THE EFFECT OF AGING PARAMETERS ON PROPERTIES OF PM Cu-Cr-Zr ALLOY

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Abstract

In this study, Cu - 1.5 wt.% Cr - 0.5 wt.% Zr alloy was prepared by powder metallurgy (PM) method. Cu-Cr-Zr powders were pressed under 390 MPa uniaxial compression and sintered at 1000 °C for 2h. After the holding time, samples were immediately taken out of furnace and pressed at 850 MPa. Sintered samples were solution-treated at 1000 °C for 15 min and water-quenched. Then, they were deformed 20 % at room temperature and aged at 450, 475 and 500 °C for 2, 4, 6 and 8 h. SEM investigation revealed that, Cr and Zr particles having limited solubility in the Cu distributed homogeneously in copper matrix. XRD analysis showed that each sample (sintered and aged at 475°C for different times) has same phases: copper and trace Cr_2O_3. The relative density of sinter-pressed sample increased from 92% to 94% by cold deformation. The highest microhardness value is obtained in sample aged at 450°C for 8 hours and electrical conductivities ranges 84.9 - 87.6 % IACS depending on increase in temperature.

Keywords: Cu-Cr-Zr, powder metallurgy, solution treatment, aging, electrical conductivity

1. INTRODUCTION

Copper based alloys are widely used in applications where good electrical and thermal conductivities are required functional properties. Pure and annealed copper has extremely good electrical conductivity that it now forms the basis for describing the electrical conductivity of conductor materials in percentage relative to its conductivity (% IACS). Though pure copper has appreciable electrical conductivity and it is the natural choice materials for most electrical applications, it has a rather weak mechanical strength. In many electrical and thermal (conductivity) applications where mechanical strength is of little significance, pure copper or lightly alloyed Cu-Sn alloys have been the materials of choice. Typically, such alloys can only be strengthened by cold work. However, improving strengths from cold work have its limits due to self-annihilation of dislocation at room temperature from dynamic recovery. In applications such as railway contact wires, lead frame and connectors materials, where the mechanical strengths as well as electrical conductivity are required, the need arise for an alloy with combined property of high strength and high conductivity (HSHC). As a result, varieties of copper alloys have been developed with varying alloying elements, such as Cr, Nb, Zr, Mg in different combinations, to improve its mechanical strength [1, 2].

Cu-Cr-Zr alloy and some of its modifications are being used in a number of engineering applications such as trolley wire, lead frames, heat sink material, and electrode of resistance welding due to their high strength, high electrical and thermal conductivities as well as outstanding tribological behavior. Thermo-mechanical treatment is an effective method for obtaining high strength, high electrical conductivity of Cu-Cr-Zr alloy. Cold working is carried out between the solution treatment and aging to assist in the aging hardening by introducing high density of dislocations. The excellent strength is attributed to precipitation hardening, work hardening, and alloy strengthening mechanisms, whereas the high electrical conductivity is due to the very low solubility of Cr and Zr in Cu matrix at room temperature [3-13].

In general, manufacturing processing of Cu-Cr-Zr alloys includes casting, hot rolling, solution-treatment, water-quenching, cold deformation and aging steps, respectively [1,12]. In the present study, the influence of aging temperature on age hardenable Cu-Cr-Zr alloys which produced in open atmosphere by powder metallurgy technique is determined which having little information in open literature.

2. EXPERIMENTAL DETAILS

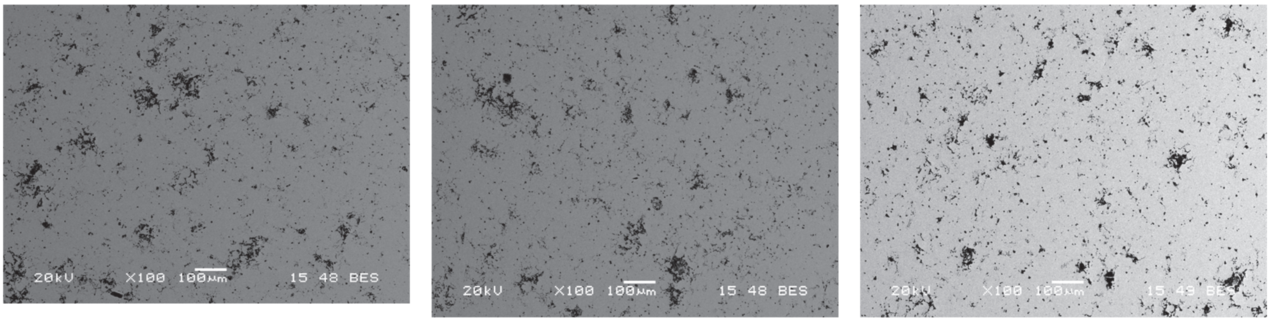
In this study, Cu - 1.5 wt.% Cr - 0.5 wt.% Zr alloy was prepared by powder metallurgy (PM) method. For this aim, Cu-Cr-Zr powders provided from Alpha Aesar with the average grain sizes of 40, < 10, 2-3 µm, respectively, are mixed mechanically for 2 h and pressed under 390 MPa uniaxial compression and sintered at 1000 °C for 2 h in an open atmospheric electric resistance furnace. After the holding time, samples are immediately taken out of furnace and pressed at 850 MPa. The sinter-pressed samples are solution-treated at 1000 °C for 15 min and water-quenched. Then, they are mechanically deformed 20 % at room temperature and aged at 450, 475 and 500 °C for 2, 4,6 and 8 h. Phase analysis of sinter-pressed, solution treated-water quenched and aged samples were performed by XRD analysis technique using Cu $K\alpha$ radiation with a wave length of 15.418 nm over a 2θ range of $10° \leq 20° \leq 90°$. The microstructures of the products were examined by means of scanning electron microscopy, energy dispersive spectroscopy (SEM-EDS). Relative densities of sintered samples were determined by Archimedes' method. The microhardness of polished specimens was measured with a load of 50 g for 15 s.

3. RESULTS AND DISCUSSION

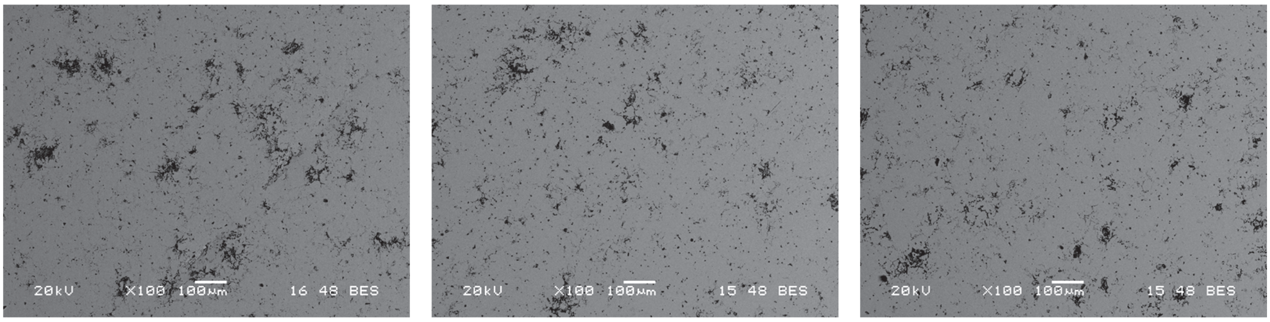
Fig. 1 shows SEM micrographs of sintered-solution treated-water quenched-cold deformed-aged sample for 2 and 8 h at 450, 475 and 500 °C. As it can be seen in **Fig. 1**, microstructures are similar to each other and a significant difference is not observed with variation of aging temperature and time. Microstructures in **Fig. 1** generally include homogenously distributed dark grey particles in light grey matrix. Light grey areas reflect copper matrix, dark grey particles include mainly chromium and less amount of copper and zirconium. In addition, lighter grey particles in copper matrix are rich in zirconium which confirmed by EDS analyses (**Fig. 2**). Also, zirconium rich regions include lower copper and chromium like chromium rich regions. Oxygen element is detected on chromium and zirconium rich regions and to a lesser extent in copper matrix. SEM-EDS analyses revealed that solubility of Cr and Zr in copper matrix is low as it is known well. XRD patterns (**Fig. 3**) of sinter-pressed sample and sintered-solution treated-water quenched-20 % cold pressed- aged samples at 475 °C for 2 and 8 h are similar to each other and have dominantly copper and trace Cr_2O_3 phases.

Relative densities of sintered and aged samples are given **Table 1**. While relative density of sintered and hot pressed sample is 92.2 %, cold pressed samples are approximately 94 %. This result shows that cold deformation slightly increases relative densities.

Hardness and electrical conductivity values of sinter-pressed and aged samples are given in **Table 2** and variations of hardness and electrical conductivity with aging time and aging temperature are shown **Fig. 4**. The hardness values were determined by taking the average of five different measurements on each sample. The maximum hardness value is obtained in sample aged at 450 °C for 8 h and hardness values of samples generally decrease with increasing aging temperature and increase with increasing aging time (especially at 450 and 475°C). Electrical conductivity values of aged samples are between 84.9 - 87.6 % IACS. The highest electrically conductivity values is obtained in sample aged at 500 °C for 8 h and its value is 87.6 % IACS. Electrical conductivity values in contrast to hardness values increase with increasing aging temperature due to more precipitation of solute atoms and recrystallization of deformed grains, the electrical conductivity under the both ageing conditions greatly increases with increasing temperature [13].



(a) 450 °C for 2 h (b) 475 °C for 2 h (c) 500 °C for 2 h



(d) 450 °C for 8 h (e) 475 °C for 8 h (f) 500 °C for 8 h

Fig. 1 SEM micrographs of aged samples

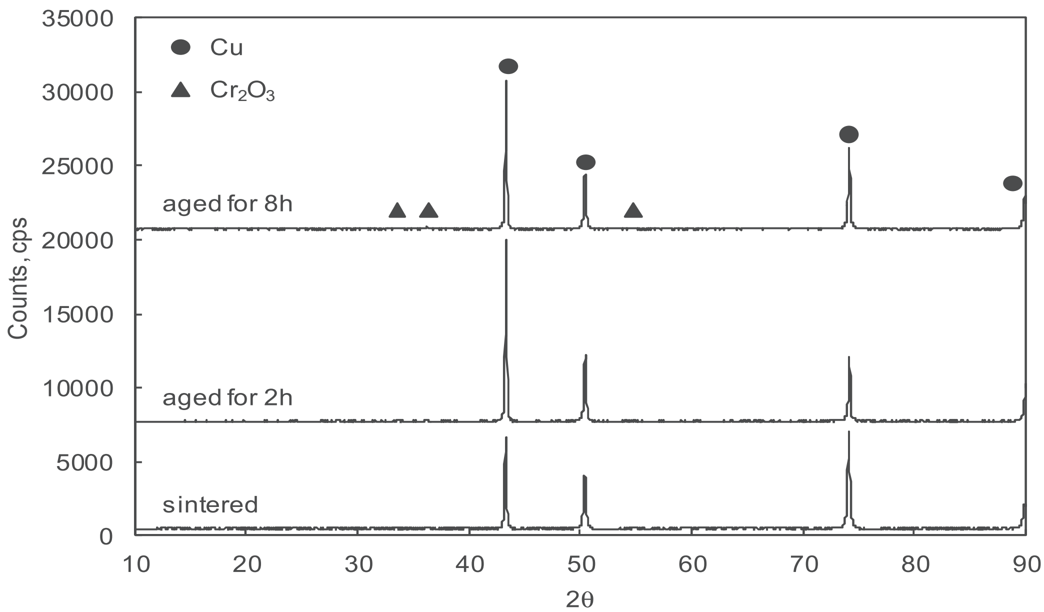
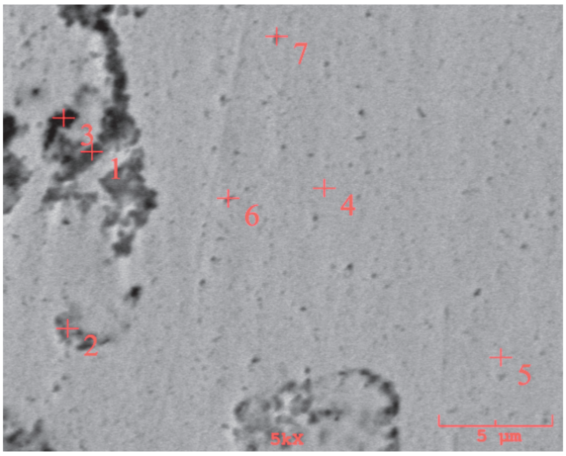
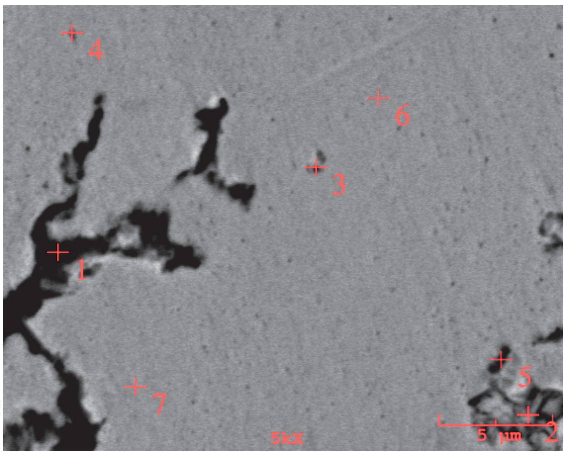


Fig. 2 XRD pattern of sinter-pressed sample and aged samples at 475 °C for 2 and 8 h



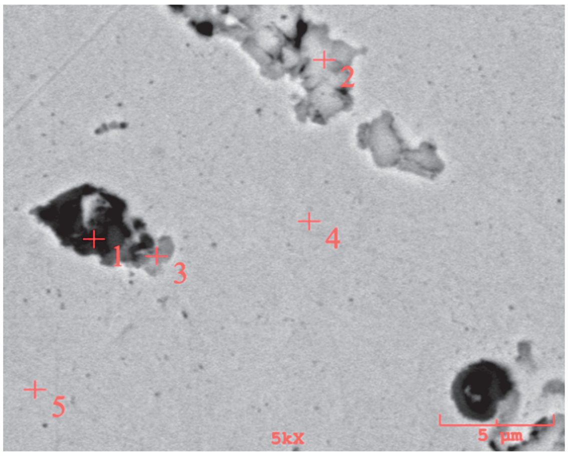
Mark	at. %			
	Cu	Cr	Zr	O
1	34.932	11.022	0.355	53.691
2	45.335	4.704	4.330	45.631
3	35.554	19.256	0.141	45.049
4	95.107	0.322	0.080	4.491
5	91.521	-	0.156	8.323
6	99.097	0.017	0.258	0.627
7	97.026	0.174	0.327	2.473

(a) 450 °C for 2h



Mark	at. %			
	Cu	Cr	Zr	O
1	17.165	20.897	0.066	61.872
2	32.474	3.114	14.953	49.458
3	86.766	1.420	0.148	11.666
4	88.889	0.305	1.256	9.550
5	70.752	3.262	0.151	25.836
6	96.871	0.484	0.254	2.390
7	97.441	0.327	0.542	1.690

(b) 500 °C for 2h



Mark	at. %			
	Cu	Cr	Zr	O
1	9.260	25.746	0.201	64.793
2	7.404	0.153	31.697	60.746
3	42.582	1.048	13.455	42.915
4	96.077	0.111	0.199	3.613
5	96.429	0.249	0.460	2.861

(c) 500 °C for 8h

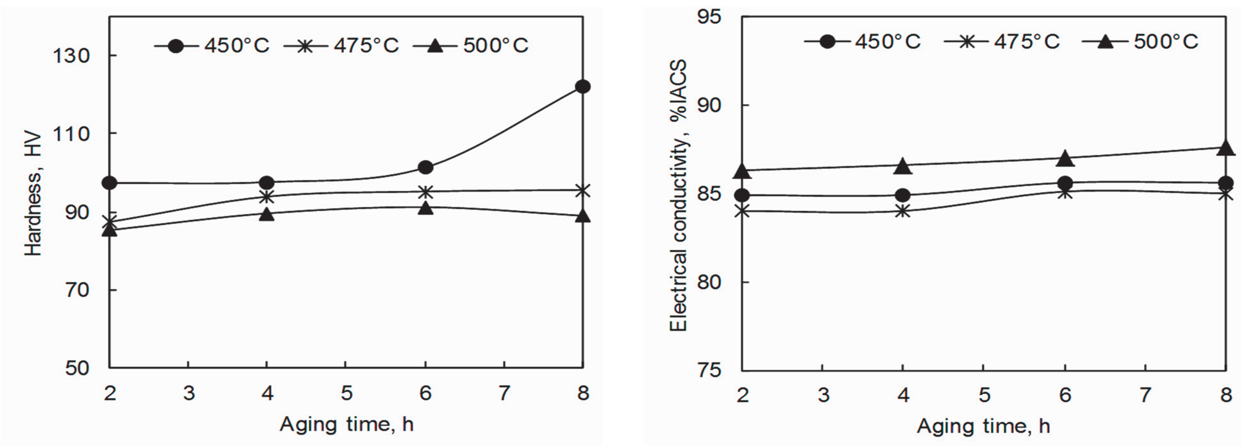
Fig. 3 SEM micrographs and EDS point analyses of aged samples at 450 and 500 °C

Table 1 Relative density of sintered and aged samples at different temperature and times

Process	Relative density (%)		
Cold pressed and aged	**Aging temperature (°C)**		
Aging time (h)	**450**	**475**	**500**
2	94.7	94.1	94.5
4	93.7	93.8	94.7
6	92.4	94.4	93.9
8	94.7	94.3	94.0
Sintered and hot pressed	92.2		

Table 2 Hardness and electrical conductivity values of samples

Aging time (h)	Hardness HV			Electrical conductivity (% IACS)		
	Aging temperature (°C)					
	450	**475**	**500**	**450**	**475**	**500**
2	97.4	87.4	85.3	84.9	84.0	86.3
4	97.6	93.9	89.6	84.9	83.9	86.6
6	101.3	95.2	91.2	85.6	85.1	87.0
8	122.0	95.6	89.0	85.6	85.0	87.6



(a) (b)

Fig. 4 Variation of hardness and electrical conductivity of aged samples as a function of aging temperature and aging time

The hardness values determined in this study are lower and electrical conductivity values are higher than that of the other reports on Cu-Cr-Zr alloys. This result can be attributed to applying cold deformation is approximately 70 % which higher than applying deformation in present study (20 %). For this alloys, hardness values and electrical conductivity values given in an open literature are 150 - 200 HV [11, 13] and 70 - 80 % IACS [10-14], respectively.

CONCLUSION

Following results obtained from the present study:

1) Cold deformation increases slightly the relative densities of sample.

2) The highest hardness is obtained in sample aged at 450 °C for 8 h and its value is 122 HV and hardness values decrease with increasing aging temperature.
3) It is observed that there is no remarkable effect of aging temperature and time on electrical conductivity of samples. Electrical conductivity of samples ranged from 84.9 - 87.6 % IACS.

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