Preliminary Results on Thermal Shock Behavior of CuZnAl Shape Memory Alloy Using a Solar Concentrator as Heating Source

C Tudora1,2, M Abrudeanu1,4, S Stanciu2, D Anghel1, G A Plaiaşu1, V Rizea1, I Ştirbu2 and N Cimpoesu2,*

1University Pitesti, 1 Targu din Vale Str, Pitesti, Arges, Romania
2Technical University “Gheorghe Asachi” of Iasi, Mangeron 44 blv., 700050, Iasi, Romania
3Institute for Nuclear Research Pitesti, 1Campului str., 115400, Mioveni, Arges, Romania
4Technical Science Academy of Romania, 26 Bd. Dacia, sector 1, Bucuresti, Romania

E-mail: nicanornick@yahoo.com

Abstract. It is highly accepted that martensitic transformation can be induced by temperature variation and by stress solicitation. Using a solar concentrator, we manage to increase the material surface temperature (till 573 respectively 873 K) in very short periods of time in order to analyze the material behavior under thermal shocks. The heating/cooling process was registered and analyzed during the experiments. Material surface was analyzed before and after thermal shocks by microstructure point of view using scanning electron microscopy (SEM) and atomic force microscopy (AFM). The experiments follow the material behavior during fast heating and propose the possibility of activating smart materials using the sun heat for aerospace applications.

1. Introduction
Shape memory alloys (SMA abbreviated) have a number of great properties compared to common metallic materials. Of these, the feature is the ability to change geometric shape when switching from low to high. Under certain conditions, the shape change can be reversible so that the material can store two geometric shapes, namely both high temperature (warm form) and low temperature (cold form) - these transformations are performed as a result of a memory effect form (through this effect the material can also perform a mechanical work during the transition from cold to hot form) [1-5].

Alloys with Cu-Zn-Al shape memory are alloys derived from ordinary brass. The chemical composition of Cu-Zn-Al AMPs is established taking into account the equilibrium diagram and critical point variation with the alloying element concentration. Thus, for a binary Cu-Zn alloy, a temperature Ms = 0 °C is obtained at a concentration of 38.5% (at) [6]. It is necessary to apply a very high-speed cooling so that phase b is retained to ambient temperature and martensite transformation without which the form memory effect cannot exist [7]. Aluminum alloy reduces the braze quenching speed, making martensitic transformation easier, besides this aluminum also increases corrosion resistance, mechanical strength and plasticity. Alloying with 4-8% Al ensures the formation of martensite 9R, which gives the transformation a good reversibility with a 5-15% hysteresis. Conventional copper Cu-Zn-Al alloys have an MS ranging from -200 °C to +100 °C and the chemical composition of shape
memory brasses is selected according to the desired MS value within the limits: 62-72% Cu, 14-30 % Zn, 4-8% Al [8].

In this article we analyze the effects of 10 thermal shocks till 300 respectively 600 °C on the microstructure of a CuZnAl shape memory alloy. The thermal shocks were realized using a solar concentrator furnace reaching heating rates of 70 °C/ms.

2. Materials and methods

The solar concentrator used is part of the Promes France facility. PROMES-CNRS at Font-Romeu Odeillo host a whole range of high and very high flux solar furnaces and 10 min nearby in Targassonne the Themis solar tower [13]. Shape memory alloys samples were heated using solar light reflection from a metallic window (5x12 m) situated at the bottom of the building, through a shutters system (used to control the intensity of the light beam) and a concentrator, as presented schematically in figure 1 a) [9, 10]. The light is forward transmitted at 1-1.5 m down to a center and spread near that. In order to locate the sample in the center of light concentration and to benefit of the biggest intensity and temperature we use an aluminum trolley, figure 1 b) that can be moved on X-Y axis.

The support system is always chilled with water (the temperature can increase really fast till 3000°C at a full opening of the shuters). The samples, 10x10 mm, were fixed using a mechanical system and under the sample, in the middle part, a K thermocouple was used to retrieve data information connected to a Graphite Corporation equipment type GL220 [11]. Both heating and cooling stages were registered and analyzed. The shocks were performed moving the trolley from and under the sun light. The heating experimental temperatures were 300 and 600°C ±(10-25).

Figure 1. (a) Temperature variations on CuZnAl sample in time (b) during the solar heating and room cooling and linear fit curve of cooling.

Copper based shape memory alloy (Cu17.5Zn7.2Al) as 10x10 mm square were used for exposure to heat (10 cycles) at 300 and 600°C. The flux was applied in the middle part of the sample by situating the sample in the middle of the solar flux. The temperature increasing and decreasing was registered using a K type thermocouple and the heat was analyzed from the middle of the sample. In figure 1 a) and b) is represent the temperature variation in time for 10 heating/cooling cycles.

The heating process consists of a mirror that collect the sun light, a concentrator of light through a shutters system and a trolley for positioning of the sample in the middle of the concentrated light. The heat intensity is given from the shuters system opening and can be control based on the clearness of the sky. Small variations near 300 and 600°C temperatures were observed. The appearance of these variations is based on the human factor that move and sustain the trolley and can be eliminated using a motorized system. In tables 1 and 2 are presented the heating/cooling rates registered during the thermal shock experiments till 300 respectively 600°C.
### Table 1. Heating and cooling rates of shape memory alloy for thermal shocks tests till 600°C.

| Thermal shocking parameters | Cycle 1  | Cycle 2  | Cycle 3  | Cycle 4  | Cycle 5  |
|-----------------------------|---------|---------|---------|---------|---------|
| Fitting rate (°C/ms)        | 9.4     | 16.9    | 24.6    | 22.9    | 59.4    |
| Calculated rate (°C/ms)     | 12.1    | 24.7    | 33.2    | 29.5    | 51.6    |

| Thermal shocking parameters | Cycle 6  | Cycle 7  | Cycle 8  | Cycle 9  | Cycle 10 |
|-----------------------------|---------|---------|---------|---------|----------|
| Fitting rate (°C/ms)        | 56.2    | 37.7    | 53.7    | 30.4    | 67.1     |
| Calculated rate (°C/ms)     | 50.5    | 39.3    | 46.6    | 36.8    | 62.1     |

Before and after the thermal shocks the metallic material surface was analyzed through scanning electron microscopy (SEM VegaTescan LMH II) and atomic force microscopy (AFM EasyScan II).

### 3. Results and discussions

The experimental samples, before and after the thermal shocks, were investigated without any surface polishing in the area affected by solar light through scanning electron microscopy, Figure 2, and atomic force microscopy, figure 3. By microstructural point of view, we follow the material behavior after a fast heating to 300 respectively 600°C and a cooling at room temperature, 25°C. As in the case of Cu-Al alloys, the solid β solution (based on the electron-intermetallic compound equiatomic, CuZn, crystalline structure A2 is ordered, it results in ordered β2 (B2) austenitic which is formed between 454 and 468°C.

At slow cooling, the α (cfc) and γ solid solutions (based on the intermetallic compound Cu5Al9, cubic complex with 52 atoms per elemental cell) are precipitated from β2. On sudden cooling or by applying an external stress, the pink colorant martensite α2 (3R) is obtained [13, 14]. SEM images, Figure 2, present an affected surface in both experimental cases b) and c) comparing with the initial alloy surface state.

**Figure 2.** SEM micrographs of CuZnAl surface: (a) initial state, (b) after 10 thermal shocks at 300°C and (c) after 10 thermal shocks at 600°C.
After heating till 300 respectively 600°C the material surface is affected structurally and chemically by formation of oxides on the surface and local thermal modification. The martensite plates are presented in similar orientation after the thermal shocks as in the initial state. The effect of the thermal shocks on the shape memory properties will be analyzed in the near future. Excepting the local surface affected areas the structure keeps a similar aspect with grains of the same dimension and primary and secondary plates. The thermal shocks effect must be analyzed also in depth in order to establish the influence of a higher temperature on the shape memory properties.

In Figure 3 are presented atomic force microscope images of CuZnAl surface 2D and 3D a) and d) initial state, b) and e) after 10 thermal shocks at 300°C and c) and f) after 10 thermal shocks at 600°C. Although Cu-Zn-Al-AMF martensitic plates have an internal defect substructure created by inverse planar shear, the acoustics of the plates in the austenitic matrix are made by twining to maintain the coherence of the crystal lattice on the austenite-martensite interface.

Macles (twins) observed in the microstructure of these alloys are accommodating rather than transforming. In addition, it should be noted that approx. 50% of these macules are type II, as well as AM-based Cu-Al-Ni [15]. Because of the twinning process, martensite from AMF Cu-Zn-Al present a shallow relief. The influence of the thermal shocks can be considered as a decrease of the relief of the martensite plates, Figure 3 b) c) and e) and f). The growth and reversal of martensite plaques is one of the most intensely studied phenomena, characteristic of the thermo-elastic martensite, for which a wide variety of characterization methods were used [16, 17]. The relief is visible also in the secondary plates, in the initial phase, the relief characteristic of the primary plates - which passes all the micrograph and plate fields secondary martensite. The latter are shorter and finer because they did not have any time or space to increase to the size of the main plates. In the case of samples subjected to thermal shock, the formation of the secondary plates is no longer observed.
4. Conclusions
In conclusion after the experimental results analyze:
- Activation of shape memory elements can be realized using sun light,
- A large domain of temperatures and heating rates can be reached including the high temperature shape memory alloys,
- Solar concentrators represent a cheap and viable solution for shape memory alloy functionalizing,
- Thermal shocks till 300 and 600 °C modify the chemical composition of the surface by forming oxides,
- SEM and AFM results present no modification at the primary plates dimensions and orientation also after the thermal shocks no secondary plates formation was observed.

5. References
[1] Lohan M N, Pricop B, Bujoreanu L-G, Cimpoesu N 2011 *International Journal of Materials Research* **102** 1345-1351
[2] Bujoreanu L G, Lohan N M, Pricop B, Cimpoesu N 2012 *Materials Science Technology* **28** 658-667
[3] Cimpoesu N, Stanciu S, Dorofoei I, Ioniță I, Radu V, Parasciv P 2010 *Optoelectronics and Advanced Materials-Rapid Communications* **4** 2028 – 2031
[4] Paun M-A, Cimpoesu Hanu R, Cimpoesu C, Agop M, Baciuc S, Stratulat S, Nejneru C 2010 *Materiale Plastice* **47** 209-214
[5] Bujoreanu L G 2015 *Journal of Optoelectronics and Advanced Materials* **17** 1437-1443
[6] Stošić Z, Manasijević D, Balanović L, Holjevac-Grgurić T, Stamenković U, Premović M, Minić D, Gorgievski M, Todorović R 2017 *Materials Research* **20** 1425-1431
[7] Dasgupta R 2014 *Journal of Materials Research* **29** 1681-1698
[8] Coseri S, Spatareanu A, Sacarescu L, Socoliuc V, Stratulat I S, Harabagiu – Pullulan V 2016 *Journal of Applied Polymer Science* **133** 42926
[9] Crane N B 2009 *Journal of Solar Energy Engineering* **132** 11007
[10] Alxneit I 2011 *Solar Energy* **85** 516-522
[11] Wieckert C, Frommherz U, Kra´upl S, Guillot E, Olalde G, Epstein M, Sante´n S, Osinga T, Steinfeld A 2007 *Journal of Solar Energy Engineering ASME* **129** 190 – 196
[12] Cimpoesu I, Stanciu S, Cimpoesu N, Munteanu C, Istrate B, Dragos A U, Dana D, Alexandru A, Nejneru C 2013 *Journal Of Optoelectronics And Advanced Materials* **15** 1392-1398
[13] Jani J M, Leary M, Subic A, Gibson M A 2014 *Materials and Design* **56** 1078-1113
[14] Liang S M, Schmid-Fetze R 2016 *Calphad* **52** 21-37
[15] Adachi K, Perkins J, Wayman C M 1986 *Acta metallurgica* **34** 2471-2485
[16] Velten B 1992 *Methods for characterization of transformation–and shape memory properties*, Progr.Shape Mem.All., (Eucken, S. ed.), DGM Informations gesellschaft Verlag, Bochum, pp 23-46
[17] Achitei D C, Vizureanu P, Dana D and Cimpoesu N 2013 *Metalurgia International* **18** 104-109

Acknowledgement
This article was made with support of project “Thermal shock and fatigue on shape memory alloy from CuZnAl and CuAlNi systems – HTSMAs” FP7-INFRA-312643, SFERA user research proposal.