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THE MECHANICAL BEHAVIOR AND SHAPE MEMORY RECOVERY OF Cu-Zn-Al ALLOYS

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ABSTRACT

The mechanical properties and shape memory capacity of thin sheets of three Cu-Zn-Al shape memory alloys were studied. In quenched specimens, martensitic structure as well as small quantity of α-phase or DO_3-phase were observed. During tensile testing of quenched specimens at room temperature, the stress plateau was observed. The deformation in the plateau region that has been found to be in the range 2.6 to 3.6% had disappeared during heating quenched and deformed specimens above A_f temperature.

Key words: shape memory alloys, mechanical properties, shape memory effect

INTRODUCTION

The alloys that exhibit so-called "shape memory" can undergo surprisingly large amounts of strain and then, upon temperature increase or unloading, revert to their original shape. Ni-Ti based shape memory alloys have to date provided the best combination of materials properties for most commercial applications. However they are very expensive compared with Cu-based shape memory alloys. In many applications, Cu-based alloys provide a more economical alternative to Ni-Ti. Cu-Zn based shape memory alloys have actually been used and Cu-Al based shape memory alloys have shown promise.

The martensitic transformation start temperature M_s of Cu-Zn binary alloys around 40 at% Zn is far below room temperature [1]. The massive transformation occurs in Cu-Zn binary alloys with Zn contents lower than about 38 at%. It is a composition invariant but diffusional phase change [2]. In order to raise M_s and stabilize the β phase, ternary elements such as Al, Ga, Si and Sn are added. Among them, Cu-Zn-Al shape memory alloys are the excellent choice in respect to ductility and grain boundary fracture [3].

In this work, the mechanical properties and shape memory capacity of three Cu-Zn-Al alloys were investigated. Microstructural changes resulting from the quenching treatments have also been studied.

EXPERIMENTAL

Three Cu-Zn-Al shape memory alloys with nominal composition given in Table 1 were prepared in a resistance-heated furnace. The production procedure and thermomechanical processing of the alloys in order to obtain plates with a final thickness of 0.3 mm is drawn schematically in Fig. 1.

Table 1. Chemical composition of alloys (in weight percent.)

Alloy	Zn	Al	Cu
A	25.38	3.30	bal.
B	20.80	5.80	bal.
C	18.05	5.35	bal.

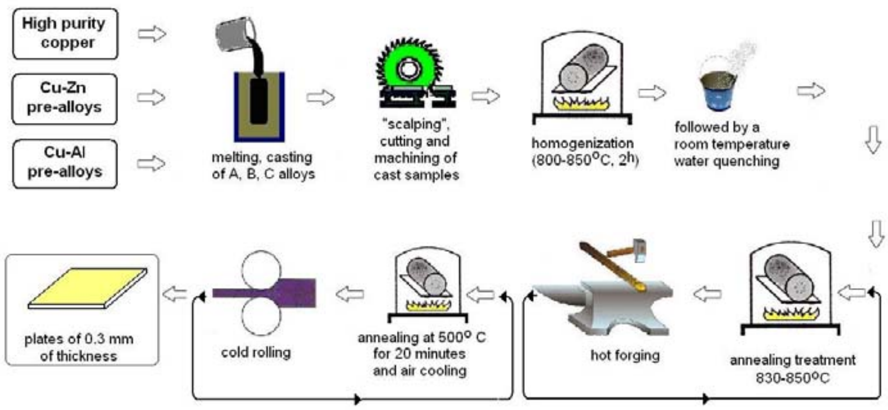


Fig. 1. Production procedure and thermomechanical processing of Cu-Zn-Al shape memory alloys

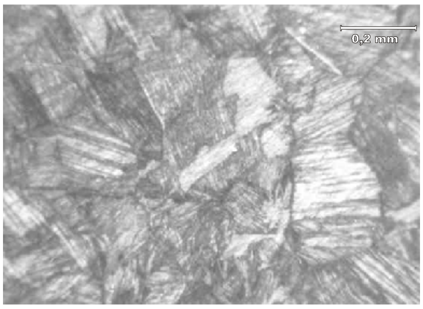
Test specimens for mechanical testing and shape memory recoveries were cut from the final plate form, solution treated and directly quenched into room-temperature water. In order to determine the mechanical properties of quenched specimens, the tensile tests at room temperature were performed. The martensitic and forward transformation temperatures were determined by measuring the variation of electric resistance with temperature. The determination of the shape memory capacity for the alloys was realized by observing quenched specimens previously deformed by strain from the plateau region and heated above the A_f temperature. The degree of shape memory capacity is expressed as the extent of the original shape recovery.

Light microscopy, X-ray diffraction and transmission electron microscopy provided the tools for microstructural analysis.

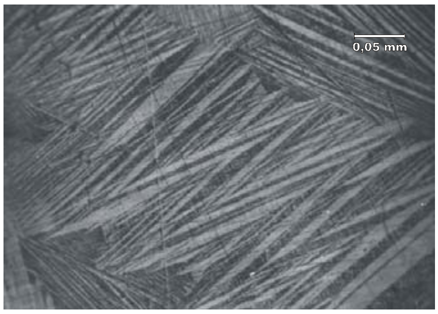
RESULTS AND DISCUSSION

The parent phase boundaries and the martensitic plates oriented in several directions are revealed by optical microscopic observations of all quenched specimens, as shown in Fig. 2.

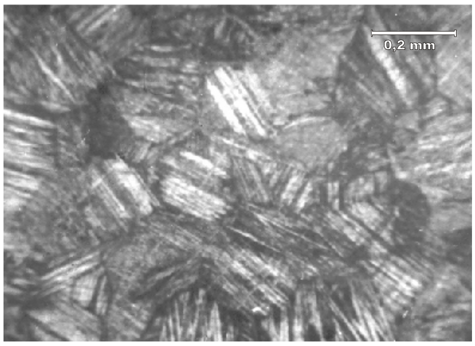
Examination of crystal structure of quenched specimens by X-ray diffraction technique has shown the presence of the martensite M18R and 2H type as well as certain quantity of parent phase (DO_3 superlattice) and f.c.c. α-phase (Table 2, Fig. 4.).



Alloy A



Alloy B



Alloy C

Fig. 2. Optical microstructures of quenched specimens

Table 2. Structure parameters of different phases in quenched specimens of the alloys

Alloy	Phase								
	Martensite M18R					Martensite 2H		DO_3	α
	a [nm]	b [nm]	c [nm]	β [°]	φ [°]	a [nm]	c [nm]	a [nm]	a [nm]
A	0.4470	0.5300	3.8390	89.47	61.40	0.3804	0.6212	-	0.3690
B	0.4470	0.5300	3.8375	89.20	61.32	-	-	0.5873	-
C	0.4430	0.5320	3.8320	89.21	61.96	0.3787	0.6185	0.5992	-

Cu-Zn-Al shape memory alloys exhibit two ordering processes, i.e. bcc $\rightarrow$ B2 and B2 $\rightarrow$ DO_3, prior to the martensitic transformation. The ordering of bcc β-phase to B2 superlattice is so rapid that it is almost impossible to quench-in the disordered bcc structure [4]. The critical temperature for B2$\Leftrightarrow$$DO_3$ order transition varies greatly from one alloy to another. The presence of DO_3 phase in quenched specimens indicates the appearance of the B2$\rightarrow$$DO_3$ ordering process that could not be suppressed even with rapid quenching. Zatulski et al. [5] have reported that the retention of α-phase in the alloy structure in an amount less than 20vol% would enhance the stability of the shape memory effect. In quenched specimens of the alloy A, the α-phase was observed in an amount less than 5vol%, so it could not significantly influence on shape memory capacity.

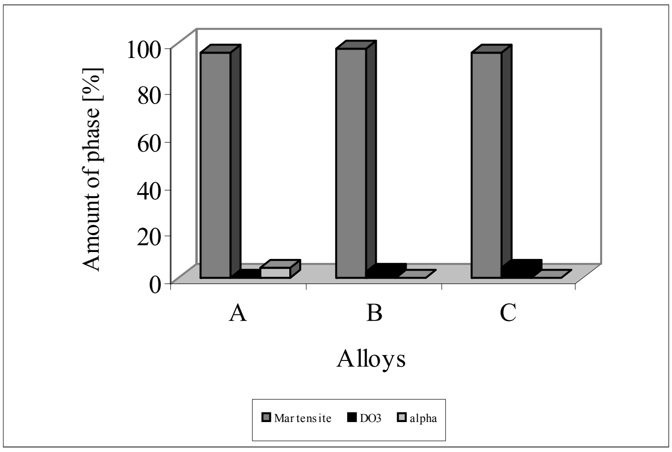


Fig. 4. The amount of various phases in quenched specimens of the alloy A, B and C

The phase transformation temperatures of quenched specimens determined by measuring the variation of electric resistance with temperature are given in Table 3. The main factor controlling the transformation temperatures is alloy composition, but they are also affected by solution treatment parameters.

Table 3. The martensitic and forward transformation temperatures

Alloy	Temperature [^oC]			
	M_s	M_f	A_s	A_f
A	273	228	245	338
B	68	37	57	100
C	259	202	223	316

The stress-strain curves obtained at room temperature for quenched specimens of examined alloys are shown in Fig. 5. These curves are not similar to that of common engineering materials. At certain stress level there is a stress plateau during which strain could be accommodated or stored within the martensitic structure. After the plateau region is passed, the increase in stress rapidly occurs with further deformation. The deformation in the plateau region that was found in the range 2.6 to 3.6% is unconventional and can be recovered thermally. The effect of the chemical composition on alloy mechanical behavior is obvious, but it could not be considered without influences of various factors. Namely, the deformation of shape memory alloys in the fully martensitic conditions depends on a number of factors such as grain size, grain orientation, the morphology of martensite plates and plate groups and their orientation with respect to the tensile axis [6].

During heating the deformed specimens above A_f temperature, the martensite and associated strain within the specimens disappear and the original shape is recovered. The values of the shape memory capacity for the alloys are shown in Fig. 6. Full shape memory recovery (100%) could not be expected, because of a great number of grains and presence of small quantity of α-phase or DO_3-phase (Fig. 4.). The shape memory capacity above 90% was observed in specimens deformed by strain from the plateau region but not close to its end. In these specimens, TEM observations revealed the twins (Fig. 7.a) indicating that the martensitic deformation was accommodated by twinning which is one of the requirements for recovery of original shape. The specimens deformed in amount that was close to the end of the plateau region were exhibited the partially memory recovering. The TEM-microphotograph of such specimen is shown in Fig. 7.b.

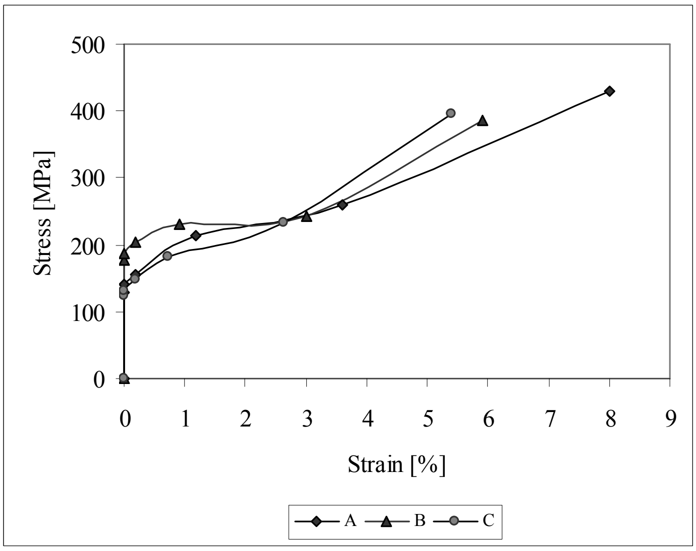


Fig. 5. Stress-strain curves of quenched specimens of the alloy A, B and C

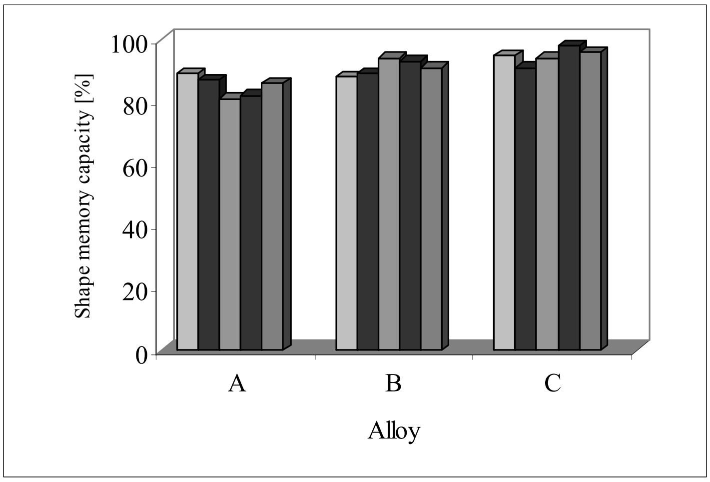
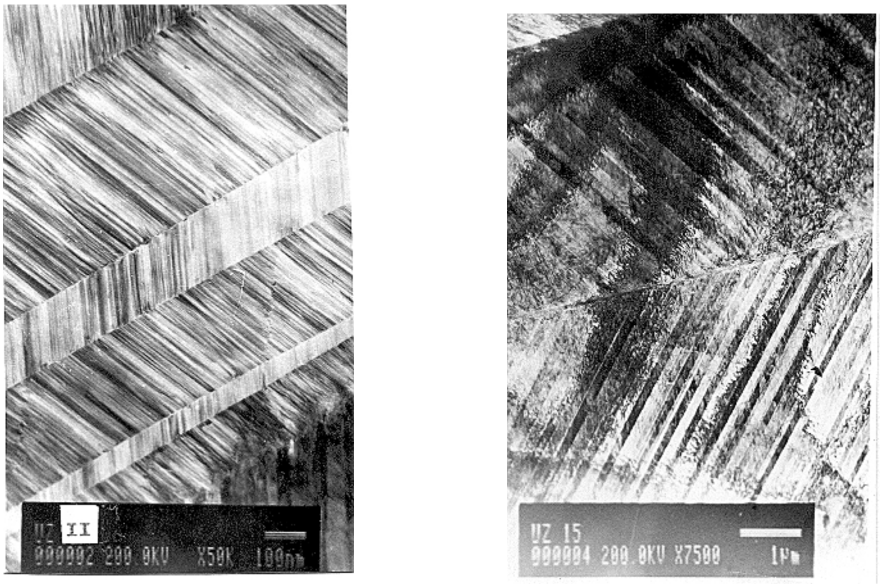


Fig. 6. The shape memory capacity of examined specimens



a) *b)*

Fig. 7. TEM-microphotographs of deformed and annealed specimens

SUMMARY

Microstructures, phase transformation temperatures, mechanical properties and shape memory capacity of three Cu-Zn-Al shape memory alloys were investigated in this paper. The martensite, together with small quantity of α-phase or DO_3-phase, was found in quenched specimens. The stress-strain curve obtained during tensile testing of quenched specimens at room temperature, were not similar to that of common engineering materials. The stress plateau was obtained on stress-strain curves during which the strain in the range of 2.6 to 3.6% was accommodated within the martensitic structure. That strain had disappeared during heating of quenched and deformed specimens above A_f temperature.

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