatures result in overaging and lower strength. However, the ductility of CuCrZr alloy remains relatively high.

The processes taking place at various cooling rates after solution annealing determine the degree of the properties variation of the CuCrZr alloy including hardening and softening at subsequent aging.

References

[1] ITER Structural Design Criteria for In-vessel Components. Appendix A Materials Design Limit Data, Report G 74 MA 8 01-05-28 W0.2, ITER Garching JWS, 2001.

[2] S.J. Zinkle, W.S. Eatherly, Fusion Materials Semiannual Progress Report for Period Ending 31 December 1996, Report DOE/ER-0313/21, Oak Ridge National Laboratory, p. 165.