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SEM ANALYSIS OF FRACTURE SURFACE OF THE CuAlNi SHAPE MEMORY ALLOY AFTER HEAT TREATMENT

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Abstract: CuAlNi shape memory alloys (SMA) belongs to a group of alloys that exhibit shape memory effect which is related to the thermoelastic martensitic transformation. In this paper the influence of heat treatment (quenching and tempering) on fracture surface morphology of the CuAlNi SMA after tensile testing was examined by scanning electron microscope. It is observed a small difference on alloys mechanical properties and surface morphology between casted and quenched (850°C/60'/WQ) condition. But after tempering at 300 °C/60'/WQ the mechanical properties and surface morphology is drastically changed. In both states (casted and quenched) can be noticed a transgranular type of fracture showing that the small amount of plastic deformation occurred, and along long oriented grains it is observed an intergranular type of fracture. After tempering the CuAlNi sample shows mostly intergranular type of fracture after tensile testing.
Keywords: shape memory alloys, CuAlNi, heat treatment, fracture analysis, microstructure

1. INTRODUCTION

Shape memory alloys (SMAs) are a special class of multi-functional materials. These materials have the ability to undergo shape change and then recover to its original shape under the influence of external stimuli, which could be mechanical, thermal, electrical, or magnetic [1]. Among many alloy systems which exhibit shape memory effect, the most familiar are Ni–Ti based and Cu-based (Cu–Al–Ni and Cu–Zn–Al) shape memory alloys which have been studied over the years extensively [2].

Although Ni–Ti is the most widely used shape memory alloys for technological applications, Cu-based alloys have been used as an excellent alternative because they offer a wide range of transformation temperatures, a large superelastic effect, small thermal hysteresis and high damping coefficient. Cu-Al-Ni SMAs have been used in a wide range of applications, especially when the high transformation temperatures are required, due to their high thermal stability and high transformation temperatures. On the other hand, these alloys have some disadvantages like low reversible deformation and high brittleness and the reason for that behavior lies on the intergranular breakdown at low stress rate [3].

The main problems in the actual utilization of Cu-based SMAs are mainly due to their low thermal stability and unsatisfactory mechanical strength. They often suffer from martensite stabilization and finally lose the thermoelastic properties. Moreover, intergranular cracking usually occurs in Cu-based SMA during the manufacturing process and in service, hence improving the thermal stability and the mechanical properties are important issues for the prospect of Cu-based shape memory alloys [4].

The Cu–Al–Ni alloy is prone to intergranular fracture because this alloys have high elastic anisotropy and large grain size (often in order of 1 mm), and also because of the existence of brittle γ_2 (Cu_9Al_4) phase. The problem with large grain size can be resolved by using elements which are grain size refinements or by producing an alloy with rapid solidification techniques. Mechanical properties improvement can be provided by adding alloying elements and by heat treatment [5].

The heat treatment procedure has an influence on shape memory properties. Even the small changes in shape memory effect (SME) might worsen the applicability of the alloy. The martensitic transformation and the associated mechanical shape reversibility in Cu-based SMAs are strongly influenced by quenching and aging treatments [6].

This paper studies the influence of heat treatment (quenching and tempering) on mechanical properties and fracture surface morphology of the alloy. The results obtained after heat treatment will be compared with the results obtained on the sample in as-cast state.

2. EXPERIMENTAL

Cu-12.8%Al-4.1%Ni (wt.%) shape memory alloy was produced by melting pure elements (99.9 %) in vacuum induction furnace and casted by vertical continuous casting procedure, Figure 1. A bar of 8 mm in diameter solidifies in the crystallizer and comes out passing between two rolls which rotate in opposite directions. The casting speed and casting temperature was 320 mm min^{-1} and 1240 °C, respectively. After the casting alloy was submitted to heat treatment which was contained from solution annealing at 850 °C held for 60 minutes and water quenched (WQ) immediately after heating and afterwards tempering at 300 °C holding for 60 minutes and WQ. The tensile testing was performed at room temperature on Zwick/Roell Z050 universal tensile testing machine. After the tensile testing, the samples fracture surface was observed by scanning electron microscope (SEM) Tescan Vega TS 5136 MM and JEOL JSM 5610.

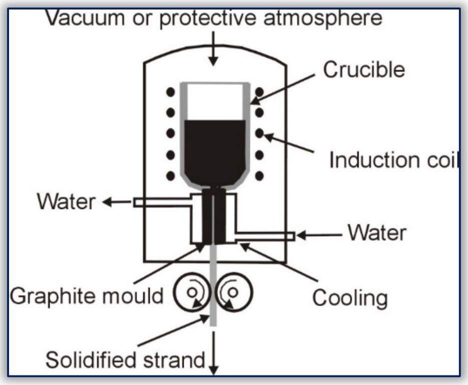

Figure 1. Schematic illustration of vertical continuous casting technology [7]

3. RESULTS AND DISCUSSION

In the results of the fractographic analysis (Figures 2-4) two types of fracture can be observed. In sample in as-cast state and after quenching (Figures 2 and 3) is visible mostly a transgranular type of fracture. On micrographs can be noticed the characteristic small and shallow dimples which means that the some amount of plastic deformation in this samples has occurred. This statement can be confirmed with the results obtained by tensile testing measurements. The elongation for these two samples (in as-cast state and after quenching) amounts 4.78 and 3.55%, respectively, Table 1. Also, at the edge of the sample can be noticed partially intergranular type of fracture (Figure 3a).

Sample after tempering (Figure 4) has shown completely an intergranular type of fracture. It is obvious that the cohesion between grain boundaries is very low. In the case of intergranular failure can be assumed that the crack often occurs at the three-fold node of grain boundaries (Figure 4b).

The brittleness of Cu-based alloys comes from the high degree of order in the parent phase with B2, DO_3 and $L2_1$ structure. Brittleness has also been attributed to their high elastic anisotropy resulting in the brittle grain boundary cracking [8]. Also, the brittle grain boundary cracking is caused by a large grain size of a parent phase (approximately 1 mm) [9, 10]. A large stress concentration at grain boundaries occurs due to large elastic anisotropy under load. The result is that a very brittle intergranular cracking occurs even during elastic deformation [11].

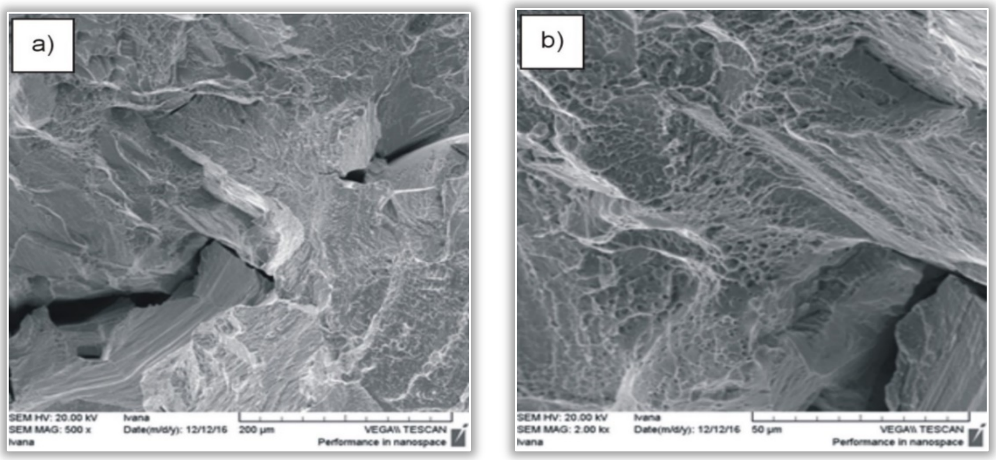

Figure 2. Microfractography of CuAlNi SMA in as-cast state at different magnifications

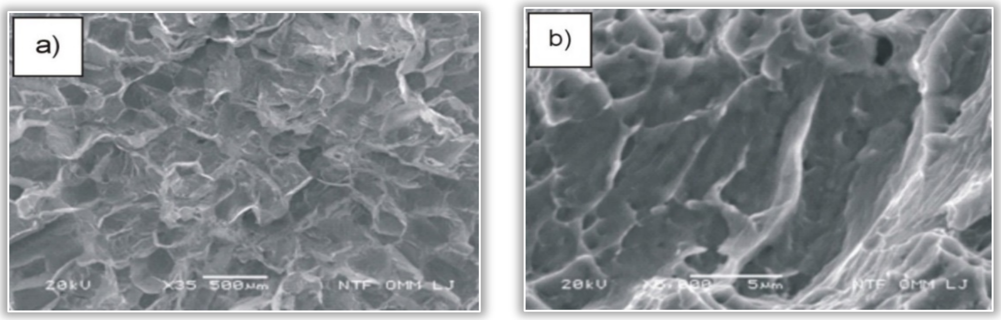

Figure 3. Microfractography of CuAlNi SMA after quenching at 850 °C/60'/WQ; magnification: a – 35x, b – 5000x

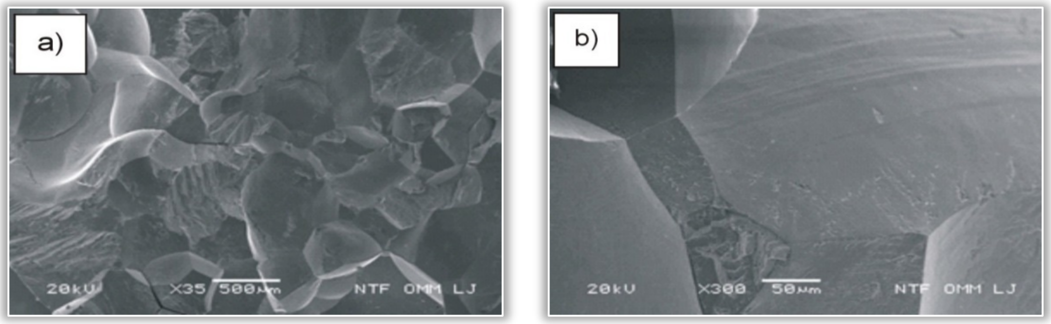

Figure 4. Microfractography of CuAlNi SMA after quenching at 850 °C/60'/WQ and tempering at 300 °C/60'/WQ; magnification: a – 35x, b – 300x

The results of mechanical properties obtained after tensile testing measurements are given in Table 1.

In is noticed an increase in value of tensile strength in sample after quenching (498.6 MPa) comparing to sample in as-cast state condition (475.5 MPa). Sample after tempering shows drastically decrease in tensile strength value (345.1 MPa) and it can be concluded that the tempering at this conditions negatively influence on CuAlNi alloys mechanical properties.

Young's modulus was in the range of 41.3 – 60.7 GPa and yield strength was in the range of 266.6 – 284.0 MPa. According to literature [5,12], this value of mechanical properties (tensile strength, yield strength and Young's modulus) is satisfactory for a Cu-based alloy.

The elongation (A) after fracture shows very low value for sample after tempering (1.12%), without a measurable contraction. In literature [12] the elongation after tensile testing for continuously casted Cu-13%Al-4%Ni (wt.%) SMA was max. 1.45% and this is below the limit of the typical recoverable strain of 4-6%. The samples in as-cast and quenched state show a similar behavior, and the elongation values reach up to 3.55 and 4.78 %, respectively.

Table 1. Results of tensile testing measurements for CuAlNi shape memory alloy

Sample	Young's modulus, GPa	Yield strength, MPa	Tensile strength, MPa	Elogation, %
L (as-cast state)	41.3	284.0	475.5	4.78
K-1 (850°C/60'/WQ)	52.4	270.7	498.6	3.55
K-1-4 (300°C/60'/WQ)	60.7	266.6	345.1	1.12

4. CONCLUSIONS

The continuously casted Cu-12.8%Al-4.1%Ni (wt.%) shape memory alloy samples were produced and the certain heat treatment procedure (quenching and tempering) was carried out. The fracture surface morphology was investigated after tensile testing measurement and on the basis of obtained results can be withdrawn following conclusions:

- The fracture surface morphology shows two types of fracture in CuAlNi samples before and after heat treatment.
- The samples in as-cast state and after quenching show mainly transgranular type of fracture with observed small and shallow dimples which confirms that certain plastically deformation was occurred.
- After tempering the results show completely intergranular type of fracture where can be noticed that the crack occurs at grain boundaries which provides the easiest crack propagation path.
- Mechanical properties of CuAlNi show satisfactory results for tensile strength and very low value of elongation, especially after tempering where the elongation was 1.12 %.

Acknowledgments

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Note

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