UDK 621.762:621.762.5:621.785.797 ISSN 1580-2949
Professional article/Strokovni članek MTAEC9, 47(1)111(2013)

CHARACTERIZATION OF AN Cu-Cr-Zr ALLOY SYNTHESIZED WITH THE POWDER-METALLURGY TECHNIQUE

KARAKTERIZACIJA ZLITINE Cu-Cr-Zr, SINTETIZIRANE S TEHNIKO PRAŠNE METALURGIJE

Mediha Ipek

Sakarya University, Engineering Faculty, Department of Metallurgy and Materials Engineering, Esentepe Campus, 54187 Sakarya-Turkey
mipek@sakarya.edu.tr

Prejem rokopisa – received: 2012-08-16; sprejem za objavo – accepted for publication: 2012-09-14

A Cu-1.5 % Cr-0.5 % Zr alloy was prepared with the powder-metallurgy (PM) method. Cu-Cr-Zr powders were pressed under 390 MPa of uniaxial compression and sintered at 1000 °C for 2 h. After the holding time, the samples were immediately taken out of the furnace and pressed at 850 MPa. The sintered samples were solution-treated at 1000 °C for 15 min and water quenched. Then they were deformed by 20 % at room temperature and aged at 470 °C for (2, 4, 6 and 8) h. A SEM investigation revealed that the Cr and Zr particles having a limited solubility in Cu distributed homogeneously in the copper matrix. An XRD analysis showed that each sample (sintered and aged at 470 °C for different times) has the same phases: copper and trace Cr_2O_3. The relative density of the sinter-pressed sample increased from 92 % to 96 % due to cold deformation. The microhardness of the samples ranged from 77 HV for the solution-treated and water-quenched sample to 116 HV for the aged sample, and the electrical conductivity of the samples increased from 76 % IACS for the sinter-pressed sample to 87 % IACS for the sample aged for 8 h.

Keywords: Cu-Cr-Zr, powder metallurgy, age hardenable, electrical conductivity, hardness

Zlitina Cu- 1,5 % Cr- 0,5 % Zr je bila izdelana po metodi prašne metalurgije (PM). Prahovi Cu-Cr-Zr so bili enoosno stisnjeni s 390 MPa in 2 h sintrani na temperaturi 1000 °C. Potem so bili vzorci vzeti iz peči in stisnjeni z 850 MPa. Sintrani vzorci so bili raztopno žarjeni 15 min na temperaturi 1000 °C in ohlajeni v vodi. Nato so bili deformirani za 20 % pri sobni temperaturi in starani (2, 4, 6 in 8) h na temperaturi 470 °C. Preiskava s SEM je odkrila, da imajo delci Cr in Zr omejeno topnost v Cu in da so enakomerno razporejeni v osnovi iz bakra. Rentgenska analiza (XRD) je pokazala, da ima vsak vzorec (sintran in različno dolgo staran na 470 °C) enake faze: baker in sledove Cr_2O_3. Relativna gostota sintranega in stisnjenega vzorca je s hladno deformacijo narasla iz 92 % na 96 %. Mikrotrdota vzorcev je bila v območju od 77 HV za raztopno žarjen in v vodi ohlajen vzorec ter do 116 HV za staran vzorec. Električna prevodnost sintranega in stisnjenega vzorca je bila 76 % IACS in je narasla na 87 % IACS pri vzorcu, staranem 8 h.

Ključne besede: Cu-Cr-Zr, prašna metalurgija, utrjevanje s staranjem, električna prevodnost, trdota

1 INTRODUCTION

Age hardenable Cu-Cr-Zr alloys are widely used for many applications such as trolley wires, electrodes for resistance welding and lead-frame materials due to their high strength, high electrical and thermal conductivities[1–3]. Thermal aging is used to obtain high strength and, simultaneously, high electrical conductivity of the Cu–Cr–Zr alloys. The high electrical conductivity of an alloy is due to a very low solubility of Cr and Zr in the Cu matrix, whereas the excellent strength is attributed to the combined effect of precipitation hardening, work hardening, texture strengthening and alloy strengthening[1,3–6]. In order to control the microstructure and improve the properties of a Cu–Cr–Zr alloy, it is of great importance to optimize the aging process and identify the composition of the precipitates. There has been no unanimous agreement on the precipitation phase of the alloy[1,7]. In general, the manufacturing processing of Cu-Cr-Zr alloys includes casting, hot rolling, solution treatment, water quenching, cold deformation and aging steps[1,2]. In the present study, we characterized the age-hardenable Cu-Cr-Zr alloys produced in the open atmosphere with the powder-metallurgy technique. There is little information about this method in the available literature.

2 EXPERIMENTAL DETAILS

In this study, an Cu-1.5 % Cr-0.5 % Zr alloy was prepared with the powder-metallurgy (PM) method. For this purpose, the Cu-Cr-Zr powders obtained from Alpha Aesar with the average grain sizes of (10, <10, 2–3) μm, respectively, were mixed mechanically for 2 h, pressed under 390 MPa of uniaxial compression and sintered at 1000 °C for 2 h in an open-atmospheric, electric-resistance furnace. After the holding time, the samples were immediately taken out of the furnace and pressed at 850 MPa. The sinter-pressed samples were solution-treated at 1000 °C for 15 min and water-quenched. Then they were mechanically deformed by 20 % at room temperature and aged at 470 °C for (2, 4, 6 and 8) h. A phase analysis of the sinter-pressed, solution-treated, water-quenched and aged samples was performed with the XRD-analysis technique using the Cu Kα radiation with a wave length of 15.418 nm over a 2θ range of 10° ≤20° ≤90°. The microstructures of the products were examined by means of scanning electron microscopy, energy dispersive spectroscopy (SEM-EDS). Relative densities of the sintered samples were determined with the Archimedes' method. The microhardness of the polished specimens was measured with a load of 50 g.

3 RESULTS AND DISCUSSION

Figure 1 shows the SEM micrographs of a sinter-pressed sample and a sintered, solution-treated, water-quenched sample aged for 8 h. The microstructures in **Figure 1** generally include homogenously distributed dark-grey particles in the light-grey matrix. The light-grey areas show the copper matrix, while the dark-grey particles mainly include chromium and small amounts of copper and zirconium (**Figure 2a**, Mark 4 and **Figure 2b**, Marks 3, 4, 10). In addition, the lighter-grey particles in the copper matrix are rich in zirconium which was confirmed by EDS analyses. As in the chromium-rich regions, the zirconium-rich regions include small

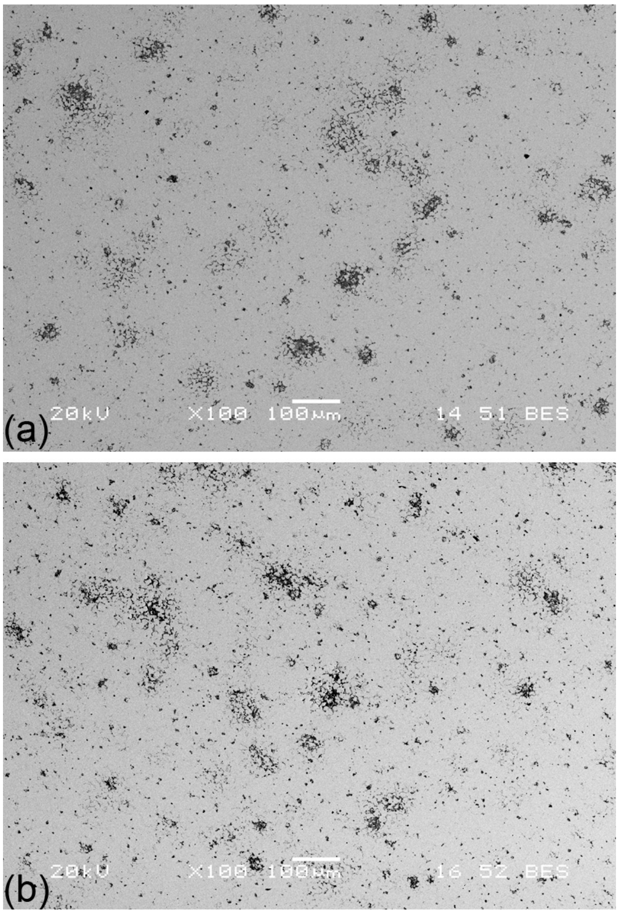
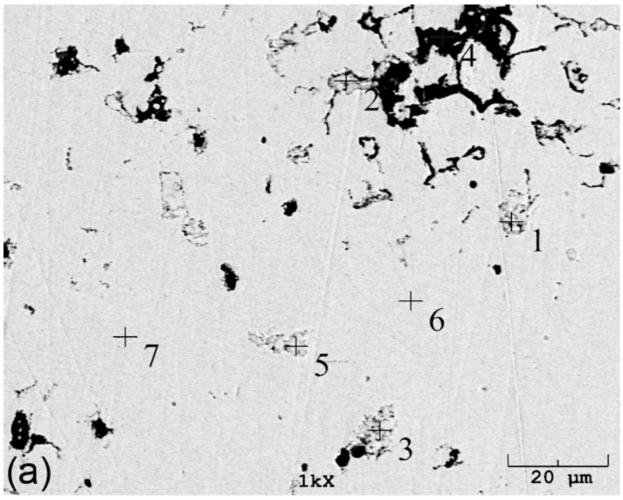
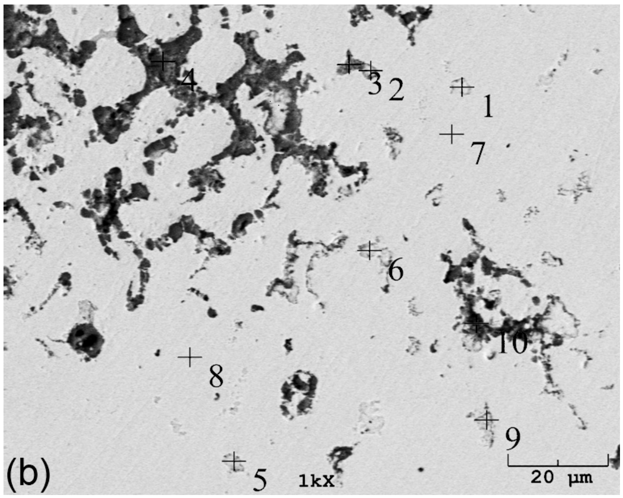


Figure 1: SEM micrographs of the samples: a) sinter-pressed, b) sintered, solution-treated, quenched and aged for 8 h

Slika 1: SEM-posnetka vzorcev: a) sintrano-stisnjeno, b) sintrano in raztopno žarjeno, hitro ohlajeno, starano 8 h



Mark	Mass fractions, *w*/%			
	O	Cr	Cu	Zr
1	10.1	0.4	56.1	33.4
2	17.0	4.4	31.0	46.6
3	18.8	0.1	11.9	69.2
4	28.5	65.2	5.8	0.5
5	13.4	0.3	45.7	40.6
6			100.0	
7			100.0	



Mark	Mass fractions, *w*/%			
	O	Cr	Cu	Zr
1	2.6	1.3	95.4	0.7
2	29.6	8.6	8.3	53.5
3	27.1	35.3	37.4	0.2
4	39.5	49.2	11.0	0.3
5	16.3	4.2	20.6	58.9
6	19.5	0.7	11,0	68.8
7	0.0	0.2	99.6	0.2
8	0.6	0.2	99.0	0.2
9	10.9	9.8	78.7	0.6
10	37.4	52.4	10,0	0.2

Figure 2: SEM micrographs and EDS point analyses of the samples: a) sinter-pressed, b) sintered, solution-treated and quenched

Slika 2: SEM-posnetka in EDS točkaste analize vzorcev: a) sintrano-stisnjeno, b) sintrano-raztopno žarjeno-hitro ohlajeno

Table 1: Variation of the relative density, hardness and electrical conductivity of the test materials as a function of process
Tabela 1: Spreminjanje relativne gostote, trdote in električne prevodnosti preizkušanih materialov v odvisnosti od postopka

Sample	Process		Relative density, %	Hardness, HV	Electrical conductivity, % IACS
Cu-Cr-Zr	Sintered and hot-pressed		91.9	123	76
	Solution-treated and water-quenched		92.2	77	77
	Cold pressed and aged (470 °C)	Time, t/h			
		2	94.5	86	85
		4	95.5	96	85
		6	95.3	98	86
		8	96.2	116	87

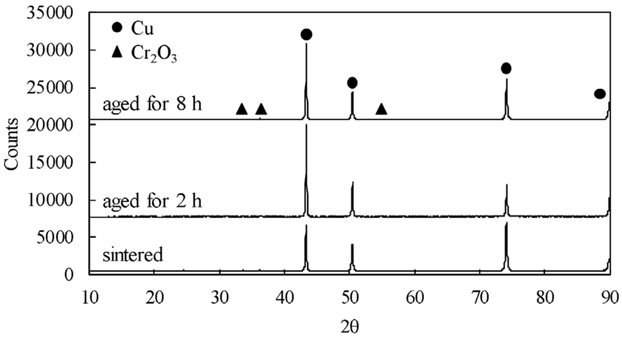


Figure 3: XRD patterns of the sinter-pressed sample and the sintered, solution-treated, quenched and aged samples
Slika 3: Rentgenski posnetek vzorcev sintrano-stisnjeno in sintrano-raztopno žarjeno-hitro ohlajeno-starano

amounts of copper and chromium (**Figure 2a**, Marks 1, 2, 5 and **Figure 2b**, Marks 2, 5, 6). In addition, oxygen was detected in the chromium- and zirconium-rich regions. SEM-EDS analyses revealed that the solution heat treatment increases the solubility of Cr and Zr in the copper matrix, but this solubility is still low. XRD patterns of the sinter-pressed samples and the sintered, solution-treated, water-quenched, 20 % cold-pressed and aged samples are similar to each other and have predominantly copper and trace Cr_2O_3 phases (**Figure 3**). In the present study, EDS analyses also revealed that chromium oxidized and this shows that the heat treatments of this alloys must be done in a controlled atmospheric medium. Relative density, hardness and electrical conductivity of the samples are given in **Table 1** as a function of process steps. While the relative densities of the sinter-pressed and sintered, solution-treated samples are approximately 92 %, the cold-deformed and aged samples have relative densities of over 94 %. It is obvious that cold deformation increases relative densities. The hardness values were determined by taking the average of the five different measurements made on each sample.

The hardness values for the sinter-pressed samples and the solution-treated, water-quenched samples are 123 HV and 77 HV, respectively. It was found that the hardness of a sample decreased after the processes of solution treatment and water quenching. The plastic deformation after the sintering may have caused the deformation hardening and the hardness therefore increased. After the aging the hardness value amounted to 116 HV for the sample aged for 8 h. A large number of dislocations and vacancies, introduced into the alloy by cold deformation, provide the nucleation sites for the formation of the Cr- and Zr-rich clusters and Guinier-Preston zones during the aging treatment, resulting in the acceleration of the precipitation process of the solute atoms[8]. These hardness values are lower than those from the other reports on the Cu-Cr-Zr alloys, which have 150–200 HV deformed by approximately 70 %.[6,9] Electrical-conductivity values for casting and hot rolling the Cu-Cr-Zr alloys given in the literature are 70–80 % IACS[10,11] and in the present study, an electrical conductivity of 87 % IACS was obtained for the sample aged for 8 h. A remarkable improvement in the mechanical and electrical properties of the Cu–Cr–Zr alloy during the aging treatment is due to the precipitation which hardens the copper matrix with the high density of the nano-scale particles and, simultaneously, depletes the solute concentration in the copper matrix. In addition, cold-deformation characteristics, such as dislocations and vacancies, provide nucleation sites for the precipitation[8].

4 CONCLUSION

The following results can be drawn from the present study: cold deformation enhances the relative density of the sinter-pressed samples; cold deformation and aging increase the hardness and electrical conductivity from 77 HV to 116 HV, and from 76 % IACS to 87 % IACS, respectively.

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