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ANALYSIS OF Cu-Al-Mn SHAPE MEMORY ALLOYS AFTER CASTING IN MOULDS

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ABSTRACT
Shape memory alloys (SMAs) are advanced functional materials suitable for technical applications. Among them Cu-Al-Mn alloy is a promising candidate for industry applications (mechanical engineering, electro-engineering etc.) due to their ductility. In this work analysis of the Cu-Al-Mn alloy after smelting and casting in the laboratory electro-arc furnace is shown. Metallographic analysis of the alloy samples were carried out by an optical microscopy and scanning electron microscopy including energy dispersive spectroscopy. It was found that after casting two-phase (α+β) microstructure occurred. Grain size of phases and hardness of alloy after smelting and casting are similar. Martensite microstructure and secondary particles are not observed.

1. INTRODUCTION
Shape memory alloys (SMAs) are advanced functional materials which are able to memorize and recover its original shape. The shape memory effect (SME) is the remembrance of previously introduced material shape. In physical aspect the SME is the consequence of reversible phase transformations of austenite to martensite. This effect was first found in Au-47.5 at.% Cd alloy (1951.) and then (1953.) in In-Ti alloy [1].

Today the three most popular polycristalline shape memory alloys are: Ni-Ti (nitinol), Cu-based (Cu-Zn-Al, Cu-Al-Ni etc.) and ferrous alloys (Fe-Pt, Fe-Mn-Si, etc.) [2-4]. Nitinol is very attractive SMA for industrial and medical applications due to the important shape memory effect, pseudoelasticity, corrosion resistance and biocompatibility [5,6]. The main advantages of Cu-based SMAs are their low price compared to Ni-Ti alloy. Among Cu-based SMAs the Cu-Al-Mn alloys can be competitive due to their high ductility. These alloys have high potential for practical applications as elements of thermomechanical joints (commercial pipe couplings), in electrical devices, micromachines and energy-storage technological applications [7,8].

The Cu-Al-Mn alloys with higher Mn content (above 8 at.%) and lower Al content (below 18 at%) have excellent cold-workability without decreasing of shape memory effect. Some investigations on Cu-Al-Mn alloys with 10-14.5 wt.%Al and 0-10 wt.%Mn have shown that lower aluminium and higher manganese contents improves superelasticity [9].

2. EXPERIMENTAL

The Cu-Al-Mn alloys were prepared from the pure metals. Purity of metals was 99.99 % Cu (pellets 6x6 mm), 99.8 % Mn (flakes <4 mm) and 99.99 % Al (granules 2-10 mm). About 10 g of pure metallic components was smelted by laboratory vacuum electro-arc furnace at high current of 112 A (Fig.1a). The alloys are smelted eight times. The melted alloys were poured into Cu-moulds with diameter of 8 mm and 12 mm high. After each vacuuming of the furnace chamber the argon was introduced in duration of 15 minutes.

The chemical composition of the alloy was determined by energy dispersive spectrometry method. Microstructure of samples was examined after smelting of pure components (Fig. 1b) as well as after casting in Cu-moulds (Fig. 1. c). Samples for microstructural analysis were prepared by mechanical grinding with paper No. 240-1000 and polishing with 0.3 μm Al_2O_3. After that, the samples are etched in mixed solution (2.5 g $FeCl_3$, 48 ml methanol and 10 ml HCl) for 12 s.

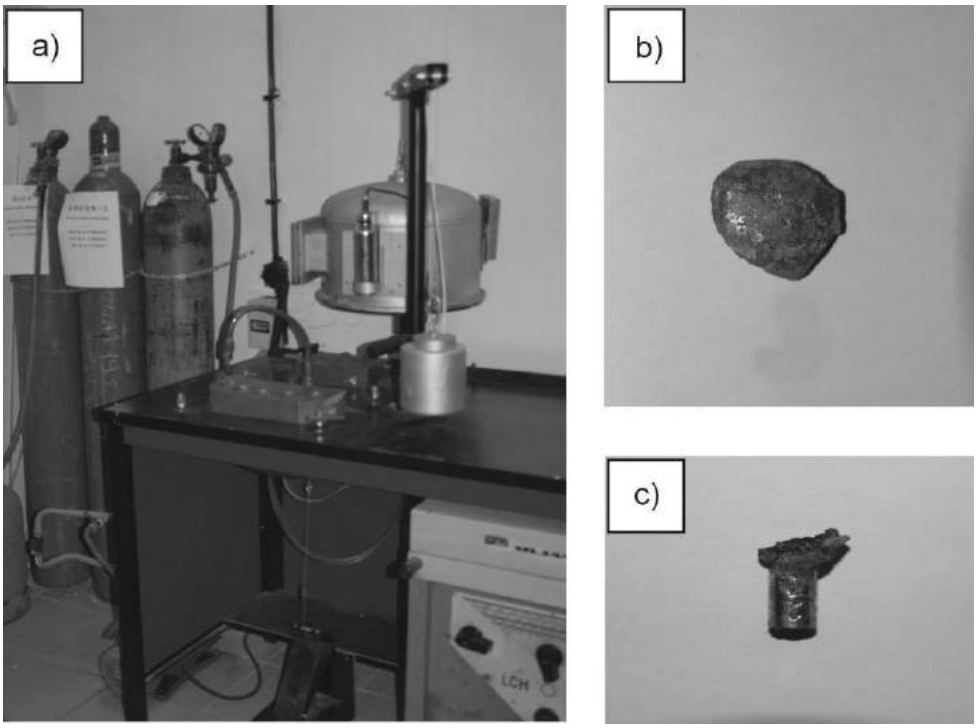
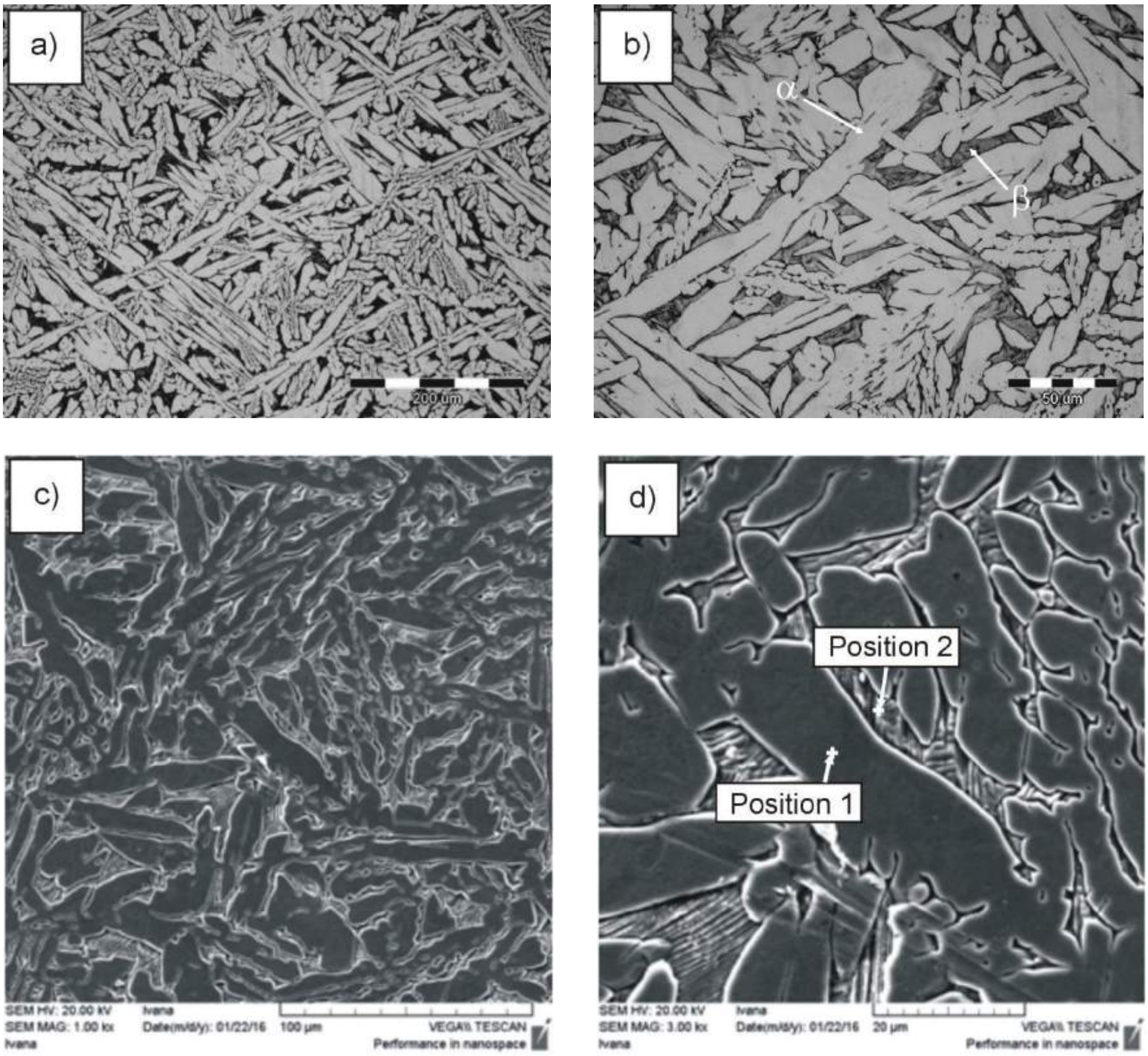


Figure 1. The electro-arc furnace for smelting (a) and photo images of CuAlMn alloys after smelting (b) and casting in Cu-mould (c)

The microstrucure characterization of alloys was carried out by optical microscopy (OM) and scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS) detector. The fraction of particular phases into microstructure was determined by AnalySIS®Materials Research Lab. software at magnification of 50x by OM. Hardness of the samples was tested by Vickers method at load of 9,804 N for 10 s.

3. RESULTS AND DISCUSSION

Figs. 2. and 3. shows results of metallographic analysis by OM and SEM methods with corresponding EDS spectrums. As can be seen, the Cu-Al-Mn alloy has two-phase (α+β) microstructure. The two-phase microstructure is in an accordance to phase equilibrium diagram of Cu-Al-Mn alloy as well as other investigations on 7.66 wt.% Al-9.52 wt.% Mn alloy after solution annealing at 750°C [10, 11]. The light areas are primary α-phase, while the dark areas are β-phase (Fig. 2. b). Fraction of α-phase is much higher (75-77%) that the β-phase (23-25%).



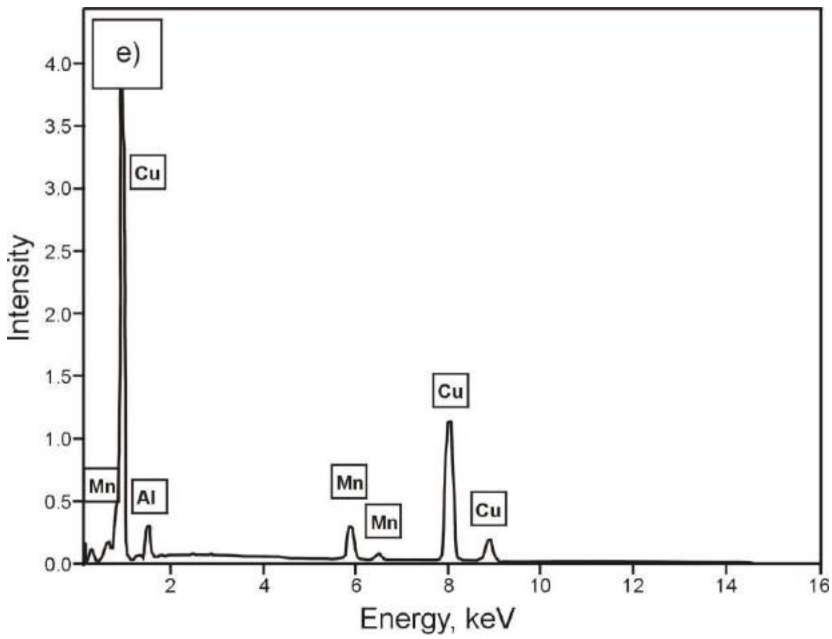
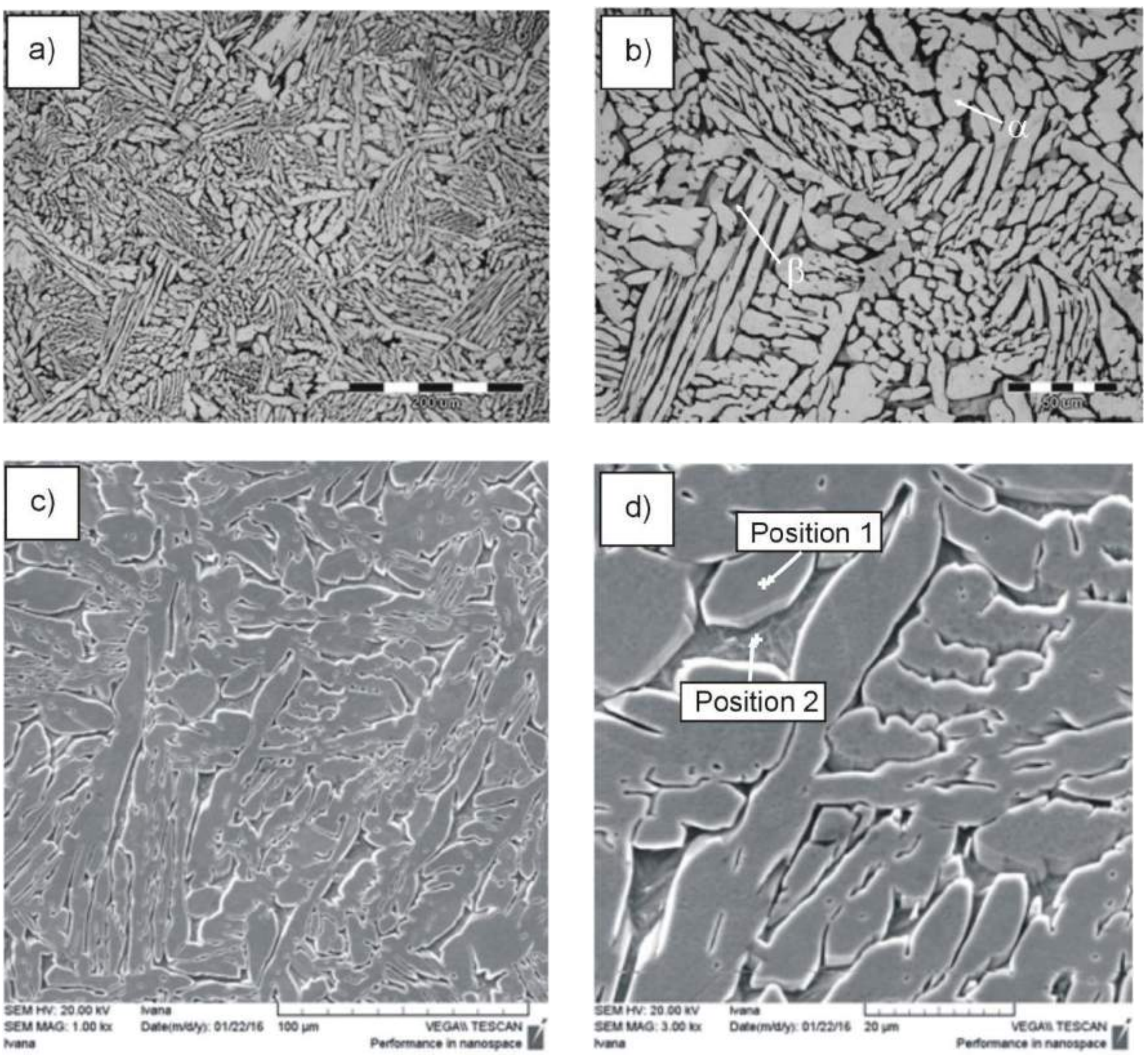


Figure 2. Optical a) and b) and scanning electron micrographs c) and d) with corresponding energy dispersive spectrum (e) of CuAlMn alloy after smelting (specimen 3, position 4/4, 140,4 HV)



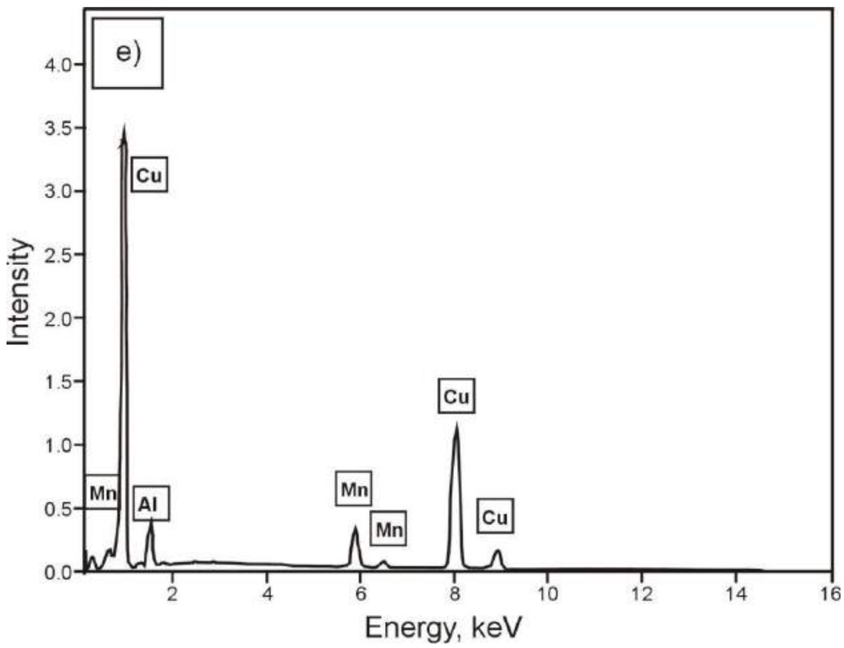


Figure 3. Optical a) and b) and scanning electron micrographs c) and d) with corresponding energy dispersive spectrum (e) of CuAlMn alloy after casting in Cu-mould (specimen 2, cross-section direction, middle of the specimen, 130,8 HV)

The content of aluminium in α-phase is lower (position 1) that in the β-phase (position 2), which is confirmed by quantitative analysis of EDS spectrums (Table 1). It is found that β-phase has pearlite morphology (Fig. 2. d). Grain size of phases after smelting and casting are similar. This two-phase (α+β) microstructure is favourable for obtaining superplasticity of SMAs due to a high ductility of α-phase [12]. In this case the secondary particles are not observed (Figs. 2. d) and 3. d).

After smelting and casting the martensite (β_1' and/or γ_1') microstructure is not observed. The main cause of the two phase microstructure and lack of martensite is the slow cooling rate. The cooling rate from liquid phase is quite slow and α-grains grow as relatively large. This gives a rather coarse structure (Figs. 2. a-d) and 3. a-d). Thus, the cooling rate is not sufficiently high for formation of the martensite phase. Also, during cooling, after casting, precipitation does not appear in the structure.

Table 1. Chemical composition of the Cu-Al-Mn alloy, the positions marked at Figs. 2. d) and 3. d)

State of the alloys	Sign of the specimens	Position	Cu	Al	Mn
			wt. %		
Smelted	3	1	86.70	4.96	8.33
		2	82.29	7.49	10.21
Casted in Cu-mould	2	1	86.10	5.48	8.42
		2	81.32	8.98	9.70

Table 2. presents the values of hardness of the investigated alloy. Values of hardness are similar after smelting (140.4 HV) and casting (130.8 HV). Further experiments are planned for obtaining the martensite microstructure (for example solution annealing followed by water quenching).

Table 2. Hardness of Cu-Al-Mn alloy

State of alloys	Hardness, HV
Smelted (sample 3)	140.4
Casted in Cu-moulds (sample 2)	130.8

4. CONCLUSION

After casting, into the Cu-Al-Mn shape memory alloy two-phase (α+β) microstructure is obtained, which favourably influence on superplasticity of shape memory alloys. Fraction of α-phase is much higher than the β-phase. Grain size of phases and values of hardness after smelting and casting are similar. The martensite microstructure and secondary particles is not observed.

Acknowledgements

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