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To cite this article: R C Crăciun *et al* 2016 *IOP Conf. Ser.: Mater. Sci. Eng.* **147** 012031

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Metallic materials for mechanical damping capacity applications

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Abstract. Some metallic materials exhibit good damping capacity of mechanical energy into thermal energy. This property along with the others metallic characteristics make this materials interesting for a big number of applications. These materials can be used as bumpers in different applications including automotive field. Beside grey cast iron and shape memory alloys few new metallic materials are presented for the supposition of high damping capacity. We analyze the causes that increase the internal friction of some metallic materials and possibilities to enhance this property through different mechanical, physical or chemical methods. Shape memory alloys, especially those based on copper, present a different damping capacity on martensite, austenite or transition state. In the transformation range $M \leftrightarrow A$, which in case of copper base shape memory alloys is quite large, the metallic intelligent materials present a high internal friction, almost comparable with natural rubber behavior that can transform mechanical energy into thermal energy till a certain value of the external solicitation. These materials can be used as noise or small vibrations bumpers or even as shock absorbers in automotive industry.

1. Introduction

Experience shows that free oscillations of a body are amortized over time. Apart from the contribution of the environment to attenuate oscillations, its cause lies inside the solid and called internal friction. Sound absorption in solids, free oscillations of a pendulum damping torque are due to the internal friction [1].

During the free oscillation damping, macroscopic and mechanical energy gradually transforms, and it is taken over by microscopic systems of atoms or even by isolated atoms giving rise to an equivalent amount of heat, therefore internal friction processes are irreversible.

Although the phenomenon of internal friction in metals has long been known being preoccupation of famous physicists since the last century [2-5], the research into the causes of internal friction is was performed only over the past three decades. The growing interest for the study of internal friction at metals has multiple aspects. For example, in technical field, there are followed extreme metal behaviors: very high internal friction (high dissipation capacity, vibration damping and sound) or very low (bells, resonators elements etc.).

Beside shape memory effect and superelasticity properties some shape memory alloys (SMA) have a high capacity mechanical damping. Damping mechanisms, generally, involves displacement of the



defects induced by stress. For metals with high damping capacity main mechanisms are either displacement of the dislocations or defects of the plan.

Most of these mechanisms can be divided into three classes phenomenological: hysteresis dynamic, static hysteresis and transformation mechanisms. Dynamic hysteresis is produced by the orientation of the defects that pass local barriers by thermal activation and amortization efficiency is dependent on frequency and amplitude independent. Static hysteresis occurs during the release process defects by application [3, 6, 7], and the effectiveness of the depreciation is independent of frequency and amplitude dependent.

Recent research efforts have expanded to the use of shape memory alloys to control and improve the quality of civil engineering. Such unique properties of shape memory alloys can be used in obtaining actuators, energy sinks and passive dampers for civilian buildings. Constructive models for these materials applications are separated by type of action performed in this respect, we alloys controllers to obtain passive, semi-active or active civil structures.

Intelligent systems for civil can be described as systems that can automatically adjust structural features functioning as a response to interference sources external and / or due to load unexpected to affect the structure safe and conducive to increase the service life of the building. In order to obtain these systems it is necessary to implement elements of shape memory alloys in their composition. The properties of these alloys, such high damping capacity, stamina, durability and ability actuators make them good candidates in solving problems of resistance [8-12].

Integrated into civil structures, shape memory alloys can be used as passive components, semi-active or active to reduce the effects of the environment, such as earthquakes. Currently most research is still only in the laboratory level, a small part of these applications being implemented in practice.

2. Experimental details

Internal friction can be measured by several methods. The simplest instrument is a pendulum torque that can be used in the lower frequency range around of 1Hz. Laboratory equipment is realized of several interconnected systems that together lead to determination of the dimensionless internal friction characteristic of the material. Regarding this, we used mechanical system (responsible for fixing, effective support and torsional movement of the sample), the electro - mechanical (responsible for creating torsional force and torque motion assembly) support system - sample – fly-wheel, electronic data acquisition system and vacuum system to eliminate friction with the air.

There were analyzed several samples of metallic materials with the experimental device described above and the results were compared. For the experimental set up we use a torsion pendulum with the solicitation force established and unlimited friction time.

3. Experimental results

For the determination of the internal friction with the pendulum torsion, tests were carried out on few unknown metallic materials but with reference in the literature and on investigated materials by mechanical and dynamic analysis with values described above.

In this regard, they were selected high purity metal materials, copper, aluminum and steel alloys, cast iron, brass or shape memory alloys based on copper (CuZnAl1, CuZnAl2, CuMnAl and CuZnAl3). In Table 1 are shown the results obtained on the laboratory made torsion pendulum [1].

It should be noted that while copper, aluminum and other materials with shape memory have been analyzed without heat treatment applied, in the deformed state, alloys copper based that show shape memory effect were treated by solution quenching [14].

Analyzing the results we observed that the low values were obtained for all materials at room temperature, indicating that none of the material suffers from phase transformation in the solid state at that temperature. The graphical representation of the results is shown in figure 1.

Good damping results are observed at shape memory alloys and at gray cast iron analyzed [6, 15]. Low internal friction values were recorded for pure copper, significantly lower than that of pure aluminum, both polycrystalline, the smallest value obtains for OLC45 steel. As for the shape memory

alloys, CuMnAl alloy has a very low internal friction, 0.0058 which is very interesting due to internal friction peak observed at negative temperature.

Table 1. The values of internal friction for various materials analyzed with torsion pendulum at room temperature with experimental alloys CuZnAl 1-3 and CuMnAl.

Nr.crt	Material investigated	Logarithmic Decrement	Torsion force [N]	Working frequency [Hz]	Internal friction Q^{-1}
1	Cu – high purity (99.9%)	0.0128805	5000	1	0.0041
2	Al – high purity (99.7 %)	0.0144513	5000	1	0.0046
3	OLC45 steel	0.0037699	5000	1	0.0012
4	Grey cast iron	0.0879645	5000	1	0.0280
5	Standard brass	0.0177873	5000	1	0.0055
6	SMA CuZnAl1	0.1099557	5000	1	0.0350
7	SMA CuZnAl2	0.0980177	5000	1	0.0312
8	SMA CuZnAl3	0.0801106	5000	1	0.0255
9	SMA CuMnAl	0.0182212	5000	1	0.0058

The alloy analyzed in this work using laboratory pendulum is a shape memory alloy CuZnAl3, developed in the laboratories of the Faculty of Materials Science and Engineering [1]. Its internal friction characteristics is compared with values obtained on other materials including two shape memory alloys previously investigated [8, 11]. After the casting, the alloy has been treated by homogenization heat treatment at 800°C, 120 minutes maintain and cooling to the furnace.

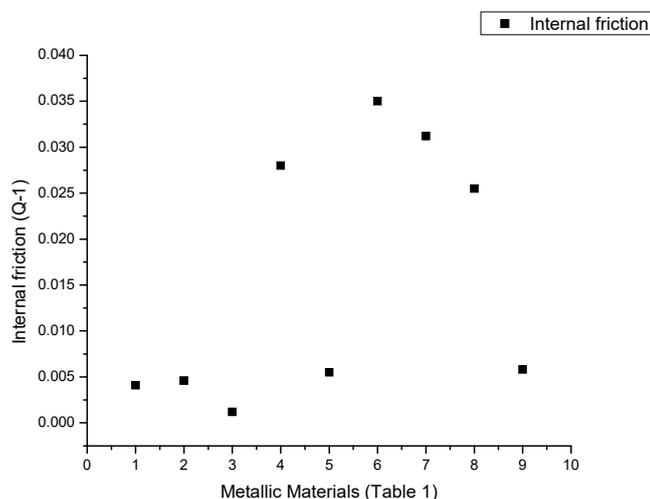


Figure 1. Internal friction for different metal materials at room temperature.

Microstructure of the material is shown in figure 2. It can be noted different scales of magnification of the image, the formation of martensite of different types and with different orientations of martensite variants within the grains [9]. Martensite variants (figure 2c), observed at the junction of three grains, are reduced size and those who managed to form are about 2 μm and those that just emerged to from are 200-250 nm in size.

The behavior of the material at heating was characterized by dilatometry of the samples, in two states. One sample in homogenized and molded state and the second sample in deformed by hot forging and treated by solution quenching.

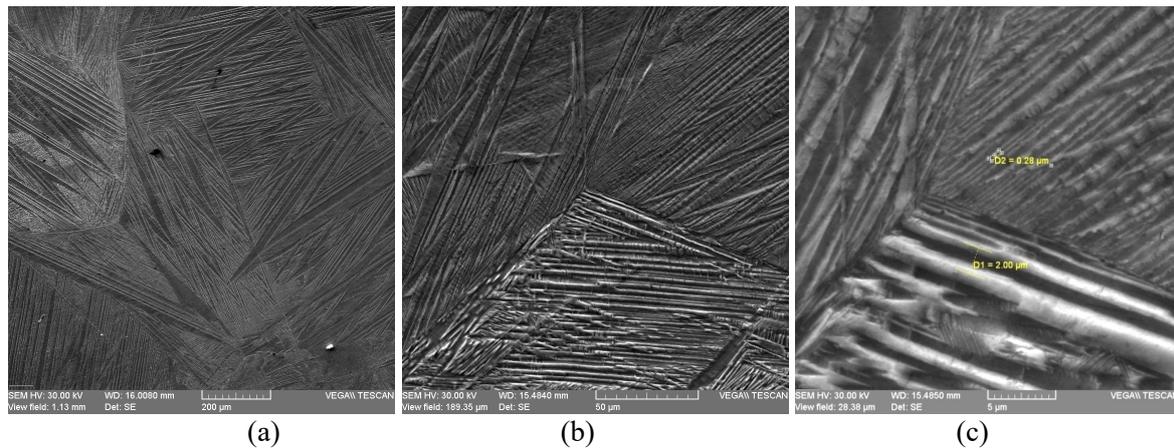


Figure 2. SEM microstructures of CuZnAl13 shape memory alloy for different scales (a) 500x (b) 1000x and (c) 5000x.

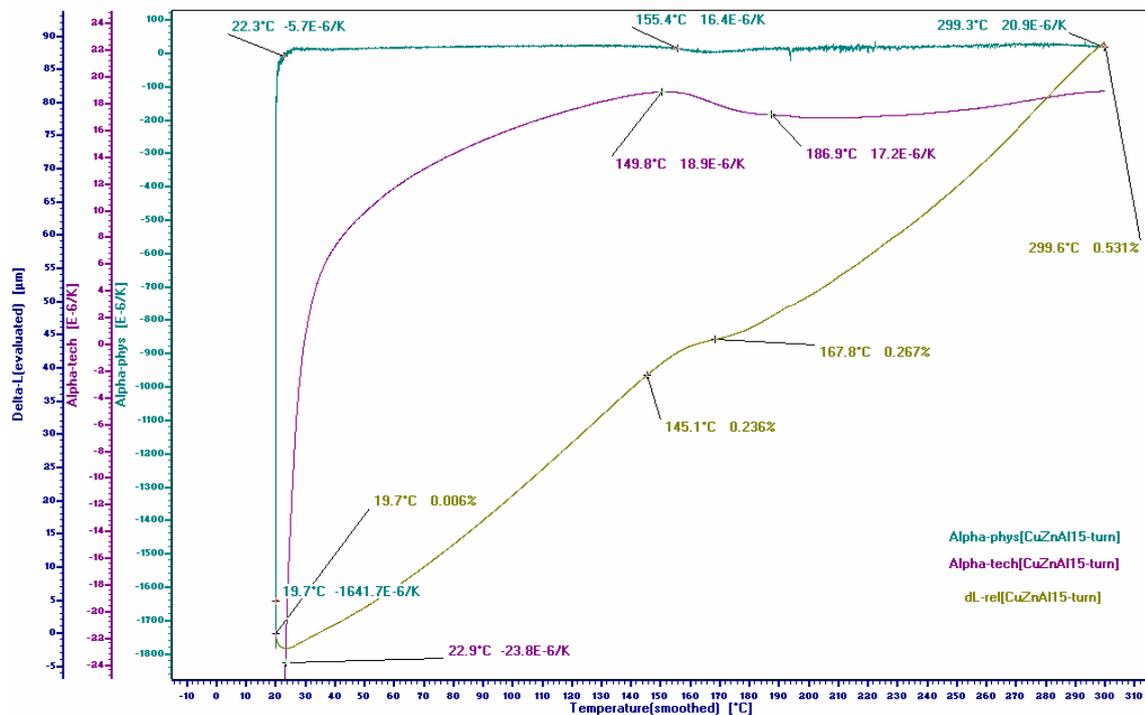


Figure 3. The variation of the elongation of the sample of CuZnAl13 alloy with shape memory, in the molten and homogenized state, by increasing the temperature.

Results from the dilatometry test on the molded and deformed material is shown in figure 3. The temperature range considered is from 30 to 310 °C using a heating rate of 5 K / min, in which it can be observed a characteristic behavior of shape memory alloys in the range of temperature 145.4°C to 167.8 °C. Changes that take place in this range are a relatively low-energy feature of a weaker shape memory effect.

The structures described above, figure 3, are characteristic for the martensitic phase of the material after the heat treatment. In order to determine the internal friction in the martensitic state or steady state were conducted several tests on samples annealed to establish the influence of martensitic structure in total internal friction coefficient.

In table 2 shows the values of internal friction, logarithmic decrement, torsion force and frequency working sample of shape memory alloy CuZnAl3 deformed by hot forging and treated by quenching implementing solution and the same samples heated and cooled in water for different temperatures.

Table 2. The values of internal friction at room temperature for the shape memory alloy CuZnAl3.

Heat treatment applied to CuZnAl3 alloy	Logarithmic decrement	Torsion force [N]	Work frequency [Hz]	Internal friction Q^{-1}
Initial treatment	0.0801106	5000	1	0.0255
Heating to 150 ° C, maintain 10 minutes and cooling in water	0.0797964	5000	1	0.0254
Heating to 200 ° C, maintain 10 minutes and cooling in water	0.0716283	5000	1	0.0228
Heating to 250 ° C, maintain 10 minutes and cooling in water	0.0691150	5000	1	0.0220
Heating to 300 ° C, maintain 10 minutes and cooling in water	0.0653451	5000	1	0.0208
Heating to 350 ° C, maintain 10 minutes and cooling in water	0.0612611	5000	1	0.0195
Heating to 400 ° C, maintain 10 minutes and cooling in water	0.0612611	5000	1	0.0195
Heating to 450 ° C, maintain 10 minutes and cooling in water	0.0596903	5000	1	0.0190
Heating to 500 ° C, maintain 10 minutes and cooling in water	0.0785398	5000	1	0.0250

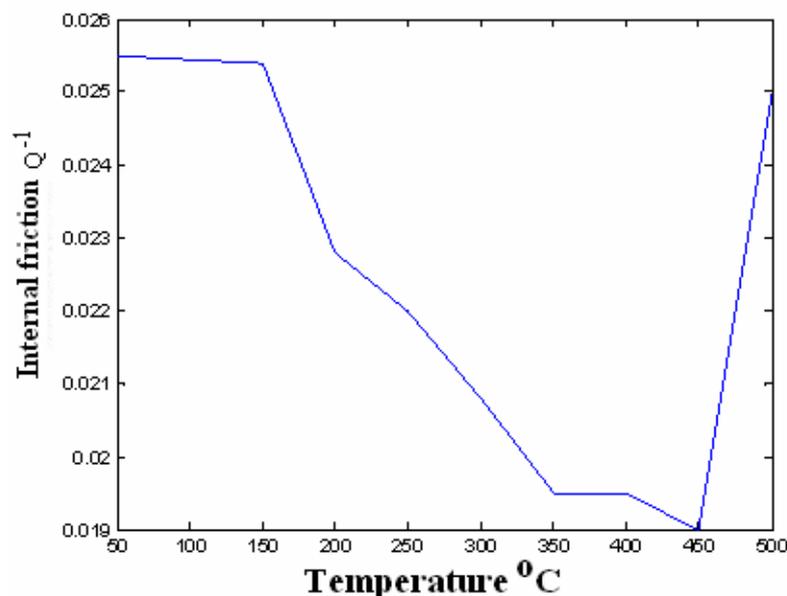


Figure 4. Variation of internal friction of the alloy CuZnAl 3 depending on the heating temperatures to which it is subjected to heat treatment after quenching implementing solution.

The graphically representation of the values obtained is shown in figure 4, where there is a decrease in the value of internal friction with treatment temperature of 200 °C, which means only partial conversion of the structure of the material to martensite. Along with the decrease of the percentage of this transformation to 500°C, again under the action of heat when the martensitic transformation takes place almost entirely. The differences are small, between 0.02 and 0.026.

The material, CuZnAl3 alloy with shape memory, was further analyzed, after a recrystallization treatment with treatment parameters shown in table 3, aiming to obtaining a particular state of the

martensite, namely equilibrium, stabilized α phase, phase in which the material behaves differently in terms of mechanical energy dissipation capacity.

Table 3. The values of internal friction at room temperature for the shape memory alloy CuZnAl3 cast and homogenization by heating at various temperatures for 5 hours and cooling to maintain the furnace.

Heat treatment applied to CuZnAl3 alloy	Logarithmic decrement	Torsion force [N]	Work frequency [Hz]	Internal friction Q^{-1}
Initial heat treatment	0.0581194	5000	1	0.0185
Heating to 150 ° C, maintain 10 minutes and cooling in water	0.0581194	5000	1	0.0185
Heating to 200 ° C, maintain 10 minutes and cooling in water	0.0593761	5000	1	0.0189
Heating to 250 ° C, maintain 10 minutes and cooling in water	0.06	5000	1	0.0191
Heating to 300 ° C, maintain 10 minutes and cooling in water	0.06	5000	1	0.0191
Heating to 350 ° C, maintain 10 minutes and cooling in water	0.0615752	5000	1	0.0196
Heating to 400 ° C, maintain 10 minutes and cooling in water	0.0622035	5000	1	0.0198
Heating to 450 ° C, maintain 10 minutes and cooling in water	0.0644026	5000	1	0.0205
Heating to 500 ° C, maintain 10 minutes and cooling in water	0.0691150	5000	1	0.0220

In figure 5a are presented the characteristic of SEM microstructures of material after recrystallization treatment applied, with a structural detail in figure 5b magnification of 8000X. Table 3 indicates the values of internal friction for CuZnAl3 alloy after hardening treatment applied but after several heating and cooling of the alloy graphically represented in figure 6.

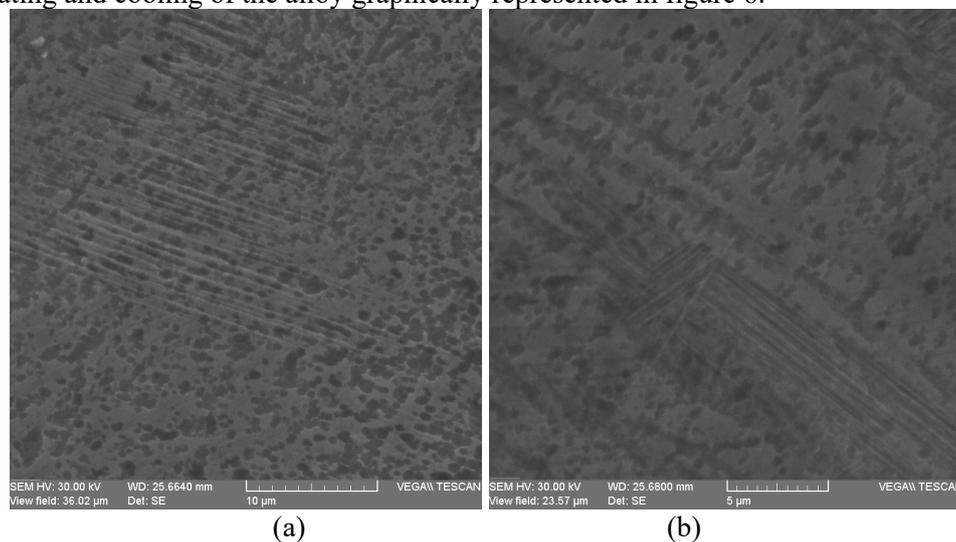


Figure 5. SEM microstructures of the shape memory alloy CuZn 15 after recrystallization treatment.

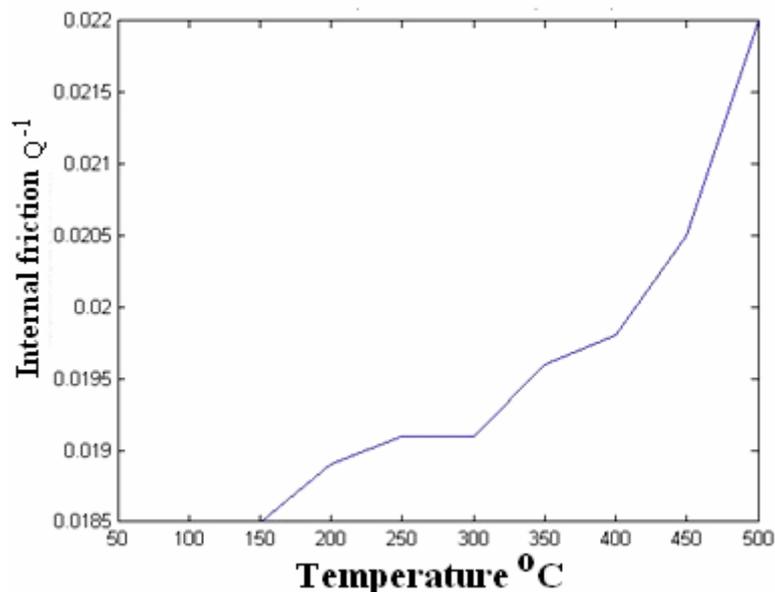


Figure 6. Variation of internal friction to a shape memory alloy CuZnAl13 temperature heat treatment applied after deformation and recrystallization annealing treatment.

The results obtained are very similar values in all cases, lower than the previous treatment has been obtained state martensite, a slight increase in the value of internal friction with increasing heating temperature, reaching the last heating actually quenching implementing the solution. Presented graphically these results show an increase in internal friction temperature heat treatment applied, signifying the transition from equilibrium to the martensitic.

4. Conclusions

Following the principles of physical and theoretical considerations in the laboratories of the faculty of Materials Science and Engineering, Iasi, laboratory equipment for the investigation of internal friction property was performed, shuttle torsion bar type materials with a diameter of 5 mm. We conducted tests on various materials, copper chloride, aluminum, pure steel, cast iron, brass and shape memory alloys. The results were in accordance with the values found in the literature [9-11]. Analysis of shape memory alloy CuZnAl3 deformed and treated by quenching deposition solution annealed in the first case and the second case presents characteristic values of internal friction martensitic state or the austenitic state respectively.

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