ANALYSIS OF THE LINK BETWEEN THE HEAT SOURCE AND MICROGRAPH FOR A SHAPE MEMORY ALLOYS CU-Zn-Al

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REZUMAT. În acest articol este prezentat studiul unor aliaje cu memoria formei pe bază de cupru, numite Cu-Zn-Al, care sunt supuse la tracţiune mecanică ciclică. Testele de tracţiune sunt executate în condiţii normale de temperatură şi presiune. Scopul acestui articol este de a studia caracteristicile microstructurale al unor probe din aliaj cu memoria formei Cu-Zn-Al în timpul testelor de încercări mecanice. Toate testele au loc in aceleași condiții. În timpul testelor aliajele se afla într-o anumită fază. Vom analiza microstructura specifică fiecărui aliaj în funcție de sursa de căldură produsă în timpul testului de ciclaj mecanic. Termografia în infraroșu va fi folosită să măsoare variația temperaturii la suprafața specimenelor în timpul testelor. O transformare de fază poate apărea în două moduri: prin aplicarea unei tensiuni sau prin variația temperaturii. Se determină faza inițială în care se afla aliajul prin microscopie. Variantele de martensită din aliaj sau orientarea diferită a unei variante joacă un rol important în producerea de căldură. S-a observat că dacă la nivel microstructural sunt multe variante de martensită valorile de căldură produse sunt ridicate în timpul testelor şi invers.

Cuvinte cheie: aliaje cu memoria formei, microstructură martensitică, surse de caldură, teste de ciclaj, termografie în infraroşu.

ABSTRACT. In this article it is presented a shape memory alloy study, based on copper, namely Cu-Zn-Al, which is subjected to periodic mechanical traction. Traction is performed in conditions of normal temperature and pressure. The purpose of this article it is to study microstructure characteristics for some samples of shape memory alloys Cu-Zn-Al during mechanical tests. All tests are performed in same conditions. During these tests materials are in different states. We will analyze them microstructure in function of heat sources produced by each samples during the cycling tests. Infrared thermography was used to measure the slight variations of the temperature field on the surface of the specimens. A transformation phase occurs in two ways: by applying a stress or temperature variation. Is determining initial phase of alloy by microscopically analysis. Martensitic variants or different orientation of martensite play an important role in producing of heat. It was observed at microstructually level are many variants in specimen we measure higher values of heat produced during de cycling test and opposite.

Keywords: shape memory alloys, martensitic microstructure, heat source, cycling tests, infrared thermography.

1. INTRODUCTION

Shape memory alloys (SMA) are a special group characterized by two main properties, shape memory effect memory defined as thermal and mechanical memory known as pseudoelasticitity. Shape memory alloys based on Ni-Ti presents the best properties for most industrial applications. But their price is very high compared to shape memory alloys based on copper. In many applications of copper based alloys offer economical alternative to the Ni-Ti [1]. Shape memory effect is defined as thermal and mechanical memory known as pseudoelasticitity.Transformation on which is based this effect occurs in two ways: by applying a stress or temperature variation. The martensite austenite phase change produces latent heat contributing to an overall increase of sample temperature. After a phase change due to a stress action in a SMA at ambient temperature, thermomechanical coupling plays an important role in the sample mechanical response. This change in temperature influences the kinetics of transformation, even more; the last one can be induced by temperature.

The connection between temperature and phase change were studied in detail by many people interested by this phenomenon [2]. This is the most important method which is used also to development of successful SMA actuator [3].

The level of irreversibility can be estimated from theoretical approaches based on the so-called crystallographic compatibility [4], [5]. Experimental assessments of the transformation irreversibility have been also proposed in the literature with a special emphasis on the influence of the chemical composition: measurement of the temperature-induced transformation hysteresis [6] and measurement of the damping properties [7]. The present work proposes to assess the level of microstructures influence for temperature variation during the mehcnical cycling tests tracked by infrared (IR) thermography.

Several Cu-Zn-Al specimens with different chemical compositions are tested. The experimental procedure followed is first discussed. Results obtained show that the nature of the phase involved (martensite) influence variation of temperature produced by the specimen.

2. METHODOLOGY

The studied alloys were prepared using an induction furnace with graphite crucible in air using high purity metals. Chemical composition was determined using Foundry Master Spectrometer. The chemical analysis was performed using the spectrometer at several points on the sample surface. Microstructure in cast state was emphasized by scanning electron microscopy (SEM). To this purpose we used a microscope of type II Vega LMH produced by TESCAN using a secondary electron detector.

All materials were first elaborated to obtain a parallelepipedic ingot for each composition. The upper and lower surfaces where then machined to obtain regular surfaces. The specimens were then heated up to 750°C and hot rolled to obtain the desired final thickness, which was equal to nearly 1 mm. The resulting sheet was finally cut to obtain the specimens that were tested. All specimens were finally tempered by heating up to 750°C and cooling by air up to ambient temperature. Square aluminum tabs were bonded on the ends of the specimens to prevent any slippage within the grips of the testing machine. The chemical composition of the studied alloy is presented in the table below.

Table 1. **Chemical composition of studied alloy**

Element	[A1 wt.%]	[A2 wt.%]	[A3 wt.%]
Copper	70.94	72.1	74.4
Zinc	22.6	21.7	18.7
Aluminium	6.44	5.94	6.67
Sum:	100	100	100

Processing of the data has been used in the analysis of polycrystalline SMA. This consists in processing temperature maps derived from the process that is subjected the SMA sample, maps recorded by a computer that is connected to the entire system. Data processing consists in analyzing the sample surface temperatures and extracting heat sources starting from the temperature maps. Link between microstructure and temperature evolution was made it with Matlab program. We elaborated one program to calculate percent of martensite variants from each specimen tested and results are presented in next part of this article.

2.1. Mechanical loading

All tests were performed on the same tensile testing machine (*MTS* ± 15kN) and temperature (T_0 = 22±2°C). The basic procedure is the same for all tests. Figure 1 shows this procedure:

Stage I. In this step we imposed deformation $\varepsilon_{macro.}$ The macroscopic deformation speed is constant for all tests: 2×10^{-3} s^{-1}. Macroscopic final deformation is noted ε_{macro};

Stage II. This corresponds to a waiting period before the imposed displacement. This procedure allowed the sample to return to room temperature

Stage III. A small periodic displacement was imposed to the mobile parts of traction machine around the position reached in the previous step. Loading frequency and strain amplitude, they are noted as follows: f_L and $\Delta\varepsilon_{macro}$.

In practice, we used the following value for $\Delta\varepsilon_{macro}$: 0.05 mm and the same value for f_L = 13 Hz.

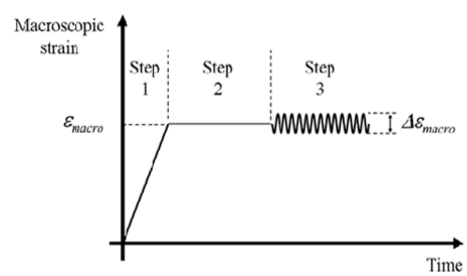


Fig. 1. Basic loading procedure.

2.2. Temperature measurement

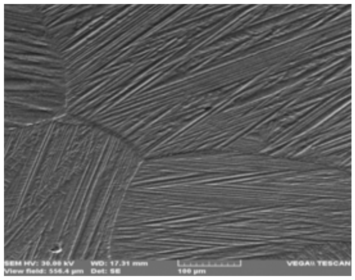
To record sample temperature evolution during charge phase 3 an infrared camera Jade III-MWIR Cedip was used. This device has IR detectors characterized by 3.5 - 5 microns wavelength. Integration time used in these measurements is 1500 microseconds.

Thermal resolution is 0.02 °C, and purchase frequency f_a = 150 Hz.

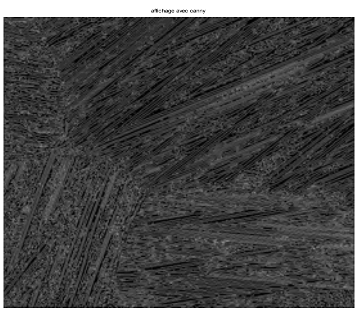
Temperature map captured by infrared camera has an 80 × 60 pixels resolution. Spatial resolution is 0.36 mm (this corresponds to a pixel size).

3. RESULTS AND DISCUSSIONS

We started analyzing alloy microstructure in quenching state highlighting typical martensitic structure is shown in Figure 2,*a*.

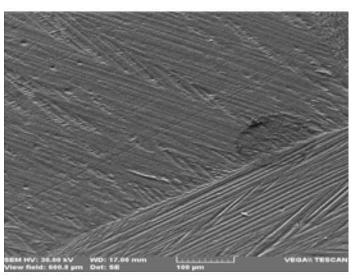


a)

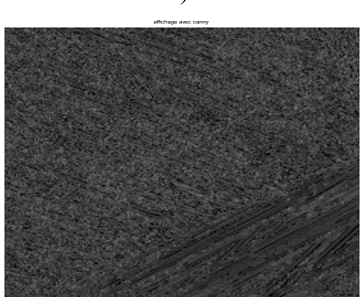


b)

Fig. 2. Microscopy of quenching state for specimen A1 at 500 × magnifications for:
a – martensitic microstructure; *b* – quantification of martensite variants with Matlab.



a)



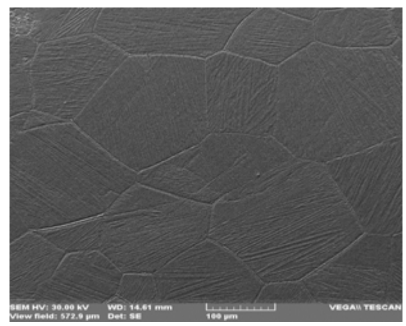
b)

Fig. 3. Microscopy of quenching state for specimen A2 at 500x magnification for:
a – martensitic microstructure; *b* – quantification of martensite variants with Matlab .

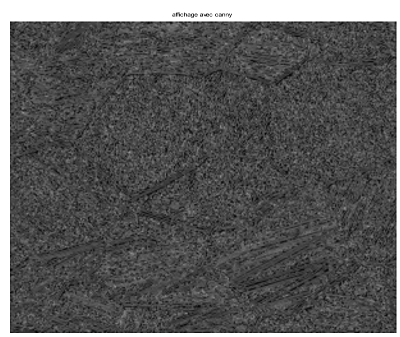
It can be seen intersection of 4 martensitic grains for specimen A1 in Figure 3,*a* increased by 500x and martensite variant percent determined analytical. We was measured a values of heat source producing by this specimen of 0.0083°C/s and one concentration of martensite variants (white stripes) equal with 21.66%.

For second specimen tested, A2 also in martenitic state at ambiants temperature present intersection of 2 big grains at 500x magnification (Fig. 3,*a*) corresponding values of heat source measured was equal 0,102°C/s and with 22.87 % of martensite variants.

For last specimen tested, A3 also in martenitic state at ambiants temperature (Fig. 4,*a*) corresponding values of heat source measured was equal 0,113°C/s and with 24.51 % of martensite variants. Here we use same magnification as above.



a)



b)

Fig. 4. Microscopy of quenching state for specimen A3 at 500× magnification for:
a – martensitic microstructure; *b* – quantification of martensite variants with Matlab.

4. CONCLUSIONS

Study of shape memory alloys is of great interest today. Martensitic transformation plays a critical role in this study. In this article was studied few Cu-Zn-Al shape memory alloys polycrystalline obtained by experimental method.

The aim of this study is to show the link between heat source produced and microstructure during the cycling tests observed with an infrared camera.

We can detach next conclusions:

- martensitic microstructure influencing heat source producing during the tests;
- if we have low number of martensite variants into a grain we obtain lower variations of temperature do to a smaller friction;
- higher concentration of martensite variants produced bigger quantity of heat source;
- also a bigger number of grains on the surface of specimen make grow temperature level on the surface at specimen during cicling tests

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