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MICROSTRUCTURE OF DIFFERENT MULTICOMPONENT SHAPE MEMORY ALLOYS

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ABSTRACT

The results of microstructure investigation of different ternary and quaternary shape memory alloys are presented in this paper. Investigated alloys belong to the ternary systems Cu-Al-Zn and Cu-Mn-Ni and quaternary system Ni-Cu-Fe-Mn. Testing was carried out using the light optic microscopy (LOM) and scanning electron microscopy with energy dispersive X-ray spectrometry (SEM-EDX).

***Keywords**: shape memory alloys, microstructure, LOM, SEM-EDX*

1 INTRODUCTION

Shape memory materials are able to recover their original shape, after being distorted, at the presence of right stimulus. These materials include: a) shape memory alloys, b) shape memory polymers, c) shape memory composites and newly developed d) shape memory hybrids [1, 2]. Shape memory effect was first discovered in the gold-cadmium alloy in 1930s, but this type of behavior of materials has not attracted the attention of researchers until 1960s, when a significant recoverable strain was observed in Ni-Ti alloy, enabling commercial applications. Shape memory alloys (SMAs) are characterized by unique properties (pseudo-elasticity and shape memory effect), which enables them to "remember" their original shapes. These alloys are used as activators which change their shape, position and other mechanical characteristics in a response to variation in temperature and electromagnetic field. The interest in SMAs is increasing continuously as the new areas of application are discovered. Today, SMAs are represented in different areas such as civil engineering [3, 4], production of microsystems [5], medicine [6-8], earthquake technologies [9-11], robotics [12, 13]. The first copper-based SMA to be commercially exploited was Cu-Al-Zn alloy and shape memory alloys from this ternary system typically contain 15-30 wt% Zn and 3-7 wt% Al. Cu-Mn-Ni shape memory alloys are magnetic, but some of their properties (like brittleness) limit their application, so alloying elements like gallium, iron or aluminum are added to alloy in order to achieve satisfying characteristics. Objective of this work is to provide some new information about thermodynamics and microstructure of selected shape memory alloys.

2 EXPERIMENTAL PART

Characterization of selected shape memory alloys was done using the light optic microscopy and SEM-EDX analysis. The samples are obtained from industrial production. Composition, shape and production method of investigated samples are given in Table 1. Samples are used as prepared (no annealing). Microstructural analysis of investigated samples was performed using the light optical microscopy (LOM), using a Reichert MeF2

microscope (magnification up to 500x) and by SEM-EDX analysis performed on a JEOL JSM-6610LV scanning electron microscope (magnification up to 300000 x) coupled with an Oxford Instrument X-Max 20 mm^2 SDD energy-dispersive X-ray spectrometer (20 kV accelerating voltage and 1,25 nA beam current). Prior to metallographic analysis, the surfaces of polished samples were etched with appropriate etching solution (Table 2) in order to reveal structure of investigated alloys.

Table 1 *Content of alloying elements in tested samples (weight %)*

Sample	Alloy	Composition (wt%)						Shape	Production method
		Al	Cu	Zn	Mn	Ni	Fe		
A1	NiCuFeMn	/	32	/	1.5	65	1.5	rod Ø1.27 cm	cast
A2	CuMnNi	/	84	/	12	4	/	wire Ø1 mm	cast, extracted
A3	CuAlZn	4.54	68.14	27.31	/	/	/	wireØ3.5 mm	cast

Table 2 *Solutions used for sample etching*

Sample	Etching solution
A1	$HCl+H_2O_2+H_2O$
A2	$FeCl_3+HCl+H_2O$
A3	$FeCl_3+HCl+H_2O$

RESULTS AND DISCUSSION

The results of microstructural analysis using the light optical microscopy and SEM-EDX for sample A1 are given in Figure 1, accompanied with chemical composition determined by EDX presented in Table 3. Microphotograph obtained by LOM (Figure 1a) shows that alloy structure consists from sharp edged polygonal grains. SEM image (Figure 1b) reveals structure of sample A1 as gray matrix with imbedded triangular grains, but EDX analysis shows that grains and matrix have almost identical chemical composition. These findings are in agreement with the fact that copper and nickel, two components which together account for over 90% of the alloymass, form continuous series of solid solutions [14].

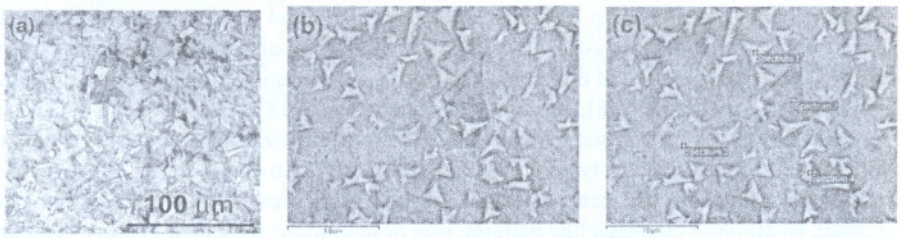

Figure 1 *Microstructure of sample A1: a) LOM (magnification 500x), b) SEM (magnification 4000x) and c) positions of EDX analysis*

Table 3 *Results of EDX analysis of sample A1 (at %)*

Position	A1			
	Mn	Fe	Ni	Cu
Spectrum 1	1.23	1.52	65.49	31.75
Spectrum 2	1.20	1.69	66.63	30.48
Spectrum 3	1.26	1.67	67.95	29.12
Spectrum 4	1.31	1.27	64.97	32.46

The results of microstructural analysis using light optical microscopy and SEM for sample A2 are given in Figure 2 with chemical composition determined by EDX analysis presented in Table 4.

Technical difficulties like a fact that maximum magnification of LOM apparatus is only 500x and really small diameter (1mm) of sample A2 prevented getting the obtainable LOM photograph. Microstructure of sample A2 (Figure 2b) is characterized by grains irregular in shape and size, and results of EDX analysis presented in Table 6 are consistent with the fact that copper forms solid solutions with nickel and manganese [14].

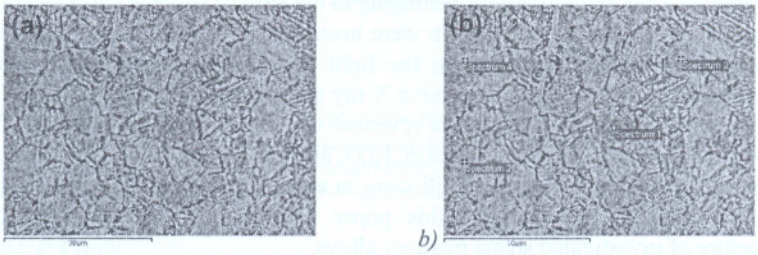

Figure 2 *Microstructure of sample A2: a) SEM (magnification 2000x) and b) positions of EDX analysis*

Table 4 *Results of EDX analysis of sample A2 (at%)*

Position	A2		
	Mn	Ni	Cu
Spectrum 1	15.04	4.70	80.25
Spectrum 2	14.92	4.50	80.58
Spectrum 3	15.11	4.48	80.41
Spectrum 4	15.35	4.41	80.24

Results of microstructural analysis using the light optical microscopy and SEM for sample A3 are given in Figure 3 with chemical compositions determined by EDX analysis presented in Table 5.

Microstructure of alloy A3 obtained by LOM microphotograph (figure 3a) consists of polygonal grains with significant variation in size.

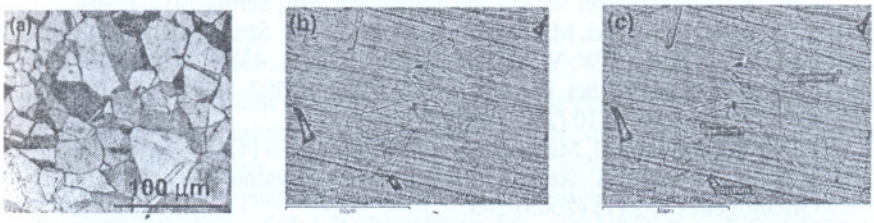

Figure 3 *Microstructure of sample A3: a) LOM (magnification 500x), b) SEM-EDX (magnification 1000x) and c) positions of EDX analysis*

Table 5 *Results of EDX analysis of sample A3 (at %)*

Position	A3		
	Al	Cu	Zn
Spectrum 1	8.83	69.75	21.42
Spectrum 2	7.93	71.11	20.96
Spectrum 3	1.11	78.03	20.87

According to the phase diagram of binary Cu-Zn and Cu-Al systems [14], solid solubility of aluminum in copper is approximately 18 at. %, and for zinc goes up to 30 at. %. Considering that for sample A3 the base material is copper (≈ 68 wt. % Cu), it is reasonable to expect that aluminum and zinc will dissolve in copper, creating solid solutions. That is confirmed by the results of EDX analysis presented in Table 5.

CONCLUSION

Different shape memory alloys belonging to the ternary systems Cu-Al-Zn and Cu-Mn-Ni and quaternary system Ni-Cu-Fe-Mn were investigated. Microstructure of selected alloys was investigated experimentally using the light optic microscopy (LOM) and scanning electron microscopy with energy dispersive X-ray spectrometry (SEM-EDX). Microstructure analysis of investigated alloys samples revealed that microstructure is build of polygonal grains, which can vary significantly in size. EDX analysis results provided information about alloys chemical composition and overall were in agreement with the known facts on tested systems. The results presented in this paper contribute to better understanding the microstructure of investigated shape memory alloys.

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