Dynamic mechanical analyze of superelastic CuMnAl shape memory alloy

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Abstract. A new shape memory alloy was obtain from high purity Cu, Mn and Al elements using a induce furnace. The intelligent material present negative transformation temperatures and an austenite like state at room temperature. The austenite state of CuMnAl shape memory alloy present superelasticity property. Five kilograms ingot was obtain of Cu10Mn10Al alloy. From the base material (melted state) were cut samples with 6 mm thickness using a mechanical saw. After an homogenization heat treatment the samples were hot rolled through four passes with a reduction coefficient of 20%. Experimental lamellas were obtained with 1.5 mm thickness and 90x10 mm length and width. After the hot rolled treatment the materials were heat treated at 800°C for 20 minutes and chilled in water. Four samples, one just laminated and three heat treated by aging, were analyzed with a Netzsch DMA equipment to establish the elastic modulus and the internal friction values of the materials. Metallic materials microstructure was analyzed using a scanning electron microscope Vega Tescan LMH II type. After the aging heat treatment a decrease of internal friction is observed on the entire analyze range which is assigned to formation of Al-based precipitates that block the internal movement of the alloy characteristic phases.

1. Introduction

In recent years, the need for materials dissipation capability for areas such as automotive, aerospace and structural led to the development of research on them. Amortization occurs in the material when there is an energy loss in the process of converting one form of energy into another. Shape memory alloys show a high damping capacity (internal friction) due to thermoelastic martensitic transformation is led by hysteretic martensitic transformation, by interfaces between phases, interfaces variants of martensite or twin boundaries between plates [1,2]. The high density of identical plates, high mobility in the martensitic phase and mobile interfaces between the basic phase and martensite phase type leads to a high internal friction.

A large amount of energy is absorbed by internal friction, which creates damping capacity of the shape memory alloys. In phase type martensite alloys, interfaces that occur between phases austenite / martensite, but similar limits between the plates are mobile self accommodating plates of martensite, leading to a greater amount of energy depreciated against the basic phase of austenitic [3,4]. Shape memory alloys show a maximum damping of mechanical energy in the temperature of thermoelastic martensite transformation [5-8]. Transitory and intrinsic component of the transition phase contributes to the overall internal friction characteristic of a material in the case of shape memory alloys, so that the IF (total) = IF (transient) + IF (due to the phase transition) + IF (intrinsic) [9-12].
2. Experimental details
Samples of cast and heat treated alloy punches were hot rolled 850°C, with a degree of reduction of 20% to a thickness of 1 mm. Slides were prepared mechanically cut and sanded to obtain samples with a width of 5 mm and a length of 20 mm. The tests for the analysis of internal friction and were performed on a Netzsch brand of equipment model DMA 242. The experiment was performed at a frequency of 1 Hz and an application rate of cooling/heating of 1°C per minute, cooling step and heating the material on the -100 to 100°C.

The microstructure of the alloy was obtained by scanning electron microscopy using VegaTescan LMH II equipment with a secondary electron detector. After the first set of experiments on dynamic mechanical analyzer alloy has been heat treated by aging at 300 °C, 120 minutes and cooling to maintain the oven.

3. Experimental results
The diagram from figure 1(a) show signs of transformation of austenite to martensite direct (TMS) located at -38 °C and an end to -89 °C transformation (TMF) value after which the material is 100% condition martensite or very close to this percentage if it takes into account the amount of retained austenite remaining after cooling material. The temperature range for conversion to experimental alloy CuMnAl is 51°C.

On heating the material, figure 1(b), the transformation temperature range moves to 0°C. The reversible transformation start temperature, martensite, austenite, T\textsubscript{AS} is located to -17°C and the temperature of the end of the processing is 7°C. Transformation temperature range is in this case lower than 24°C, but the recorded value of internal friction is higher for middle transformation range, located at 4°C, reaching 0.187. This value approaches the recorded values on the internal friction polymeric materials used in civil engineering for vibration damping [6].

Differences between the internal friction in cooling and heating can be attributed to differences between the energies with which the A↔M change occurs, the number of dislocations in the number of primary and secondary martensite plates and the relationship between phases A and M appearing in cooling and heating. Higher values of internal friction at the heating of metal materials is important for practical applications alloys with damping capacity that used to temperatures around 0°C may develop a high capacity damping of mechanical vibrations and transform these requests external in thermal energy.

Figure 2 presents the variation in modulus of elasticity of the alloy CuMnAl driven rolling equipment DMA also on the temperature variation) in cooling and that b) heating.

In both experimental cases, at the cooling and at the heating, shown in figure 2 (a) and (b), there is a decrease in the modulus of elasticity in the range of transformation temperatures. The modulus of elasticity of the alloy Cu10Mn10Al varies depending on the temperature through the phase in which the alloy is.

In the martensitic state alloy have a high modulus, between 70 000 and 75 000 MPa, and in the austenitic state, including at room temperature is 59000 MPa. This difference is due to specific microstructural characteristics of each phase so that the typically martensitic state plates will lock the sliding planes plates and will increase the value of modulus of elasticity. In case M↔A transformation range, where increases the mobility of the martensitic plates, the rigidity of the material has a value of 46142 MPa at -59°C and heating decreases to 29,276 MPa at -3 °C.
These decreases in the stiffness of the material Cu10Mn10Al in transformation range are based on changes in microstructure that occur in the transition from phase A to phase B and reversing its temperature range.

**Figure 1.** DMA sample laminate (a) cooling and (b) heating.

These decreases in the stiffness of the material Cu10Mn10Al in transformation range are based on changes in microstructure that occur in the transition from phase A to phase B and reversing its temperature range.
Figure 2. CuMnAl modulus alloy molding (a) in cooling and (b) heating.

Cu10Mn10Al in-rolled alloy was heat-treated by isothermal aging after tempering, in the austenite phase at a temperature of 300 °C with a hold for 120 minutes. We followed the capacity of dissipating properties, microstructure and chemical composition of the alloy after the heat treatment.
Figure 3 presents the behavior of CuMnAl alloy aged at 300 °C and maintained at 120 minutes at a external request on a standard support with three-point of the DMA equipment. It has been observed that through the aging of CuMnAl shape memory alloys is forms precipitate like $\gamma$ and $\gamma_3$, followed by a martensitic transformation to martensite $\alpha'$ and $\gamma'$ [3]. It is noted that the value of internal friction is approximately constant over the range of temperatures.
After aging treatment the alloy CuMnAl has not presents any transformation, indicating that phase $\beta_1$ could not transform to thermoelastic martensite. In this case, due to the formation of a large number of particles precipitated of $\gamma_2$, is achieved a decrease in its base austenite phase (parent phase) [13-16]. Overall, the samples aged over 300 °C, have a decreased damping capacity, primarily due to the formation of a high density of particles precipitated $\gamma_2$, which serve full mobility restrictions and limitations similar interfaces. In this case, the mobility of the A/M, M/M transformation phase is blocked by the formation of precipitates to give very low values of dissipation capacity. [17].

Analysis of the microstructure of the alloy molding-CuMnAl, figure 4 (a) and heat treated by aging treatment, figure 4 (b) was carried out by electron microscopy.

**Figure 3.** The behavior of the Cu10Mn10Al alloy heat treated by aging at 200 °C at 1 Hz vibration request with a heating rate of 1 °C / min for one cycle), and (b) cooling and (c) heating.

**Figura 4.** The microstructure of the CuMnAl alloy (a) after rolling, (b), (c) and (d) after aging heat treatment at 200, 300 and 400 °C.
In figure 4 (a) precipitates are not observed and the microstructure formed in figure 4 (b) there is a mixed microstructure of austenite and martensite induced by tension (MIT) plates.

4. Conclusions
Cu10Mn10Al experimental alloy shows at cooling a transformation temperature range under 0°C and about 0°C to heating. It shows a higher value of the internal friction in the martensitic to the austenitic state, in which there is at room temperature when they show superelasticity. The transformation temperature range, particularly in heating the material, the experimental alloys have a very high internal friction value closer to the set values of natural rubber type polymer material. The elasticity modulus has a behaviour similar to the internal friction on the two areas based on martensite and austenite phases with different values for the two phases in the transition and M↔A falls below half the value of the martensite phase due to the sharp increase mobility. Aging alloy in the austenitic condition leads to lower internal friction and loss of value variation of the transformation M↔A, cooling and heating, variation observed for sample laminate. For heat-treated alloys through aging, there is a difference between the values of internal friction and modulus of elasticity between the two phases characteristic of the alloy. Mechanical energy dissipation capacity is higher in the martensitic state towards austenitic state.

5. References
[1] Mallik U S and Sampath V 2008 Effect of composition and ageing on damping characteristics of Cu−Al−Mn shape memory alloys Materials Science and Engineering A 478 pp 48–55
[2] Yoshida I, Monma D, Iino K, Otsuka K, Asai M and Tsuzuki H 2003 Damping properties of Ti50Ni50−xCux alloys utilizing martensitic transformation Journal of Alloys and Compounds 355 pp 79–84
[3] Stanciu S, Bujoreanu L G, Comănci R I, Cimpoesu N, Ionîţă I and Moldoveanu V V 2009 Particularities of phase transitions in thermomechanically processed Cu-Al-Mn shape memory alloys ESOMAT 2009 - 8th European Symposium on Martensitic Transformations Prague
[4] Cimpoesu N, Stanciu S, Vizureanu P, Cimpoesu R, Achiţei DC and Ionîţă I 2014 Obtaining shape memory alloy thin layer using PLD technique Journal of Mining and Metallurgy, Section B: Metallurgy 50 pp 69-76
[5] San Juan J and No M L 2003 Damping behavior during martensitic transformation in shape memory alloys J. Alloys Compd. 355 pp 65–71
[6] Cimpoesu N., Stanciu S., Meyer M., Ionîţă I. and Cimpoesu Hanu R 2010 Effect of stress on damping capacity of a shape memory alloy CuZnAl Journal of Optoelectronics and Advanced Materials 12 pp 386-391
[7] Sutou Y, Omori T, Wang J J, Kainuma R and Ishida K 2004 Characteristics of Cu−Al−Mn-based shape memory alloys and their applications Mater. Sci. Eng. A 378 pp 278–282
[8] Mallik U S and Sampath V 2006 Effect of alloying on microstructure and shape memory characteristics of Cu-Al-Mn shape memory alloys Proceedings of the International Conference on Advances in Materials and Materials Processing (ICAMMP-2006) pp 583–588
[9] Paun M-A, Cimpoesu Hanu R, Cimpoesu N, Agop M, Baciu C, Stratulat S and Nejneru C 2010 Internal friction phenomena at polymeric and metallic shape memory materials. Experimental and theoretical results Materiale Plastice 47 pp 209-214
[10] Kainuma R, Takahashi S and Ishida K 2009 Thermoeelastic martensite and shape memory effect in ductile Cu-Al-Mn alloys Metall. Mater. Trans. A 27A pp 2187–2195
[11] Kustov S, Pons J, Cesari E and Van Humbeeck J 2004 Pinning-induced stabilization of martensite: Part I. Stabilization due to static pinning of interfaces Acta Mater. 52 pp 3075–3081
[12] Paun V-P, Cimpoesu N, Hanu Cimpoesu R, Munceleanu G V, Forna N and Agop M 2010 On
the Energy Dissipation Capacity and the Shape Memory. A Comparative Study between Polymer Composites and Alloys Materiale Plastice 47 pp 158-163

[13] Matsushita K, Okamoto T and Okamoto T 1985 Effects of manganese and ageing on martensitic transformation of Cu–Al–Mn alloys J. Mater. Sci. 20 pp 689–699

[14] Cimpoesu N, Axinte M, Cimpoesu Hanu R, Nejneru C, Achitei D C and Stanciu S 2010 Behavior simulation of a copper based shape memory alloy under an external solicitation Journal of Optoelectronics and Advanced Materials 12 pp 1772-1776

[15] Wu S K and Lin H C 2003 Damping characteristics of TiNi binary and ternary shape memory alloys, J. Alloys Compd. 355 pp 72–78

[16] Suresh N and Ramamurthy U 2008 Effect of Aging on the Damping. Properties of Cu-Al-Ni Shape Memory Alloys Smart Mater. Struct. 14 pp N47–N51

[17] Sutou Y, Kainuma R and Ishida K 1999 Effect of alloying elements on the shape memory properties of ductile Cu-Al-Mn alloys Mater. Sci. Eng. A 273–275 pp 375–379